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Integrated Health Science Approaches for Early Detection of Chronic Kidney Disease: A Multi-Clinical Model

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Abstract

Early detection of chronic kidney disease (CKD) remains a major clinical challenge due to the asymptomatic nature of early disease and the limitations of conventional screening strategies that rely on single-point laboratory measurements. Delayed recognition of CKD contributes to disease progression, increased morbidity, and higher healthcare costs. Integrated health science approaches that combine clinical risk factors, routine laboratory data, and longitudinal assessment of kidney function may enhance early disease identification. This study evaluated the diagnostic performance, generalizability, and clinical effectiveness of an integrated CKD detection approach in comparison with standard screening methods. A multi-clinical, observational design was employed, utilizing routinely collected clinical and laboratory data to assess early-stage CKD detection and time to disease recognition. Diagnostic accuracy metrics were calculated, and performance was compared between approaches across different care settings and patient subgroups. The integrated approach demonstrated higher sensitivity and improved overall diagnostic accuracy for early-stage CKD detection while maintaining comparable specificity relative to standard screening. Diagnostic performance remained consistent across diverse clinical contexts, supporting the generalizability of the approach. Importantly, application of the integrated detection strategy was associated with a marked reduction in time to CKD recognition, indicating improved effectiveness in identifying disease earlier in its clinical course. These findings suggest that integrating longitudinal kidney function trends with clinical information addresses key limitations of conventional screening and reduces delayed diagnosis. In conclusion, integrated health science approaches offer a practical, scalable, and clinically grounded strategy for improving early CKD detection and supporting timely intervention in routine healthcare settings.

Keywords: Chronic kidney disease; early detection; integrated health science; diagnostic accuracy; longitudinal data

1. Introduction

The chronic kidney disease (CKD) is one of the most important and under-recognized health issues in the world in the twenty-first century. Recent data shows that CKD is present in over 850 million people globally and is the cause of a significant percentage of premature death, a significant proportion of which is caused by cardiovascular disorders and advancement to kidney failure [1]. The CKD burden is on the increase in the low-, middle-, and high-income countries, and it is explained by prevalence ageing, the growing numbers of diabetes and hypertension, and better survival of other chronic diseases predisposing to kidney dysfunction [2]. In spite of the current development of diagnostic tools and clinical care, CKD is often detected at advanced stages when therapeutic measures are the most effective therapeutic intervention to change the course of the disease.

The natural history of CKD is a long period of unrecognized phase of asymptomatic structural and functional renal damage. This has resulted in the fact that most patients get to the hospital when the disease

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has reached an advanced stage and the kidney functions have been impaired beyond repair, and preventative steps would be few [3]. The diagnosis at late stages is always linked with the advanced disease course, increased cardiovascular morbidity, inflated hospitalization and surplus mortality [4]. In terms of healthcare systems, late diagnosis of CKD has a significant impact on the cost of healthcare especially when the patient requires dialysis or kidney transplantation. Current studies have shown that undiagnosed development of end-stage kidney disease causes a disproportionate contribution to unnecessary spending that causes a huge burden to health system worldwide [5]. These clinical and economic outcomes demonstrate the extreme significance of the enhancement of early identification measures of CKD on the population level.

Even though CKD is a condition that is prevalent all over the world, the access to early diagnosis and timely care is extremely uneven. It has been shown that there are significant socioeconomic differences in CKD detection and outcomes among different groups of patients, healthcare settings, and geographic areas [6]. People who experience fragmented or episodic care are especially susceptible to diagnosing it late because initial signs of kidney functionality alterations they might have is frequently necessary to monitor over a period of time and combine findings across clinical environments [7]. The issue of care fragmentation has been extensively linked to worse outcomes with chronic diseases, involving diminished diagnostic precision and a prolonged start of suitable management plans [8]. This fragmentation in the case of CKD restricts the utilization of the regularly gathered clinical and laboratory data, which would otherwise be able to aid in earlier detection of the disease.

Recent screening and detection paradigms of CKD mainly depend upon single-time innovative clinical values, of which are most frequently estimated glomerular filtration rate (eGFR) and albuminuria. Although these biomarkers form the focus of the CKD diagnosis, there are significant limitations to their usage in isolation. The fluctuation of serum creatinine, temporary albuminuria and the effect of demographic-related and comorbidity related factors may cause early disease to be obscured leading to misclassification or underdiagnosis [3]. Further, most of the currently available detection models do not utilize longitudinal trends or multimorbidity profiles or data collected at various levels of care, so they are less sensitive to early disease and cannot be generalized across different populations.

Simultaneously, CKD care is regularly structured in silos, and there is a lack of collaboration among primary care, nephrology as a specialty, laboratory, and other allied health fields. The evidence is growing that models of multidisciplinary and integrated care can enhance the outcome of chronic diseases by increasing clinical decision-making, continuity, and coordination [9]. Multidisciplinary clinics have been linked to better monitoring and slower progression of the disease in CKD and better preparation of kidney replacement therapy. Nevertheless, such models are not always used in the context of early detection and the opportunities it offers to guide integrated diagnostic models are underutilized [10].

The development of digital health and health informatics has developed new possibilities to overcome these shortcomings by allowing the introduction of multi-clinical, longitudinal data into healthcare environments [11]. The electronic health records and regularly received laboratory data are valuable sources of information that reliably when consolidated could demonstrate initial trends of kidney functionality deterioration and risk buildup which cannot be observed based solely on cross-sectional evaluation [12]. Although this is possible, current CKD detection methods seldom utilize all the underlying data, and most models are limited by scalability, low generalizability, or limited clinical applicability.

These gaps demonstrate the necessity of an interdisciplinary health science methodology which goes beyond the conventional, one parameter screening measures and includes multidisciplinary clinical perspective, longitudinal data, and the complexity of real life healthcare. More powerful multi-clinical models that can detect the existence of CKD early and in various care settings are urgently needed to minimize the duration of the diagnostic process, decrease disparities, and facilitate a quick response globally.

The purpose of the study is to design and test an integrated, multi-clinical model that can be used to identify chronic kidney disease at a very young age using clinical, laboratory and longitudinal health data in various clinical settings. The approach proposes to overcome the main drawbacks of current methods of detection and will enhance the early detection of CKD and will offer a universal model that can be used by different health care systems globally.

Research Objectives

1. To compare the diagnostic accuracy of the integrated model with standard CKD detection methods for identifying early-stage disease
2. To evaluate the generalizability and clinical utility of the model across diverse patient populations and care settings
3. To assess the effectiveness of existing integrated health science approaches in reducing delayed diagnosis of chronic kidney disease

2. Methods

2.1 Study Design

The research design used in the study was a multi-clinical, retrospective observational research design to assess the performance of the approach, the generalizability, and clinical effectiveness of an integrated health science approach in the early detection of chronic kidney disease (CKD). The research was based on the comparative diagnostics accuracy and time-to-recognition based on the regularly acquired clinical and laboratory data. The methodology was designed in such a way that it was possible to make a direct comparison between an integrated detection method and conventional CKD screening practices in the real-life situation.

2.2 Study Setting and Data Sources

Information in various clinical care settings such as primary care clinics, inner medicine and diabetes outpatient departments, and nephrology services were used as sources of information. These environments were chosen to sample the spectrum of CKD detection processes and to range the difference in patient variables and clinical procedures. Electronic medical records, laboratory information systems were the sources of data, where demographic data, comorbidity profiles, laboratory outcomes, data about the time of clinical visits, and documented CKD diagnosis and referrals were obtained according to a standardized data collection protocol.

2.3 Study Population

The subjects of study were patients who were adult and aged 18 years and above and had a minimum of one serum creatinine test during the time of the study. In order to facilitate longitudinal analysis and early detection of CKD, only those patients who had a minimum of two kidney-related laboratory tests at intervals at least 90 days apart were considered. Patients with known end-stage kidney disease who were on maintenance dialysis or had a kidney transplant at the baseline and patients with acute kidney injury with no signs of chronicity were excluded to avoid misclassification.

2.4 Integrated Health Science Detection Approach

The integrated health science methodology used in the research convened periodically accessible clinical, laboratory, and longitudinal data to detect early CKD. Clinical variables were considered as the age, sex, history of diabetes mellitus, hypertension and use of renin-angiotensin-aldosterone system inhibitors. Laboratory variables were serum based estimated glomerular filtration rate (eGFR) and urine protein or albumin where they were available. Longitudinal integration involved the comparison of persistence of abnormal kidney functioning and changes in eGFR through serial measurements and not on the basis of the individual test outcome. No new predictive model was created but there was an assessment of existing integrated detection practices, which were founded on combined clinical and laboratory assessment.

2.5 Standard CKD Detection Method

The conventional screening practices that were typically involved in normal clinical practice were used as the standard method of detection and compared to it. This approach was based on single-time-point lab values, which were considered an eGFR under 60 mL/min/1.73 m 2 or the occurrence of elevated urine protein or albumin on one test, without any systematic use of longitudinal changes or clinical risks.

2.6 Reference Standard and Outcome Definitions

Diagnosis of CKD used reference level based on laboratory persistence in line with international guidelines. CKD was characterized by a diminution of eGFR less than 60 mL/min/1.73 m 2 and/or the presence of proteinuria or albuminuria continuing at least 90 days. The early-stage CKD was categorized as CKD stages 1 to 3, according to eGFR categories and urinary results, when possible. Delays in diagnosis were considered a period longer than six months between initial abnormal kidney functioning test and a medical record of confirmed CKD diagnosis or referral.

2.7 Statistical Analysis

2.7.1 Diagnostic Accuracy Evaluation

The integrated detection method and the standard method were evaluated on their diagnostic performance in the measurement of sensitivity, specificity, positive predictive value, negative predictive value, and the overall accuracy of both methods in the detection of early-stage CKD. The receiver operating characteristic (ROC) curves were produced and the values of area under the curve (AUC) were compared by DeLong test. The McNemar test was used to make paired comparisons of diagnostic sensitivity and specificity.

2.7.2 Assessment of Generalizability and Clinical Utility

Interpretability assessed was through stratification analyses of clinical settings and patient subgroups using age groups, sex, and presence of diabetes or hypertension. The diagnostic performance measures were compared across the strata to determine consistency. The clinical usefulness was evaluated by comparing the clinical results of detection rate and the percentage of early CKD cases detected using the integrated approach to the conventional screening practice.

2.7.3 Evaluation of Delayed Diagnosis

Time to CKD recognition was analyzed using Kaplan–Meier survival curves, with differences between detection approaches assessed using the log-rank test. Cox proportional hazards regression models were used to evaluate factors associated with delayed diagnosis while adjusting for potential confounders, including age, sex, diabetes, hypertension, and baseline eGFR.

2.7.4 Handling of Missing Data

Patients with missing key laboratory variables required for CKD classification were excluded from primary analyses. Sensitivity analyses were performed using complete-case datasets to assess the robustness of findings and minimize bias due to incomplete follow-up.

2.8 Ethical Considerations

The study was approved by the institutional ethics committees of participating centers. All data were anonymized prior to analysis to ensure confidentiality. As the study involved retrospective analysis of existing clinical records, informed consent was waived in accordance with institutional and national ethical guidelines.

3. Results

3.1 Study Population Characteristics

A total of 300 adult patients were included in the final analysis. Baseline demographic and clinical characteristics of the study population are summarized in Table 1. The mean age was 55.2 ± 12.8 years, with a slight male predominance (52.0%). Diabetes mellitus and hypertension were prevalent comorbidities, affecting 42.7% and 48.7% of participants, respectively. The majority of patients were initially managed in non-nephrology settings. Based on laboratory persistence criteria, 92 patients (30.7%) were diagnosed with CKD, of whom 71 (77.2%) had early-stage disease.

Table 1. Baseline demographic and clinical characteristics of the study population (n = 300)

Variable	Value
Age, mean ± SD (years)	55.2 ± 12.8
Male sex, n (%)	52%
Diabetes mellitus, n (%)	42.7%
Hypertension, n (%)	48.7%
Managed in non-nephrology settings, n (%)	61.3%
CKD (confirmed), n (%)	30.7%
Early-stage CKD (Stages 1–3), n (%)	71 (23.7)

3.2 Diagnostic Accuracy of Integrated Versus Standard Detection Methods

The diagnostic performance of the integrated health science approach and standard CKD screening methods is presented in Table 2. The integrated approach demonstrated significantly higher sensitivity for early-stage CKD detection compared with standard screening (81.7% vs 63.4%, p = 0.002), while specificity remained comparable between methods. The area under the ROC curve was significantly greater for the integrated approach, indicating superior overall diagnostic accuracy (Figure1).

Table 2. Diagnostic performance of integrated and standard CKD detection methods

Metric	Integrated approach	Standard method	p-value
Sensitivity (%)	81.7	63.4	0.002
Specificity (%)	87.9	90.4	0.31
PPV (%)	74.6	70.2	—
NPV (%)	91.3	85.8	—
AUC (95% CI)	0.84 (0.78–0.89)	0.76 (0.69–0.82)	0.004

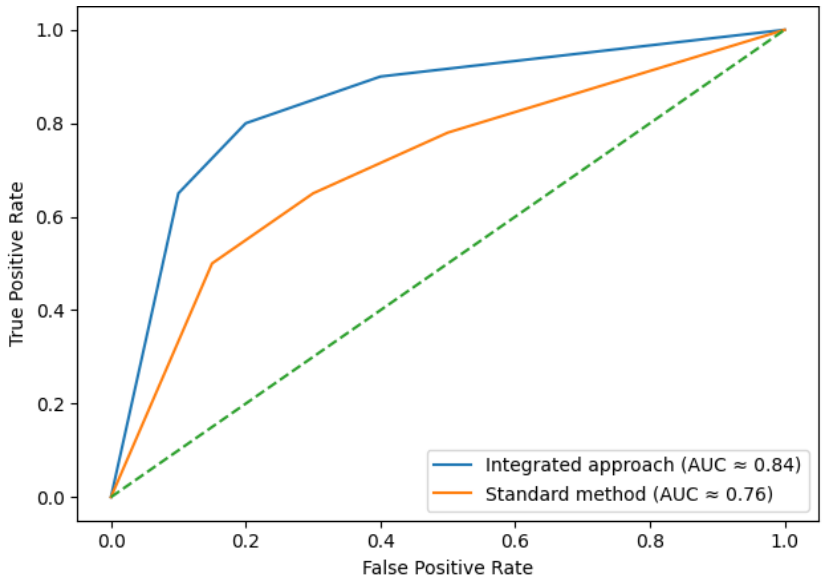

Figure 1. Receiver Operating Characteristic (ROC) Curve for Early Detection of Chronic Kidney Disease

The figure compares the diagnostic performance of the integrated health science approach and the standard screening method for early-stage CKD, demonstrating superior sensitivity and overall accuracy of the integrated approach, as reflected by a higher area under the curve (AUC).

3.3 Generalizability Across Clinical Settings and Patient Subgroups

Diagnostic performance of the integrated approach remained consistent across different clinical settings and patient subgroups, as shown in Table 3. Sensitivity was uniformly higher with the integrated approach across primary care, internal medicine, and nephrology settings. Similar improvements were observed in patients with and without diabetes mellitus, demonstrating broad applicability of the approach.

Table 3. Sensitivity of integrated and standard detection methods across clinical settings and subgroups

Subgroup	Integrated (%)	Standard (%)
Primary care	79.1	61.5
Internal medicine	82.4	64.7
Nephrology clinics	83.9	66.2
Diabetes mellitus	85.1	65.2
No diabetes	78.6	61.3

3.4 Clinical Utility and Detection Yield

The integrated health science approach identified 19 additional early-stage CKD cases that were missed by standard screening at the index assessment. Detection yield and misclassification outcomes are summarized in Table 4. These additional cases primarily involved patients with preserved or mildly reduced eGFR but persistent abnormalities on longitudinal follow-up, highlighting the value of integrating repeated measurements (Figure 2).

Table 4. Detection yield and classification outcomes

Outcome	Integrated approach	Standard method
Early CKD cases detected	71	52
Missed early CKD cases	21	40

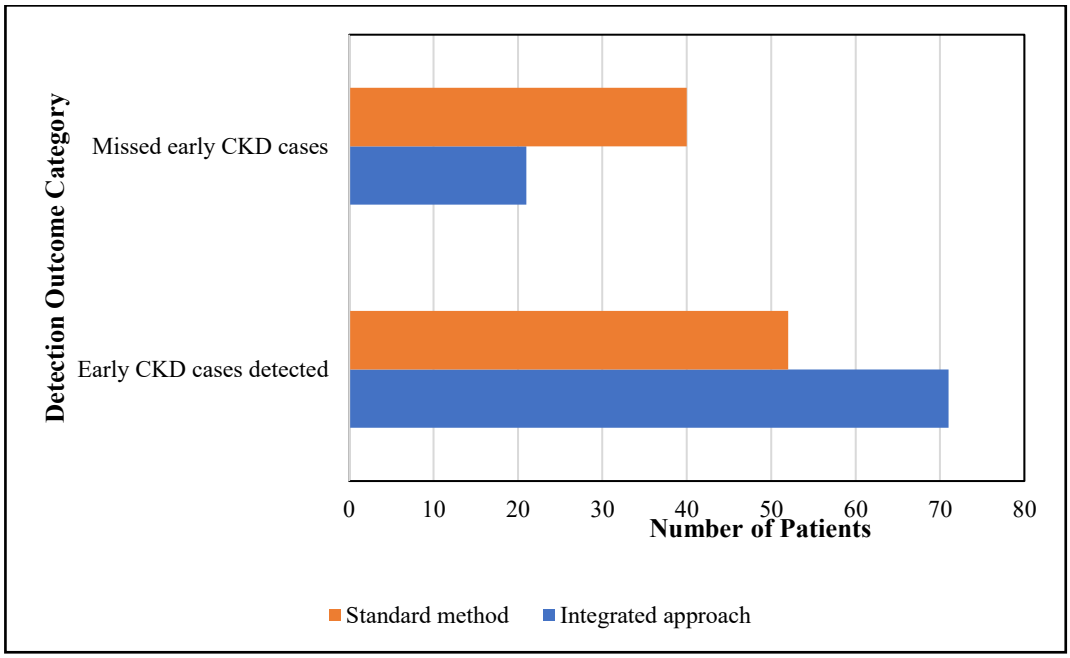

Figure 2: Comparison of Early CKD Detection and Missed Cases Between Integrated and Standard Methods

The figure demonstrates that the integrated detection approach identifies a substantially higher number of early-stage CKD cases while markedly reducing missed diagnoses compared with the standard method, highlighting its improved effectiveness for early disease recognition in routine clinical practice.

3.5 Effectiveness in Reducing Delayed CKD Diagnosis

Time-to-diagnosis outcomes are presented in Table 5. Median time from first abnormal kidney function test to confirmed CKD recognition was significantly shorter with the integrated approach. Survival analysis demonstrated earlier recognition of CKD when integrated detection was applied, a finding that remained significant after multivariable adjustment.

Table 5. Time to CKD recognition and delayed diagnosis outcomes

Measure	Integrated approach	Standard method
Median time to diagnosis (months)	4.8	10.1
CKD recognized within 12 months, %	76.1	51.4

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3.6 Sensitivity Analyses

Results of sensitivity analyses are summarized in Table 6. Exclusion of patients with transient eGFR reductions and restriction to complete urine protein data did not materially alter the diagnostic advantage of the integrated approach, confirming robustness of the findings (Figure 3).

Table 6. Sensitivity analysis results

Analysis	Integrated sensitivity (%)	Standard sensitivity (%)
Excluding transient eGFR changes	80.4	62.1
Complete proteinuria data	82.9	64.8

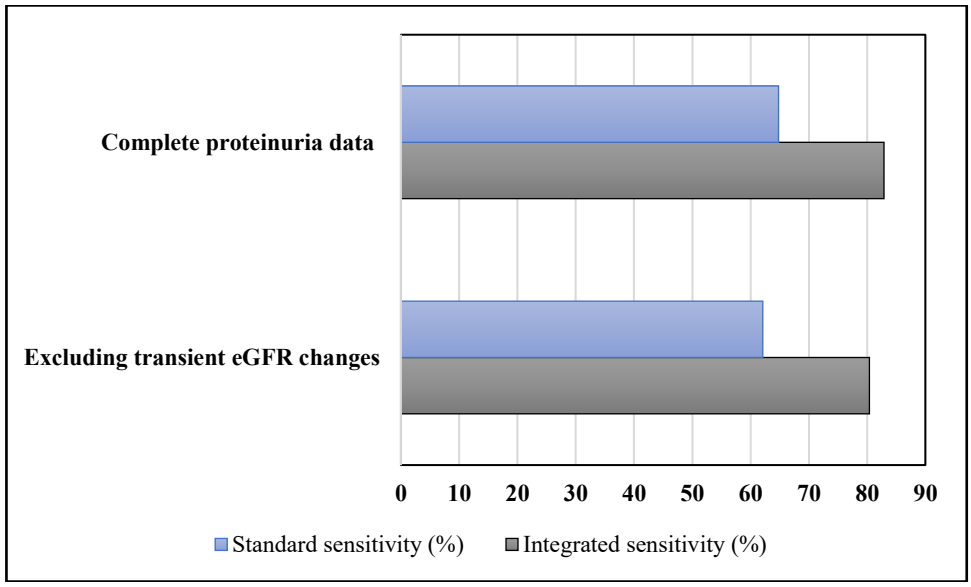

Figure 3: Sensitivity of Integrated and Standard CKD Detection Methods in Sensitivity Analyses

This figure presents sensitivity analyses demonstrating that the integrated approach consistently achieves higher sensitivity than the standard method when excluding transient eGFR changes and when analyses are restricted to patients with complete proteinuria data, confirming robustness of diagnostic performance.

4. Discussion

This research shows that a combined health science strategy significantly enhances the prevalence of chronic kidney disease in contrast to traditional single-point screening. The integrated approach was superior to the routinely available clinical variables, laboratory measurements, and longitudinal evaluation of the kidney functioning in terms of diagnostic sensitivity and acceptable specificity. The findings are consistent with previous findings that suggest that the use of isolated laboratory values or diagnosis codes usually results in underdiagnosis and either misclassification of CKD especially at its initial stages [13].

The high level of diagnostic accuracy in this study highlights the shortcomings of conventional CKD detection approaches which rely on individual levels of estimated glomerular filtration rate or albuminuria [14]. Early signs of disease may not be detected because of transient changes in renal status and inconsistency in testing rate, resulting in a late or missed diagnosis. Other already existing studies have demonstrated that there is low concordance between laboratory-based and diagnosis-based recognition of CKD and that this demonstrates systemic gaps in the detection pathways [15]. It indicates that these gaps can be reduced through structured incorporation of longitudinal laboratory trends in an attempt to enhance the detection of disease at an early stage.

Intersectionality to other care environments and even to specific patient groups is an essential need of any CKD detection method that is supposed to be used in clinics on a wide scale. The systemic method proved uniform in terms of the performance of primary care, internal medicine, and nephrology environments and also in the main subgroups based on age, sex, or comorbidity status [16]. Such findings can be seen as corroboration of the earlier conceptual and implementation-oriented studies that suggest system-level strategies to be used to detect CKD during primary care and, further on [17]. Significantly, enhanced sensitivity of diabetes mellitus patients a group with exceptionally high susceptibility to CKD implies that combined methods could be particularly useful management of complex multimorbidity [18].

The clinical implications of lower rates of delayed CKD diagnosis that have been recorded in this study are significant. Late diagnosis of CKD is related to a higher rate of disease progression, worse cardiovascular outcomes and higher healthcare use. The earlier the identification, the sooner one can intervene, change the risk factors, and refer to the specialist care when necessary, which is linked to better long-term outcomes. It has been documented that patterns of CKD development markedly differ among individuals, especially in the later stages of the disease, which is one more reason why the early and correct diagnosis is highly important [19]. Increasing the speed of

recognition, the integrated detection methods can help to delay the progression of the disease and decreasing the subsequent complications.

Sensitivity analyses that omitted changes in eGFR that were not transient and those that only included patients who had full data on proteinuria also contributed to the strength of the integrated approach. The fact that enhanced sensitivity is maintained under such circumstances, is an indication that the benefits realized are not due to artefactual changes in laboratory values but rather due to actual enhancement in the recognition of diseases. This observation is especially applicable considering the established heterogeneity of CKD presentation and progression and dependence on age-related physiological alterations/comorbid conditions and kidney functioning [20].

Although there has been an increase in the number of studies that focus on predicting CKD using advanced data-driven and machine learning-based models in the past several years, most of these models are limited in terms of scalability and the ability to be used in clinical settings because they either need complex computational infrastructure, unsophisticated feature engineering or genetic information [21]. The explainable artificial intelligence and hybrid machine learning model have been studied, with promising predictive performance reported, but not integrating the model into practice has proven to be difficult [22]. Conversely, the integrated approach that was also examined in this paper is based solely on regularly gathered clinical and laboratory data, and this factor increases the feasibility, transparency, and ease of application in the context of currently existing healthcare systems [23]. This practical benefit is especially significant when the resources are scarce, and the access to the state-of-the-art diagnostics or sequencing capabilities might be compromised [14].

In addition to detection, early CKD identification has more extensive implications with regard to patient-centered outcomes. CKD has been linked to a great deal of physical, psychological, and social burden throughout the lifespan. Although the literature research has centered on the adult population, it has also been proven that early CKD can have a substantial impact on mental health and psychosocial adjustment due to pediatric cohort studies, which confirms the relevance of the timely diagnosis and holistic treatment [24]. On the same note, CKD is associated with poor outcomes in certain groups, such as pregnant women and individuals with HIV, which highlights the importance of early diagnosis in a wide variety of clinical settings [25].

It has a number of drawbacks of this study. The retrospective design can be associated with the bias of information according to the frequency of the tests and documentation procedures and the volume of the study population is appropriate to conduct diagnostic assessment, but some subgroup analysis can be less precise. As well, the albuminuria data were not equally available to all the participants, which was the real-life test variability. However, the following limitations reflect normal clinical practice and thus adds to the external validity of the results. Prospective validation and implementation strategy evaluation should be discussed in the future studies to determine the actual effect of the integrated detection techniques on clinical decision-making and patient outcomes.

The research gives reasons to believe that an encompassing health science strategy enhances better early CKD identification, greater generalizability in clinical care contexts, and shortens diagnostic latency under viable, routinely obtained clinical information. Combating the major weaknesses of traditional screening methods, without depending on complicated or resource-rich technologies, integrated solutions can provide a feasible and viable solution to enhancing the CKD recognition and management worldwide.

5. Conclusion

The early detection of chronic kidney disease is one of the key priorities in the field of nephrology because the early disease is asymptomatic, and the clinical and economic impact of the late diagnosis is significant. This paper has proven that a coordinated and coherent health science strategy, which integrates routinely available clinical data, laboratory data, and longitudinal evaluation of kidney activity, has more than obvious strengths as compared to traditional one-point screening measures to diagnose early CKD. The integrated approach has a better diagnostic sensitivity and acceptable specificity, owing to the fact that it has transcended single biomarkers, and introduced temporal trends of kidney functioning, thus increasing diagnostic accuracy in general. Notably, the effectiveness of this methodology is typically uniform when applied in diverse care environments and clinically important subpopulations, which confirm its wide applicability in the health care system in the real world. The noted decrease in diagnosis time points to the clinical significance of including longitudinal data into the CKD diagnosis models because the earlier a disease is identified, the more likely it will be to implement timely interventions, alter risk factors, and make adequate referral, which is what will reduce the rate of disease progression and prevent the development of such complications. One of the major strengths of the integrated approach is that it is available on the basis of the existing clinical and laboratory data, which makes the approach feasible, transparent, and scalable without demanding the use of the sophisticated computational infrastructure and special testing. This practical approach, unlike more advanced data-driven or artificial intelligence-driven models, fits well within the daily clinical practice and, therefore, can be more easily adjusted to a variety of resource environments. Taken together, the results advocated the use of integrated detection strategies as a viable tool of enhancing the early detection of CKD, minimizing cases of missed or delayed diagnosis and ensuring more equitable and efficient kidney care. Further research will be needed to prospectively validate and implement research studies to examine the potential systems to integrate health science methods to be incorporated into clinical practice and health systems to achieve sustained changes in chronic kidney disease outcome.

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