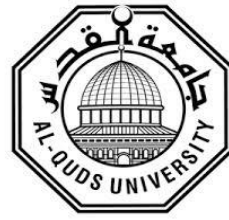


**Deanship of Graduate Studies
Al-Quds University**



**Enhancing Acute Kidney Injury Management in
Southern West Bank Governmental Hospitals: Risk
Triage, Novel Biomarkers, and Electronic Health Alerts
A Mixed-Methods Study**

Bilal Abdulrahman Nimer Jawabreh

Ph.D. dissertation in Public Health

Jerusalem-Palestine

2026/1447

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Prepared By

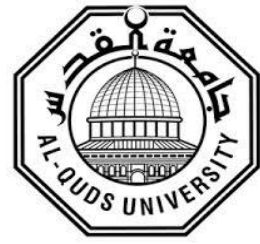
Bilal Abdulrahman Nimer Jawabreh

Supervisor: Prof. Motasem Hamdan

**A Dissertation Submitted in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy in
Public Health / School of Public Health/ Al-Quds
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Program/ Department



Thesis Approval

Enhancing Acute Kidney Injury Management in Southern West Bank Governmental Hospitals: Risk Triage, Novel Biomarkers, and Electronic Health Alerts - A Mixed Methods Study

Prepared by: Bilal Abdulrahman Nimer Jawabreh

Registration No.:22112445

Supervisor: Prof. Motasem Hamdan

Ph.D. dissertation submitted and accepted, Date 17/1/2026

The names and signatures of the examining committee members are as follows:

1. Head of Committee: Prof. Motasem Hamdan	Signature	
2. Internal Examiner: Prof. Nuha El-Sharif	Signature	
3. External Examiner: Prof. Zaher Nazal	Signature	
4. External Examiner: Dr. Jawad Atrash	Signature	

Jerusalem-Palestine

1447/2026

Dedication

This thesis is dedicated to my family, whose unwavering support, patience, and encouragement sustained me throughout this doctoral journey.

To my father, may God have mercy on him, whose guidance, values, and wisdom continue to shape my life and academic path.

To my mother, who passed away during this PhD journey, whose love, prayers, and enduring spirit remain a constant source of strength and inspiration.

I dedicate this work to my beloved nephew, the martyr Obeida Jawabreh, who was martyred at the very beginning of this journey. His loss is a profound reminder of the cost borne by our people and of the resilience required to continue striving for knowledge, dignity, and justice. This work is also dedicated to my wife, Amani, for her patience, sacrifice, and steadfast support, and to my children, Dr. Qassam, Leen, Abdelrahman, and Judi, who are my greatest motivation and hope for the future.

I further dedicate this thesis to my brothers and sister, Dr. Ezdehar Jawabreh, whose encouragement and solidarity strengthened me throughout this journey.

To all Palestinian people, especially those who continue to endure suffering under prolonged war and occupation. Your resilience gives meaning to this work and to every effort toward building a healthier and more just society.

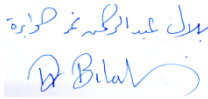
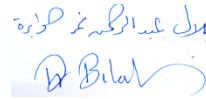
Finally, this thesis is dedicated to all patients affected by kidney disease, whose experiences and struggles continue to motivate efforts toward earlier detection, better care, and health equity.

Bilal Abdulrahman Nimer Jawabreh

Declaration

I, the undersigned, submit the thesis titled: **"Enhancing Acute Kidney Injury Management in Southern West Bank Governmental Hospitals: Risk Triage, Novel Biomarkers, and Electronic Health Alerts - A Mixed Method Study**, I acknowledge that this thesis was submitted to Al-Quds University to obtain the degree of Doctor of Philosophy in Public Health, and that what it contains is the product of my own effort, except for what has been indicated wherever mentioned, and that this thesis as a whole or any part of it has not been previously submitted to obtain a degree. Or a scientific or research title at any other educational or research institution.

أنا الموقع أدناه مقدم الأطروحة التي تحمل العنوان: "تعزيز إدارة إصابة الكلى الحادة في المستشفيات الحكومية بجنوب الضفة الغربية: تقييم وتصنيف المخاطر، المؤشرات الحيوية المخبرية المستجدة، والتنبيهات الصحية الإلكترونية – دراسة بالمنهج المختلط" أقر بأن هذه الأطروحة قدمت لجامعة القدس لنيل درجة الدكتوراة في فلسفة الصحة العامة، وأن ما اشتملت عليه إنما هو من نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل أو أي جزء منها، لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Student name: Bilal Abdulrahman Nimer Jawabreh	اسم الطالب: بلال عبد الرحمن نمر جوابرة
The signature : 	التوقيع: 
Date: 17/1/2026	التاريخ: 17/1/202

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understanding the real-world feasibility of AKI interventions within the Palestinian healthcare context.

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Finally, I would like to thank all colleagues, mentors, collaborators, and individuals who supported me throughout this doctoral journey, including those whose names I may have unintentionally omitted. Your contributions, in all their forms, are sincerely appreciated and will always be remembered.

Bilal Abdulrahman Nimer Jawabreh

Abstract

Background: Acute kidney injury (AKI) is a major driver of hospital-based morbidity and mortality, with the burden disproportionately higher in low- and middle-income countries. In Palestine, delayed recognition, nephrology workforce shortages, and the absence of national AKI protocols contribute to fragmented care and poor outcomes. These system-level gaps demand scalable, context-sensitive strategies that integrate early detection and improved care pathways.

Aim: This study evaluated the effectiveness and feasibility of an integrated AKI detection and management model in Southern West Bank hospitals, assessing its clinical impact and implementation context.

Methods: A mixed-methods design was used. The qualitative phase involved interviews with all 13 board-certified nephrologists in the West Bank to explore readiness and perceived barriers. The quantitative phase consisted of a prospective quasi-experimental cohort study design in two hospitals: an intervention hospital and a control hospital. A total of 469 inpatients with AKI were enrolled. The intervention combined electronic alerts, risk triage, and biomarker testing (including neutrophil gelatinase-associated lipocalin, NGAL).

Results: The intervention group showed significantly improved acute kidney injury recognition (68.4% vs. 37.8%, $p < 0.001$), with higher detection of stage 1 cases and earlier nephrology consultations. Kidney recovery was higher (33% vs. 20.5%, $p = 0.001$) and dialysis need was reduced (7.9% vs. 16.5%, $p = 0.005$). NGAL emerged as a key biomarker, with moderate diagnostic accuracy (cutoff = 90.2 ng/mL, AUC = 0.736, sensitivity = 56.7%, and specificity = 80.3%, $p = 0.001$), and NGAL levels above 300 ng/mL were linked to poor outcomes. In addition, neutrophil gelatinase-associated lipocalin level and 3 injuries were significantly associated in the univariate analysis. Also, risk triage scores were significantly associated with AKI severity, aiding in early stratification and targeted intervention. Multivariable analysis identified circulatory shock, sepsis, and ≥ 3 AKI episodes within three months as independent predictors of mortality. Discontinuation of angiotensin receptor blockers significantly improved short-term recovery (hazard ratio = 2.12, $p = 0.031$), while diabetes was associated with delayed recovery (hazard ratio = 0.69, $p = 0.045$). Process indicators showed significantly better documentation, medication safety, fluid adjustment, and follow-up testing in the intervention group. In the qualitative study, the interviews revealed strong support for the model, citing ministry-level backing, trends in preventive care, and digital innovation as key enablers. Barriers included governance fragmentation, workforce shortages, and the absence of national renal registries. Participants emphasized the importance of policy reform, specialist training, and public awareness to sustain improvements in kidney care.

Conclusion: The integration of risk triage, early biomarkers, and electronic alert care pathways significantly improved acute kidney injury outcomes and care processes. Combining technological innovation with clinical and policy engagement offers a scalable strategy for advancing kidney care in resource-constrained settings.

Keywords: Acute kidney injury, biomarkers, NGAL, digital alert system, electronic alert.

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Chapter One

Introduction

1.1 Background

Acute Kidney Injury (AKI) manifests as a rapid decline in renal function, compromising the kidneys' capacity to filter metabolic waste, regulate fluid balance, maintain electrolyte homeostasis, and stabilize acid-base equilibrium (Kellum et al., 2021). Beyond being a singular disease, AKI exists along a complex kidney dysfunction with diverse etiologies that often co-occur in individual patients, thereby complicating diagnosis and management strategies. Recent data confirm that AKI remains a major contributor to morbidity and mortality worldwide (Ostermann et al., 2025).

Globally, an estimated 13 million individuals develop AKI each year, with approximately 85% of cases occurring in low- and middle-income countries (Sengthavisouk et al., 2020). The majority of the 1.7 million annual deaths from AKI are also concentrated in these regions, underscoring remarkable inequities in outcomes (Francis et al., 2024; Gameiro et al., 2025). In high-income settings, AKI is often hospital-acquired, commonly linked with sepsis, major surgery, or drug toxicity, whereas in LMICs, community-acquired causes such as infection, dehydration, toxins, and obstetric complications predominate (Gameiro et al., 2025).

Mortality rates remain unacceptably high across age groups. A meta-analysis of pediatric AKI reported a pooled in-hospital mortality of 18.3% (Zarei et al., 2025). In adult ICU populations, mortality is even more pronounced: in one prospective study, 43.2% of patients with AKI died during hospitalization, compared to 14.4% without AKI, with excess mortality persisting at six months (Havaladar et al., 2024). Moreover, AKI is now recognized not only as an acute event but also as a gateway to chronic morbidity, accelerating progression to chronic kidney disease (CKD), increasing cardiovascular risk, and substantially amplifying long-term healthcare costs (Batte et al., 2023; Francis et al., 2024)

Taken together, these epidemiological and clinical realities underscore that AKI is not merely a hospital-based complication but a pressing public health challenge with far-reaching implications for equity, health system sustainability, and population well-being. Late

recognition and fragmented care pathways illustrate a critical gap between biomedical advances and their routine implementation, particularly in health systems with characteristics of low- and middle-income countries (LMICs). Yet, promising innovations as clinical risk scores, tubular injury biomarkers such as Neutrophil gelatinase-associated lipocalin (NGAL), and electronic health alerts emerging as system-strengthening tools. These interventions, though relatively low-cost, have the potential to improve efficiency, guide rational resource allocation, and reduce preventable morbidity and mortality.

In Palestine, this challenge carries unique urgency. While the healthcare system is relatively well-structured and laboratory infrastructure is available, the limited number of nephrologists constrains the capacity to meet rising demand. Hospitals are often overcrowded, and the escalating burden of dialysis-dependent patients highlights the unsustainable economic strain. Implementing integrated AKI management models that combine risk stratification, biomarker-based diagnostics, and e-alert platforms offers an opportunity to improve patient outcomes, slow progression to end-stage renal disease, and optimize scarce resources. Mixed-methods research is essential for this endeavor, enabling not only the measurement of clinical effectiveness but also the exploration of contextual and system-level determinants and ensuring that innovative, cost-efficient strategies are both feasible and sustainable within the Palestinian healthcare landscape.

1.2 Justification of the Study

AKI represents a major clinical and economic challenge worldwide, consuming nearly 1% of the NHS budget in England and contributing to \$5.4–24 billion in hospitalization costs in the United States, with dialysis-dependent cases bearing the greatest financial burden (Silver & Chertow, 2017). These pressures are even more profound LMICs, where late detection, limited specialist capacity, and fragmented care pathways accelerate progression to end-stage kidney disease (ESKD). In Palestine, the situation is striking over 3,500 patients are currently dependent on renal replacement therapy, with dialysis cases increasing by more than 100% in the past decade (Palestinian Ministry of Health, 2023). The absence of a national renal registry, coupled with annual dialysis costs exceeding \$16,000 per patient (Younis et al., 2015), underscores both the human and financial unsustainability of the current practices.

By generating evidence on both outcomes and processes, this research has the potential to inform cost-effective resource allocation, reduce the economic burden of kidney disease, and strengthen Palestine's alignment with global calls from WHO (2025) and Kidney Disease: Improving Global Outcomes (KDIGO) for innovation in kidney health. To date, most studies on AKI biomarkers, electronic alerts, or risk triage have been conducted in high-income countries, typically as stand-alone interventions with inconsistent effects on outcomes (Xu et al., 2022; Jawabreh, 2025). To the best of current knowledge, studies have not yet integrated these three pillars into an integrated framework or employed a mixed-methods design to capture both clinical effectiveness and contextual feasibility. This study is therefore the first of its kind in an LMIC setting to test such a hybrid model, offering methodological originality and direct health system relevance for Palestine and other resource-limited contexts.

1.3 Problem Statement

Although international guidelines for AKI management emphasize minimizing nephrotoxic exposure, evidence shows that AKI is often asymptomatic and frequently remains undetected, and essential diagnostic and therapeutic measures are inconsistently applied (Wilson et al., 2023). In Palestine, these challenges are compounded by a shortage of nephrology specialists and the absence of a national renal registry, leading to under-detection, delayed management, and fragmented care. Equally important, there are no standardized protocols to guide the follow-up of patients considered at risk, whether they present in primary healthcare centers or are hospitalized, resulting in missed opportunities for early intervention and continuity of care. These systemic gaps contribute to preventable progression to chronic kidney disease (CKD) and end-stage kidney disease (ESKD), further straining an already resource-limited health system (Bello AK et al., 2023).

Globally, AKI affects 15–20% of hospitalized patients (Ostermann et al., 2025), yet fewer than 10% of survivors receive nephrology follow-up within 90 days of discharge, despite evidence of long-term risks (Neyra & Silver, 2021). Universal specialist follow-up is not feasible, underscoring the need for scalable solutions. Innovations such as predictive laboratory tests, risk triage, and electronic alerts offer promise, but their clinical effectiveness and implementation feasibility in Palestine remain unexplored. This study addresses two critical gaps: (1) the lack of local evidence on AKI incidence, management, and outcomes, and (2) the absence of validated, context-sensitive models for integrated AKI care. Using a mixed-methods design, the study will assess both the clinical impact of an integrated model and the system-level factors shaping its implementation.

1.4 Study Aim and Objectives

To evaluate the feasibility and effectiveness of an integrated acute kidney injury (AKI) detection and management approach in Southern West Bank governmental hospitals, and to explore contextual and system-level factors influencing its implementation.

Quantitative Objective

To evaluate the effectiveness of a multifaceted AKI detection and management approach on clinical outcomes and care-process indicators.

Qualitative Objective

To explore nephrologists' perspectives on the feasibility, acceptability, and sustainability of implementing an integrated AKI management approach across hospitals in the West Bank.

Hypotheses

H1: Patients managed using the integrated AKI approach will have improved clinical outcomes compared with usual care.

H2: The integrated approach will be associated with improved care-process indicators (timeliness of nephrology review, medication optimization, fluid monitoring).

Specific Objectives.

The specific objectives of the study are:

1. Assess how accurately clinical risk triage stratifies patients by likelihood of AKI and need for timely intervention.
2. Assess the diagnostic and prognostic performance of AKI biomarkers, including NGAL, serum creatinine, urine protein, and protein-to-creatinine ratio (PCR), individually and in combination, for early detection and staging.
3. Evaluate the effect of the integrated model on primary outcomes (AKI progression, initiation of dialysis, in-hospital mortality) and secondary outcomes (renal recovery, AKI duration, length of stay, healthcare utilization).
4. Evaluate changes in key care-process indicators (e.g., timeliness of nephrology review, medication optimization, fluid/monitoring practices).
5. Explore nephrologists' views on feasibility and acceptability, identify major facilitators and barriers, and elicit their recommendations for adoption and sustainability.
6. Generate actionable evidence that informs Palestinian health authorities on optimizing AKI care pathways, while providing a transferable framework for strengthening kidney care in other countries.

1.5 Research Questions

Q1. How accurately does risk triage stratify AKI risk and trigger timely intervention?

Q2. What is the diagnostic and prognostic performance of NGAL, serum creatinine, urine protein, and protein-to-creatinine ratio for early AKI detection and staging?

Q3. Does the integrated model improve patient outcomes (primary and secondary) compared with usual care?

Q4. To what extent does the model change provider response indicators (nephrology review, medication/fluids, monitoring)?

Q5. What facilitators, barriers, and recommendations do nephrologists report regarding feasibility, acceptability, and sustainability?

Q6. How can the findings from this integrated AKI management study be translated into actionable recommendations for Palestinian health stakeholders, and to what extent are these strategies transferable to other similar contexts?

1.6 Significance of the Study

This study makes contributions at three levels:

- Empirical: It will generate the first comprehensive data on AKI incidence, outcomes, and care gaps in Palestinian governmental hospitals, filling the evidence void created by the absence of a renal registry.
- Policy: By testing a hybrid model of risk triage, biomarkers, and e-alerts, the findings will provide actionable guidance for cost-effective, scalable interventions. These insights will support Palestinian policy decision makers in strengthening kidney care, optimizing resource allocation, and aligning with the World Health Organization's (WHO, 2025) resolution on kidney health.
- Global knowledge: By documenting how integrated AKI care can be adapted in resource limited contexts, the study contributes to international dialogues on AKI management. It offers transferable lessons for LMICs and proposes a scalable model that could be adapted to other noncommunicable diseases (NCDs), reinforcing health system resilience beyond nephrology.

Together, these contributions will inform national kidney care strategies in Palestine, shape evidence-based policies and provide a transferable framework that can be used in comparable international settings.

Chapter Two

A. Literature Review

This chapter reviews the literature on Acute Kidney Injury (AKI) management, including risk triage protocols, novel biomarkers, and electronic health alerts. This search utilizes several esteemed databases, including EBSCOhost, Medline-PubMed, and the Cochrane Library, to ensure a comprehensive collection of relevant studies. This chapter is methodically divided into two main sections: the first section presents a focused literature review, synthesizing the findings pertinent to the themes above; the second section delineates the conceptual framework, which underpins the study and posits the interplay between these critical components in the enhancement of AKI management.

Part One: Quantitative literature review

2.1 Definition of acute kidney injury (AKI)

Acute Kidney Injury (AKI) is defined by the Kidney Disease: Improving Global Outcomes (KDIGO, 2012) guidelines as a rapid deterioration in kidney function occurring within seven days. It is identified by one or more of the following criteria:

- An increase in serum creatinine (SCr) by ≥ 0.3 mg/dL within 48 hours
- An increase in SCr to ≥ 1.5 times the baseline within seven days
- A reduction in urine output to < 0.5 mL/kg/h for six hours or more (KDIGO, 2012; Lameire et al., 2021).

Unlike chronic kidney disease (CKD), which requires a duration of over three months, AKI is temporally defined within a shorter window and does not require structural abnormalities for diagnosis.

As illustrated in Figures 1 and 2, the KDIGO consensus document delineates functional and structural criteria that distinguish AKI, acute kidney disease (AKD), CKD, and normal kidney function (NKD, No kidney diseases). Notably, AKI is a phase within the broader AKD spectrum, encompassing kidney abnormalities lasting up to three months (Lameire et al., 2021). This classification highlights that AKI is not a standalone disease but part of a

continuum of kidney disorders, with potential outcomes including progression to CKD, incident CKD, or recovery with reduced renal reserve.

	AKI	AKD	CKD	NKD
Duration	Within 7 days	≤3 months	>3 months	
Functional criteria	Increase in SCr by 50% within 7 days Or Increase in SCr by 0.3 mg/dl (26.5 μmol/l) within 2 days Or Oliguria for ≥6 hours	AKI Or GFR < 60 ml/min/1.73 m ² Or Decrease in GFR by ≥35% Or Increase in SCr by >50%	GFR < 60 ml/min/1.73 m ²	GFR > 60 ml/min/1.73 m ²
And/or		And/or	And/or	And
Structural criteria	Not defined	Marker of kidney damage (albuminuria, hematuria, or pyuria are most common)	Marker of kidney damage (albuminuria is most common)	No kidney damage

Figure 2.1 Functional and structural criteria for kidney diseases and disorders. AKD, acute kidney disease; AKI, acute kidney injury; CKD, chronic kidney disease; GFR, glomerular filtration rate; NKD, no kidney disease; SCr, serum creatinine. Source:(Lameire et al., 2021).

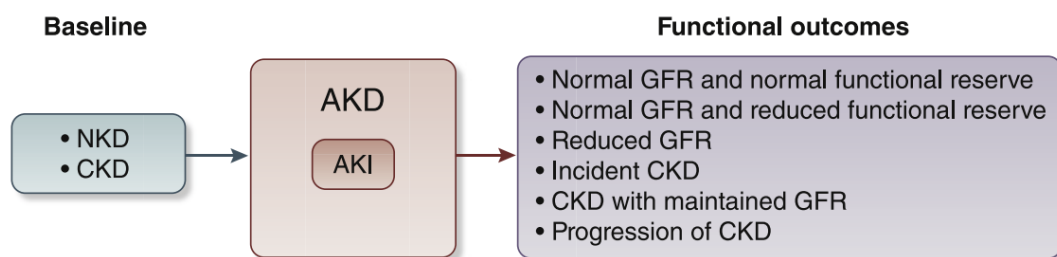


Figure (2.2) Acute kidney disease (AKD), acute kidney injury (AKI), and kidney disease outcomes. CKD, chronic kidney disease; GFR, glomerular filtration rate; NKD, no kidney disease. Source: (Lameire et al., 2021)

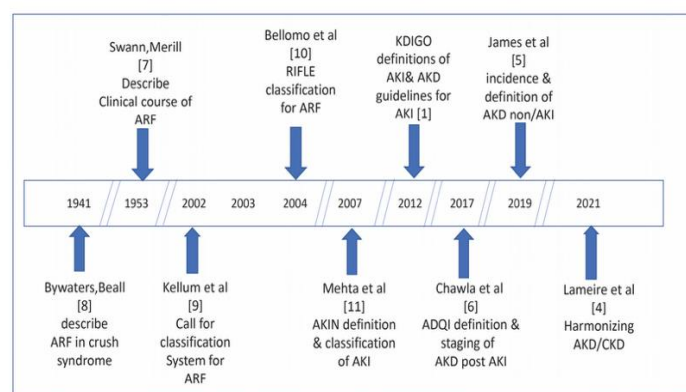


Figure 2.3 Timelines of the most important contributions on the evaluations of the definitions and classifications of AKI.

2.2 Classification Systems of AKI

Historically, as shown in Figure 2.3, the diagnosis of AKI was hindered by the absence of a standardized definition, leading to variability in reported incidence, severity, and outcomes. This prompted several international efforts to develop unified classification criteria that could stratify AKI severity based on serum creatinine (SCr) changes and urine output.

RIFLE Criteria (2004)

The RIFLE classification introduced by the Acute Dialysis Quality Initiative (ADQI) in 2004 was the first consensus-based system to define AKI. It stratified kidney injury into three severity stages:

- Risk
 - Injury
 - Failure
- ...and two outcome stages:
- Loss of function (persistent renal failure >4 weeks)
 - End-stage renal disease (ESRD) (>3 months)

Each level was based on either changes in SCr or urine output, using the worst of either measure (Srisawat et al., 2010).

AKIN Criteria (2007)

In 2007, the Acute Kidney Injury Network (AKIN) modified the RIFLE criteria by:

- Introducing an absolute increase in SCr of ≥ 0.3 mg/dL ($26.5 \mu\text{mol/L}$) as an early diagnostic trigger.
- Eliminating the outcome categories (Loss and ESRD).
- Requiring changes to occur within 48 hours.

These refinements aimed to improve early detection and reduce underdiagnosis in milder cases (Mehta et al., 2007).

KDIGO Classification (2012 – Present)

To unify RIFLE and AKIN systems, KDIGO (2012) proposed a three-stage AKI classification that:

- Maintained the ≥ 0.3 mg/dL rise in serum creatinine.
- Expanded the diagnostic window to seven days
- Standardized urine output thresholds

Today, KDIGO is the globally endorsed framework for AKI classification, used in both clinical care and research (KDIGO, 2012). However, reliance on SCr and urine output remains problematic, as they are delayed indicators of injury (Docherty et al., 2024).

To address this, experts advocate integrating novel biomarkers and electronic health alerts to improve early detection and patient outcomes (Hasson et al., 2022).

Table (2.1): Comparison of RIFLE, AKIN, and KDIGO Classification Criteria for AKI. Adapted from KDIGO Clinical Practice Guideline for Acute Kidney Injury, 2012

AKI stage	Increase in serum creatinine concentration	Urinary output criteria
RIFLE		
Risk	≥ 1.5 - to 2-fold increase, <i>or</i> decrease in GFR $>25\%$	<0.5 ml/kg/h for ≥ 6 h to <12 hours
Injury	≥ 2.0 - to 3.0-fold increase, <i>or</i> decrease in GFR $>50\%$	<0.5 ml/kg/h for ≥ 12 h
Failure	≥ 3.0 -fold, <i>or</i> $44 \mu\text{mol/l}$ absolute increase if baseline SCr $\geq 354 \mu\text{mol/l}$ <i>or</i> decrease in GFR $\geq 75\%$	<0.3 ml/kg/h for ≥ 24 h <i>or</i> anuria for ≥ 12 h
Loss of Kidney Function	Complete loss of renal function for >4 weeks	
End-stage Renal Disease	End-stage renal disease >3 months	
AKIN		
Stage 1	≥ 1.5 - to 2-fold increase, <i>or</i> $\geq 26.4 \mu\text{mol/l}$ absolute increase within 48 h	<0.5 ml/kg/h for >6 h to 12 hours
Stage 2	>2.0 - to 3.0-fold increase	<0.5 ml/kg/h for >12 h
Stage 3	>3.0 -fold increase, <i>or</i> $\geq 44 \mu\text{mol/l}$ absolute if baseline $\geq 354 \mu\text{mol/l}$	<0.3 ml/kg/h for ≥ 24 h <i>or</i> anuria for ≥ 12 h
KDIGO		
Stage 1	≥ 1.5 - to 1.9-fold increase within 7 days, <i>or</i> $>26.5 \mu\text{mol/l}$ within 48 hours	<0.5 ml/kg/h for 6 to 12 h
Stage 2	≥ 2.0 - to 2.9-fold increase within 7 days	<0.5 ml/kg/h for ≥ 12 hours
Stage 3	≥ 3.0 -fold increase, <i>or</i> $>354 \mu\text{mol/l}$ increase within 7 days, <i>or</i> initiation of renal replacement therapy, <i>or</i> a decrease of GFR to $<35 \text{ ml/min/1.73m}^2$ in patients <18 years of age	<0.3 ml/kg/h for ≥ 24 h <i>or</i> anuria for ≥ 12 h

AKI = acute kidney injury, AKIN = Acute Kidney Injury Network, KDIGO = Kidney Disease: Improving Global Outcomes, RIFLE = Risk, Injury, Failure, Loss of kidney function, and End-stage renal disease.

2.3 AKD and the transition from AKI to CKD

According to the KDIGO framework, AKI refers to a sudden decline in kidney function over ≤ 7 days, while AKD spans up to 90 days and includes both AKI and persistent kidney injury that does not meet criteria for CKD. AKD can also occur independently of AKI. Both AKI and AKD are associated with increased risk of mortality, renal replacement therapy (RRT), and progression to CKD (Ostermann et al., 2025). As shown in Figure 2.4, AKI, AKD, and CKD form an interrelated continuum, with shared clinical features and overlapping outcomes. Including both S.cr and urine output improves detection sensitivity and prognostic accuracy. Recovery patterns vary: some patients regain baseline function, while others progress to CKD or ESKD or experience systemic complications. Even patients who appear to recover may retain subclinical renal damage.

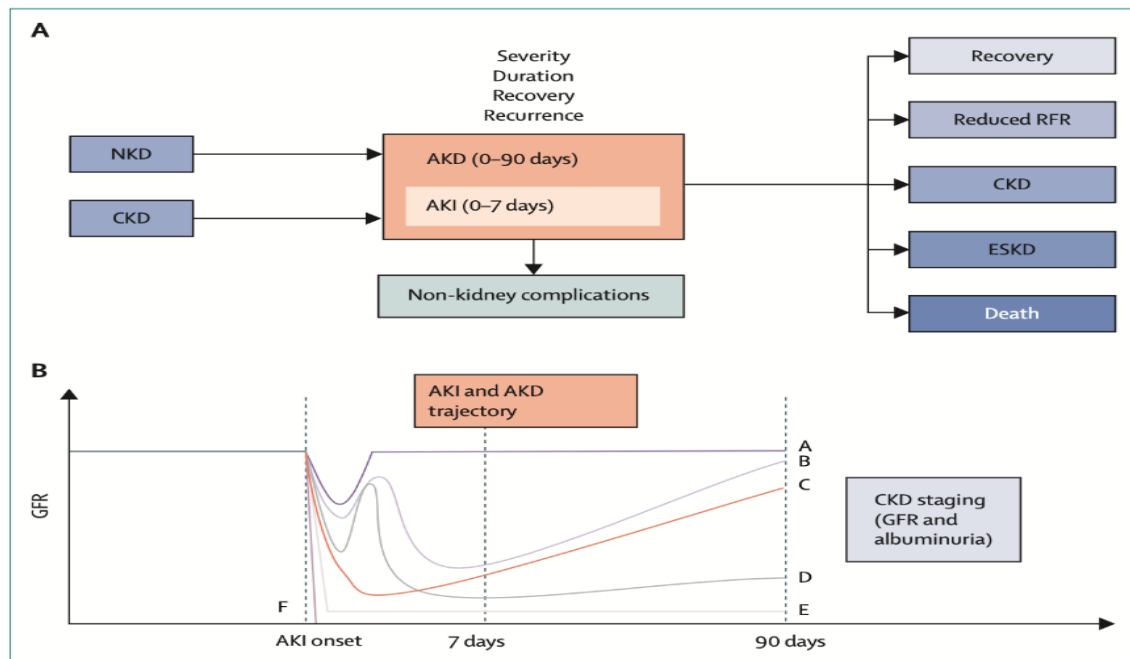


Figure (2.4): 4A: AKI within the continuum of acute kidney disease and chronic kidney diseases

4B: GFR Trajectories Across the AKI–AKD–CKD Continuum

Six clinical pathways based on timing, severity, and reversibility of AKI.

Trajectory A: Mild, transient AKI with full recovery

Trajectory B: Transient AKI with recurrence and recovery

Trajectory C: Severe AKI with delayed recovery

2.4 Recovery Patterns and Clinical Trajectories

Full recovery

Patients with mild or transient AKI often return to baseline kidney function within 90 days, with minimal long-term effects.

Reduced renal functional reserve (RFR)

Some patients, despite normalization of Scr., experience reduced renal reserve. This subclinical impairment increases the risk of future injury, fluid imbalance, and drug toxicity.

Progression to CKD

Persistent dysfunction beyond 90 days indicates CKD. Risk factors include severe/recurrent AKI, diabetes, hypertension, or pre-existing CKD.

Transition to end-stage kidney disease (ESKD)

In cases of maladaptive repair, AKD progresses to irreversible kidney failure requiring dialysis or transplant.

Death and systemic complications

AKI/AKD patients, especially in the ICU, may die due to multiorgan failure, sepsis, or

cardiovascular complications. Non-renal outcomes (stroke, infection, GI bleeding) also increase mortality.

2.5 Epidemiology of AKI

AKI is a global health concern, with an estimated 13 million cases annually, leading to 1.7 million deaths, primarily in low- and middle-income countries (LMICs) (Francis et al., 2024; Gameiro et al., 2025). Hospital-based studies report a 22% incidence in adults and 34% in children, with rates exceeding 50% in intensive care units (ICUs) (Ostermann et al., 2025).

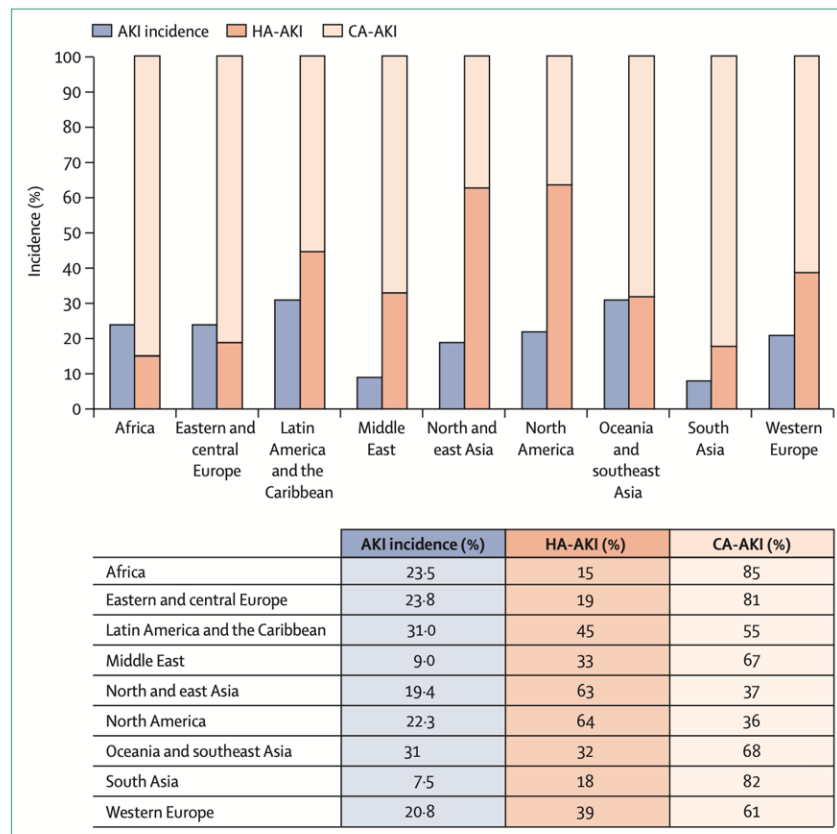


Figure (2.5). Global AKI Incidence by Region AKI burden by geographic region, showing higher incidence and mortality in LMICs Source: Ostermann et al., 2025.

Regional patterns: High-Income Countries vs. LMICs

In high-income countries (HICs), AKI is typically hospital-acquired, caused by:

- Sepsis (40–50%)
- Major surgery (20–30%)
- Nephrotoxic drugs (e.g., NSAIDs)

In contrast, LMICs face a predominantly community-acquired AKI burden (80% +), often due to:

- Dehydration
- Diarrheal illness
- Infections (e.g., malaria, leptospirosis)
- Snakebites, herbal remedies, obstetric complications

Access to dialysis is severely limited in LMICs <10% of patients receive renal replacement therapy, leading to 2–3× higher mortality rates (Francis et al., 2024).

2.5.1 AKI in Arab countries and Palestine

In the Arab region, studies have revealed a concerning pattern of high AKI incidence and mortality, particularly among critically ill and elderly populations. In Egypt, Shemiesa et al., (2022) examined elderly patients with community-acquired AKI and reported that 40% were aged above 65 years. Diabetes and chronic kidney disease were the most common comorbidities, while dehydration and sepsis were identified as major causes. The study reported a mortality rate of 16%, emphasizing the vulnerability of older adults to AKI. Similarly, an intensive care study from Saudi Arabia by Albeladi & Algethamy, (2017) found that approximately 28% of ICU patients developed AKI, with more than half requiring dialysis. Mortality exceeded 50%, and the absence of renal recovery increased the risk of death to over 80%. Notably, urinary NGAL was highlighted as an effective biomarker for early AKI detection in this cohort.

In Palestine, recent hospital-based studies have provided valuable insight into AKI epidemiology. Damin Abukhalil et al., (2024) reported an AKI incidence of 6.2% among hospitalized patients, with pre-renal causes such as dehydration and sepsis accounting for nearly two-thirds of cases. Chronic kidney disease, diabetes, and the use of nephrotoxic drugs were identified as key predictors, while in-hospital mortality reached 18.2%. Only 48.6% of patients achieved full recovery by discharge. Another study by Nazzal et al., (2022) on oncology patients revealed a 6.9% incidence of AKI and a sevenfold increase in mortality risk, with nearly half of affected patients dying during hospitalization. Collectively, these findings demonstrate that AKI in Palestine arises from both community and hospital factors and remains associated with poor recovery and high mortality rates. These data highlight that AKI in Palestine is driven by both community and hospital factors, with high mortality and low recovery rates.

2.5.2 Disease-Specific contexts

AKI frequently complicates a range of underlying diseases, amplifying their morbidity and mortality. In patients with liver cirrhosis, AKI has been shown to increase ICU mortality to as high as 76% (Lekakis et al., 2025), reflecting the synergistic burden of multi-organ dysfunction. Similarly, among critically ill patients with COVID-19, AKI incidence ranges between 50% and 85%, with up to 15% requiring dialysis (Rubin et al., 2024; Schaubroeck et al., 2022). In a large multicenter cohort of over 87,000 hospitalized adults (Esposito et al., 2025), reported an AKI incidence of 20.6%, with mortality rates more than doubling among affected patients (27.8% vs. 11.4%) compared to those without AKI. The study also noted prolonged hospital stays and persistent renal dysfunction in survivors.

In pediatric and critical care populations, the clinical impact of AKI is similarly profound. Zarei et al. (2025) observed that more than 30% of children who developed AKI in intensive care settings died during hospitalization. Across these diverse disease contexts, AKI acts as an independent predictor of poor outcomes, underscoring the urgent need for early detection

strategies, biomarker integration, and improved management pathways in both adult and pediatric populations.

2.6 Economic burden of AKI

Beyond its clinical consequences, AKI imposes a substantial economic burden on healthcare systems worldwide. It is strongly associated with prolonged hospital stays, increased ICU admissions, greater use of dialysis (RRT), and higher readmission rates (Silver & Chertow, 2017; Monard et al., 2023). These factors contribute to markedly higher healthcare costs.

In the United States, AKI adds an estimated \$5.4–24 billion annually to healthcare expenditure. In England, AKI-related hospitalizations account for nearly 1% of the entire NHS budget (Silver & Chertow, 2017)

Per-hospitalization costs are significantly higher in AKI patients requiring dialysis, an additional \$11,000–42,000, compared with non-AKI cases. Similarly, European studies report that AKI admissions incur median costs of €4,719 vs. €735 for non-AKI cases, with length of stay extended by up to nine days (Monard et al., 2023).

The burden is even more pronounced in LMICs, where out-of-pocket payments predominate due to limited insurance coverage. Dialysis is often unavailable or unaffordable, leading not only to poor outcomes but also to catastrophic household expenses.

Cost-effectiveness analyses indicate that early AKI detection and bundled interventions can reduce long-term costs by preventing CKD progression and decreasing dialysis initiation. For example, one intervention study reduced average per-admission costs from £5,065 to £4,333, saving £732 per patient (Gameiro et al., 2025).

Taken together, these findings emphasize that AKI is not only a clinical crisis but also a major global economic challenge. For LMICs such as Palestine, the dual impact of poor outcomes and high out-of-pocket expenses underscores the urgent need for cost-effective strategies such as early detection, standardized management, and structured post-AKI follow-up.

2.7 Recent advances in AKI

2.7.1 World Health Assembly 2025 Resolution on Kidney Health

In March 2025, the WHO officially recognized kidney disease, including AKI, as a major global health priority. The declaration emphasized that millions of deaths from AKI remain preventable through earlier recognition, improved access to diagnostics, and affordable renal replacement therapy. It called for integrating kidney health into universal health coverage, expanding nephrology workforce capacity, and scaling up innovations such as risk triage, biomarker-based diagnostics, and electronic health alerts. These global recommendations resonate strongly with this study's objectives in the Palestinian context, where systemic constraints limit early AKI detection and management.

2.7.2 Lancet Seminar on AKI

The most recent Lancet seminar (Ostermann et al., 2025) highlighted emerging innovations that are reshaping AKI care. These include:

- Novel biomarkers (e.g., NGAL, TIMP-2·IGFBP7, cystatin C, dickkopf-3) enable earlier and more precise detection of subclinical AKI. Notably, NGAL received FDA approval in 2023 for pediatric AKI prediction.
- Digital health tools, such as electronic alerts, clinical decision support systems (CDSS), and even wearables, which enhance detection and monitoring though with mixed outcome benefits.
- Structured follow-up pathways, with evidence that up to 37% of patients develop major adverse kidney events within a year, and up to 94% in ICU survivors by three years, highlighting the urgent need for post-AKI clinics and multidisciplinary care (Ostermann et al., 2025).

2.8 Drivers of AKI in Developing Regions

The causes of AKI in LMICs are strongly shaped by environmental, infectious, and healthcare system factors. In contrast to high-income countries, where AKI is largely hospital-acquired (e.g., sepsis, surgery, nephrotoxins), in LMICs, most cases are community-acquired and often preventable (Patidar et al., 2025).

As shown in Table 2, the drivers of AKI in developing countries are context-specific. Community-acquired AKI is often linked to infections, dehydration, obstetric causes, herbal remedies, trauma, and environmental toxins, whereas hospital-acquired AKI is mainly due to surgery, hemorrhage, sepsis, and nephrotoxic drug exposure (Ponce & Balbi, 2016; Patidar et al., 2025).

These patterns underscore that AKI in LMICs is not only a medical condition but also a reflection of health system capacity. Limited diagnostics, late hospital presentation, and restricted ICU access amplify the risks of poor outcomes. Understanding these drivers is essential for developing context-appropriate triage and prevention strategies, which is a central aim of this thesis.

Table (2.2): Causes of AKI in Developing Countries Adapted from Ponce & Balbi (2016); Patidar et al. (2025)

Community-acquired AKI	Hospital-acquired AKI
Tropical infections (e.g., malaria, leptospirosis, dengue)	Major surgeries
Other infections (gastroenteritis, pneumonia, skin)	Hemorrhage
Acute glomerular diseases	Infections
Obstetric causes	Septic shock
Underlying chronic diseases (kidney disease, cardiac disease, diabetes, etc.)	Drug toxicity
Herbal remedies	Underlying chronic diseases
Trauma (traffic injuries, natural disasters)	
Nephrotoxins	
Environmental causes (e.g., snakebites)	

2.9 Management of patients with AKI

The International Society of Nephrology (ISN) recommends a structured approach to AKI management, emphasizing early recognition, prevention of harm, and renal support as shown in Figure 2.6. A widely adopted model is the STOP AKI protocol, which highlights four priorities:

- **Sepsis:** Identify and treat infection promptly
- **Toxins:** Avoid nephrotoxic drugs
- **Optimize:** Blood pressure and volume status, ensure adequate perfusion
- **Prevent harm:** Review medications, fluids, and complications.

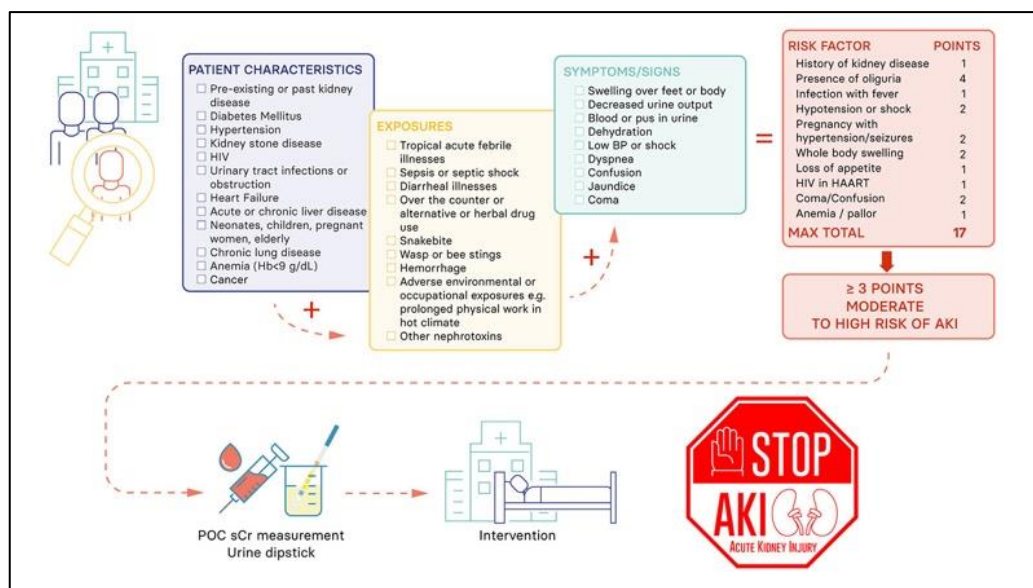


Figure (2.6) The STOP AKI Protocol for AKI Management *Source:* ISN AKI Toolkit (Mehta et al., 2015)

2.10 The ISN 0by25 Initiative and the 5R Framework

The ISN 0by25 initiative was launched to eliminate preventable deaths from AKI (0 deaths by 2025), especially in LMICs. Its strategy is summarized in the 5R framework: **R**isk assessment, **R**ecognition, **R**esponse, **R**enal support, and **R**ehabilitation (Mehta et al., 2015). These pillars provide a global roadmap for AKI care across the continuum. This thesis aligns with the 0by25 vision by focusing on three components: risk assessment, recognition, and response (Mehta et al., 2015). Building on the 0by25 framework, this thesis focuses on three core strategies to enhance AKI care in resource-limited settings: risk triage systems, novel biomarkers, and electronic health alerts.

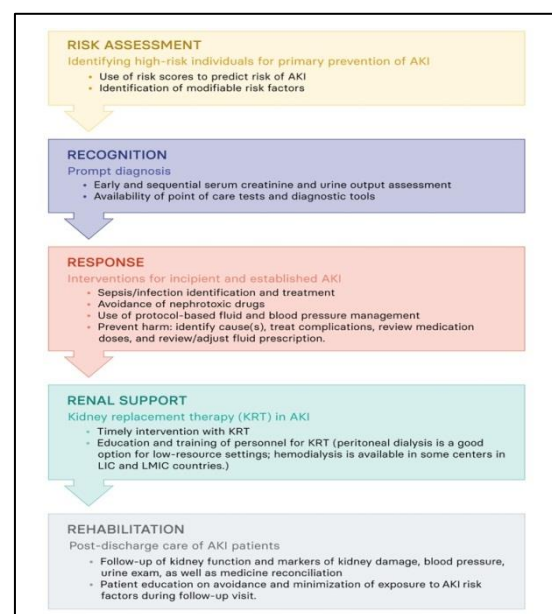


Figure (2.7) The ISN 5R Framework for AKI Management, *Source:* ISN 0by25 Initiative (Mehta et al., 2015).

The following sections review the evidence and practical applications of each.

2.10.1 Risk triage systems

Early and accurate risk stratification is crucial in AKI care, as it guides clinical decision-making, resource allocation, and prevention strategies. Risk triage systems allow clinicians to identify vulnerable patients, prioritize investigations, and initiate preventive measures before irreversible damage occurs. These tools range from general critical-care scores, such as the Sequential Organ Failure Assessment (SOFA) and the Acute Physiology and Chronic Health Evaluation (APACHE), to AKI-specific models like the Renal Angina Index (RAI) and ISN's risk score (Goldstein et al., 2022).

In high-income countries, advanced models increasingly integrate biomarkers (e.g., NGAL, TIMP-2-IGFBP7) and machine learning algorithms for real-time prediction (Flechet et al., 2017). By contrast, in LMICs, simpler bedside tools, such as the Kampala Trauma Score or modified early warning scores, are more practical, enabling early identification when laboratory resources are limited (Hakimzadeh et al., 2024; Naidu, 2023).

Risk Factor	Points
History of kidney disease	1
Presence of oliguria	4
Infection with fever	1
Hypotension or shock	2
Pregnancy with hypertension/seizures	2
Whole body swelling	2
Loss of appetite	1
HIV in HAART	1
Coma/Confusion	2
Anemia / pallor	1
Max Total	17

Figure (2.8) The ISN AKI Risk Score, Scores ≥ 3 indicate moderate to high risk of AKI, prompting further monitoring and intervention. Source: ISN AKI Toolkit (2023)

2.10.2 Novel biomarkers in early AKI detection

The diagnosis of AKI traditionally relies on serum creatinine and urine output. However, these measures have important limitations: SCr rises late after injury, is influenced by muscle mass, hydration, and drugs, and cannot detect subclinical injury.

Traditional AKI markers such as SCr and urine output are delayed and often unreliable. The international consensus report by Ostermann et al. (2025) concluded that novel biomarkers of kidney damage, stress, and function provide earlier and more specific detection, especially when combined with clinical assessment.

Among the most validated is NGAL. Studies show NGAL rises much earlier than creatinine and predicts outcomes, including RRT need and persistent AKI (Albeladi & Algethamy, 2017; Lumlertgul et al., 2020; Côté et al., 2022). Other injury biomarkers such as KIM-1, L-FABP, and IL-18, along with the cell-cycle arrest markers TIMP-2-IGFBP7, have shown strong predictive value, particularly in ICU and perioperative settings (Hatton et al. 2020; Neyra et al. 2019).

Comprehensive reviews confirm that biomarkers not only detect injury earlier but also help differentiate pre-renal vs. intrinsic AKI and identify patients with subclinical AKI who remain at risk of CKD progression (Schrezenmeier et al., 2017; Zou et al., 2022). However, barriers such as cost, heterogeneity, and lack of standardization continue to limit global adoption (Koyner et al., 2020; Oh, 2020).

For LMICs, including Palestine, the pragmatic approach is to integrate feasible assays such as NGAL or cystatin C into risk triage pathways to enable earlier recognition and targeted management.

Taken together, this growing body of evidence highlights a clear paradigm shift: AKI is increasingly viewed not solely as a disorder detectable through delayed functional decline but as a spectrum of injury detectable at the molecular level. Biomarkers offer the potential to identify patients at risk earlier, stratify disease severity more precisely, and guide targeted interventions.

Urine output

- Risk of measurement error (eg, absence of a urinary catheter)
- Can be manipulated by diuretics
- Oliguria might be physiological (eg, during surgery)

Serum creatinine

- Affected by liver function, muscle mass and metabolism, recent (<6 h) meat-containing meal, and exogenous creatine intake
- Small increases can occur due to physiological and analytical variability, particularly with low baseline glomerular filtration rate (eg, chronic kidney disease)
- Can increase without true reduction in glomerular filtration rate, for instance in the setting of:
 - Hemoconcentration (eg, diuresis)
 - Inhibition of tubular secretion (eg, medications such as trimethoprim and cimetidine)
- Real increases might be concealed:
 - by fluid resuscitation and volume expansion
 - in case of malnutrition, liver disease, and muscle wasting during pregnancy, which is associated with physiological decrease of serum creatinine
- Some increases predict better long-term outcomes:
 - Renin-angiotensin-aldosterone inhibitors can increase serum creatinine due to renal afferent arteriole vasodilation; however, relatively small increases soon after initiation predict long-term preservation of kidney function
 - Sodium glucose-2 transporter inhibitors are associated with increases in serum creatinine concentration through tubuloglomerular feedback mechanisms leading to afferent arteriole constriction, yet improve cardiovascular and kidney outcomes and appear to lower the risk of acute kidney injury

Figure (2.9) Limitations of serum creatinine as a Biomarker for AKI. Source: Adapted from Kashani et al. 2023.

2.10.3 Electronic alerts, Clinical Decision Support (CDS) & Care bundles in AKI

Electronic alert (e-alert) systems have been developed to improve the timely recognition of AKI by automatically flagging changes in serum creatinine or urine output within electronic health records (EHRs). These tools aim to reduce delays in diagnosis, support decision-making, and trigger early intervention.

Evidence shows mixed but promising results. Kolhe et al. (2015) reported that AKI e-alerts in a UK hospital improved documentation and early nephrology consultation, while Wilson et al. (2014), demonstrated better compliance with care bundles. However, several randomized trials, including (Perry Wilson et al., 2021) and (Selby et al., 2019), found that alerts alone had limited impact on hard outcomes such as mortality or dialysis, emphasizing that alerts must be paired with clinical decision support and education.

More recent studies highlight the value of integrated systems. Koyner et al. (2020) showed that combining e-alerts with care bundles, pharmacist input, or risk prediction models improved prescribing safety, reduced nephrotoxin exposure, and supported personalized triage. The Lancet 2025 update further underscored digital health innovations, including e-alerts and CDSS as key components for advancing AKI (Ostermann et al., 2025a).

The most up-to-date synthesis of evidence is the meta-analysis by Jawabreh (2025), which found that e-alerts did not significantly reduce mortality or dialysis, though they increased nephrology consultations. Importantly, medication-focused alerts (e.g., proton pump inhibitors) showed benefit in reducing adverse outcomes, suggesting that tailored alerts may be more effective than generic ones. The authors also recommended mixed-methods evaluations to capture both outcome data and contextual factors influencing alert effectiveness.

2.11 Challenges in LMICs

AKI in LMICs is shaped not only by clinical risks but also by systemic inequities. The ISN Global Kidney Health Atlas (2023) identifies major gaps as illustrated and summarized in Table 2.3 in care that amplify mortality and hinder innovation.

Table (2.3): Challenges in AKI Care Across LMICs

Source: Adapted from ISN Global Kidney Health Atlas (2023).

Challenge	Key Issues
Limited access to care	Basic diagnostics (S.cr, urine output) and nephrology services are scarce.
Workforce shortages	<5 nephrologists per million; lack of trained allied staff.
Weak preventive services	Few community programs for early detection or education.
Dialysis barriers	Dialysis often unavailable, unaffordable, or geographically inaccessible.
Data gaps	No registries or surveillance; limited use of biomarkers/e-alerts.

These challenges are consistent with international health policy priorities (ISN 2023), underscoring the need for stronger AKI surveillance, investment in workforce capacity, and expansion of affordable RRT in LMICs. In Palestine, they provide a roadmap for system-level reforms to support AKI innovation.

2.12 Gaps and justification for this study

Despite global advances, several gaps remain:

- Diagnostic gaps, reliance on late markers (SCr, urine output) without biomarker or predictive tools.
- Implementation gaps, limited use of e-alerts, care bundles, or KDIGO-based protocols.
- Evidence gaps, no systematic data on AKI burden, management, or outcomes in Palestine.
- Equity gaps, innovations are largely untested in LMICs.

Justification: This study addresses these gaps by evaluating risk triage, biomarkers, and e-alerts within Palestinian hospitals, generating context-specific evidence and contributing to the global LMIC agenda.

2.13 Towards a hybrid model for AKI

No single tool is sufficient for early AKI detection. A hybrid approach combining risk assessment, e-alerts, and biomarkers may provide the most effective solution. Scores using clinical and demographic data stratify patients but depend on reliable records and integration.

Electronic Alerts

E-alerts trigger action when thresholds are crossed. Alone, they mainly improve recognition; when combined with bundles and nephrology review, they reduce AKI progression.

Biomarkers

NGAL, TIMP-2·IGFBP7, and cystatin C detect subclinical injury earlier than creatinine, improving sensitivity when paired with risk tools.

A Synergistic Model

An effective pathway integrates:

- ⇒ Risk stratification at admission.
- ⇒ Continuous monitoring with e-alerts.
- ⇒ Biomarker confirmation for precision diagnosis.

In LMICs, including Palestine, simplified models may rely on clinical scores and basic e-alerts, with gradual introduction of biomarkers for high-risk cohorts.

Part Two: Qualitative Literature Review

While quantitative research has mapped the incidence, causes, and outcomes of AKI, it provides limited insight into the “how” and “why” of care delivery gaps. Qualitative and mixed-methods studies address this limitation by examining clinicians’ perceptions, patient experiences, and organizational barriers that shape the implementation of AKI and CKD management strategies. These studies are essential for understanding real-world contexts, why guidelines are inconsistently applied, why electronic alerts sometimes fail to improve outcomes, and why preventive strategies are slow to diffuse into practice. Integrating this evidence is particularly important for the present thesis, which employs a mixed-methods approach to evaluate risk triage, biomarkers, and electronic health alerts in AKI care.

Provider Awareness and Guideline Adherence

Several studies highlight persistent knowledge and practice gaps among primary care physicians (PCPs). Abdel-Kader et al. (2014) found that more than half of PCPs were unfamiliar with CKD guidelines, while many questioned the clinical value of albuminuria testing and expressed concerns about overdiagnosis in elderly patients. Wright Nunes (2013) also emphasized that PCPs often feel ill-equipped to educate patients about CKD due to limited time, lack of staff, and uncertainty about shared care responsibilities between primary and specialty providers. Tuot et al. (2016) showed that CKD awareness among patients was low across various measures, indicating ongoing gaps in communication and disease recognition, which may contribute to low adherence to testing and early intervention.

protocols. Collectively, these findings suggest that education alone is insufficient; provider beliefs and competing priorities strongly influence adherence.

Systemic and Organizational Barriers

Beyond knowledge, organizational challenges limit the implementation of AKI and CKD prevention strategies. Nash et al. (2018) identified both enablers (e.g., EMR tools, Kidney Wise toolkit, team-based care) and barriers (competing priorities, patient non-compliance, resource limitations, time constraints). Similarly, Carpenter-Song et al. (2024) pointed to organizational inertia, workflow disruption, and lack of leadership support as major obstacles to adopting preventive strategies.

Electronic Alerts and Decision Support

E-alerts represent one of the most studied digital interventions for AKI. Selby et al. (2021) and (Sawhney et al., 2018) reinforced that alerts alone did not improve outcomes unless embedded within actionable protocols, supported by training, and accompanied by feedback loops. Barker et al. (2021) emphasized that electronic alerts become effective when integrated into care teams and electronic health record (EHR) decision support systems. Together, these findings suggest that technological solutions succeed only when embedded in broader organizational workflows.

Preventive Care and Patient-Centered Barriers

Preventive strategies in CKD and AKI care face significant challenges in primary care. (Martindale et al. (2017) observed that while ‘sick day guidance’ cards offered a standardized approach to reducing AKI risk, primary care teams struggled to clearly explain temporary medication cessation, particularly to patients with limited self-management capacity. The intervention’s impact was further constrained by inconsistent implementation and limited resources. These findings underscore the ongoing tension between standardized preventive frameworks and the need to tailor care to individual patient understanding and capacity.

Table (2.4): Qualitative and Mixed-Methods Studies on AKI and CKD

Study	Author	Design	Year	Country	Outcome
AKI Electronic Alerts (Implementation)	Scott et al.	Mixed methods	2019	UK	Clinicians valued AKI e-alerts, but normalization was limited due to workflow misalignment, unclear responsibilities, lack of training, and limited feedback.
Sick Day Guidance Cards	Martindale et al.	Qualitative study	2017	UK	Implementation faced challenges in communicating medicine cessation, especially for patients with limited self-management; effectiveness limited without resourcing or broader integration.
PCP Perceptions of CKD Management	Wright Nunes et al.	Qualitative PCP survey	2018	USA	Struggles with guidelines, adherence, unclear roles
Non-Diabetic CKD Guidelines	Tuot et al.	Survey study	2016	USA	Half unfamiliar with guidelines, skeptical of albuminuria testing
CKD Lab Testing in Primary Care	Nash et al.	Qualitative descriptive	2018	Canada	EMR tools/support staff helpful; barriers: compliance, time
PCP CKD Barriers (Survey)	Abdel-Kader et al.	Survey study	2014	USA	51% unfamiliar with guidelines; concerns about overdiagnosis
Automated AKI Warning System	Sawhney et al.	Implementation study	2020	UK	Alerts effective when supported by training, systems
AKI Electronic Alerts	Selby et al.	Mixed-methods evaluation	2019	UK	Alerts ineffective unless embedded in protocols
AKI Prevention Strategies	Carpenter-Song et al.	Qualitative study	2024	USA	Identified organizational and workflow barriers to implementing evidence-based AKI prevention strategies, including leadership engagement and culture constraints.
Nephrology Rapid Response Team Model (NRRT)	Jawabreh et al.	Qualitative study	2025	Palestine	Identified enablers (e.g., MoH support, tech tools, early nephrologist engagement) and barriers (e.g., workforce shortages, policy gaps, weak surveillance); recommended reforms in policy, training, and awareness.

This body of qualitative evidence reveals that barriers to effective AKI and CKD management are multi-level and interlinked. At the provider level, gaps in guideline adherence, limited communication, and competing priorities persist. Organizational constraints, including fragmented systems, limited staffing, and insufficient training infrastructure, further hinder the implementation of evidence-based practices. Technological tools like electronic alerts offer potential but often falter when not integrated into broader workflows and team-based care. Moreover, preventive efforts struggle in the absence of patient-centered strategies and resource investment. Notably, Jawabreh et al. (2025) emphasized that successful AKI care reform in low-resource contexts such as Palestine

requires systemic policy leadership, early nephrologist involvement, and investment in education and prevention.

Synthesis and Contextual Relevance

The literature demonstrates that AKI risk triage systems, novel biomarkers, and digital decision-support interventions represent complementary strategies for early detection and improved outcomes. Scoring models such as SOFA, APACHE, and the Renal Angina Index (RAI) provide structured ways to identify high-risk patients, while simplified tools like the ISN 0by25 clinical assessment score remain essential in resource-limited settings. Biomarkers such as NGAL and TIMP2·IGFBP7 offer earlier and more sensitive detection of renal injury, particularly when applied selectively to patients identified as high-risk by clinical scores. Meanwhile, e-alerts and CDS systems, when integrated with structured care bundles, enhance recognition and standardize management but require adequate electronic health record (EHR) infrastructure.

In the Palestinian context, the healthcare system is relatively well-equipped compared to many low- and middle-income countries. Routine laboratory diagnostics are widely available, enabling reliable application of creatinine- and urine-based definitions of AKI. This creates a realistic pathway for the gradual integration of novel biomarkers (e.g., NGAL, TIMP2·IGFBP7) into tertiary care centers, complementing clinical scoring tools such as RAI. Although electronic alert systems are not yet systematically deployed, there is feasibility for future implementation within existing hospital information systems. Thus, Palestine occupies a unique position: able to draw from LMIC-relevant triage innovations while also preparing for biomarker-based risk prediction and EHR-driven CDS, aligning local practices with international AKI care frameworks.

B. The Conceptual Framework

B.1 Theoretical Framework

This study is grounded in three core models that directly inform its design and interpretation:

1. Donabedian's Structure–Process–Outcome Model explains why AKI interventions must be assessed not only on clinical outcomes but also on structural readiness and process changes. This study applies Donabedian's Structure–Process–Outcome model, which conceptualizes healthcare quality as the interaction between structural factors (infrastructure, workforce, hospital systems), processes of care (risk triage, biomarker testing, e-alert activation, nephrology consultation), and outcomes (AKI progression, dialysis, mortality). By using this model, the study examines how improvements in processes may not translate into better outcomes unless supported by adequate structural capacity an especially relevant issue in Palestinian hospitals with resource constraints (Donabedian, 2005).
2. The Clinical Decision Support “Five Rights” model emphasizes that interventions are effective only when they deliver the right information, to the right person, in the right

format, through the right channel, and at the right time. This study it provides the foundation for designing AKI e-alerts, ensuring they go beyond flagging abnormal creatinine values to provide actionable, context-specific recommendations, particularly for high-risk patients or those exposed to nephrotoxic drugs (Osheroff et al., 2007).

3. The Technology Acceptance Model (TAM) explains adoption of innovations through two key factors: perceived usefulness and perceived ease of use. In this study, TAM is particularly relevant for understanding clinician engagement with e-alerts and biomarkers. It predicts that providers will adopt these tools only if they perceive them as improving patient care and fitting smoothly into their workflows. Conversely, if alerts are viewed as disruptive or lacking clinical value, they may contribute to alert fatigue and non-use, limiting their effectiveness (Davis, 1989).

Together, these theories provide a robust foundation for the hybrid conceptual framework tested in this thesis, linking structure, process, and outcomes to the feasibility and effectiveness of triage, biomarkers, and e-alerts in Palestinian hospitals.

B.2 Conceptual Framework

The conceptual framework for this study (Figure 10) is a hybrid AKI management model implemented through the AKI PhD Research Platform. It integrates three interdependent components:

- Risk triage: Structured data modules on exposures, comorbidities, examination, and labs were used to stratify patients at admission and during hospitalization, enabling proactive identification of high-risk groups.
- Biomarkers: Laboratory data, including NGAL and urine indices, provided earlier and more specific detection of kidney injury compared to serum creatinine alone.
- Electronic alerts (e-alerts): The platform generated staged SMS messages to treating physicians, first notifying them of AKI detection and then delivering biomarker results with interpretation and ISN toolkit links, prompting timely clinical actions such as nephrology referral, medication review, or fluid management.

The framework assumes that combining triage, biomarkers, and alerts will improve process outcomes (timely recognition, documentation, nephrology involvement, appropriate interventions) and clinical outcomes (reduced progression, dialysis initiation, mortality).

A defining feature of this framework is the inclusion of implementation feasibility as an explicit endpoint. By embedding data capture, alert performance, provider response, and workflow integration within the same platform, the study not only evaluates effectiveness but also assesses the practicality of adapting this model to resource-limited hospitals in Palestine.

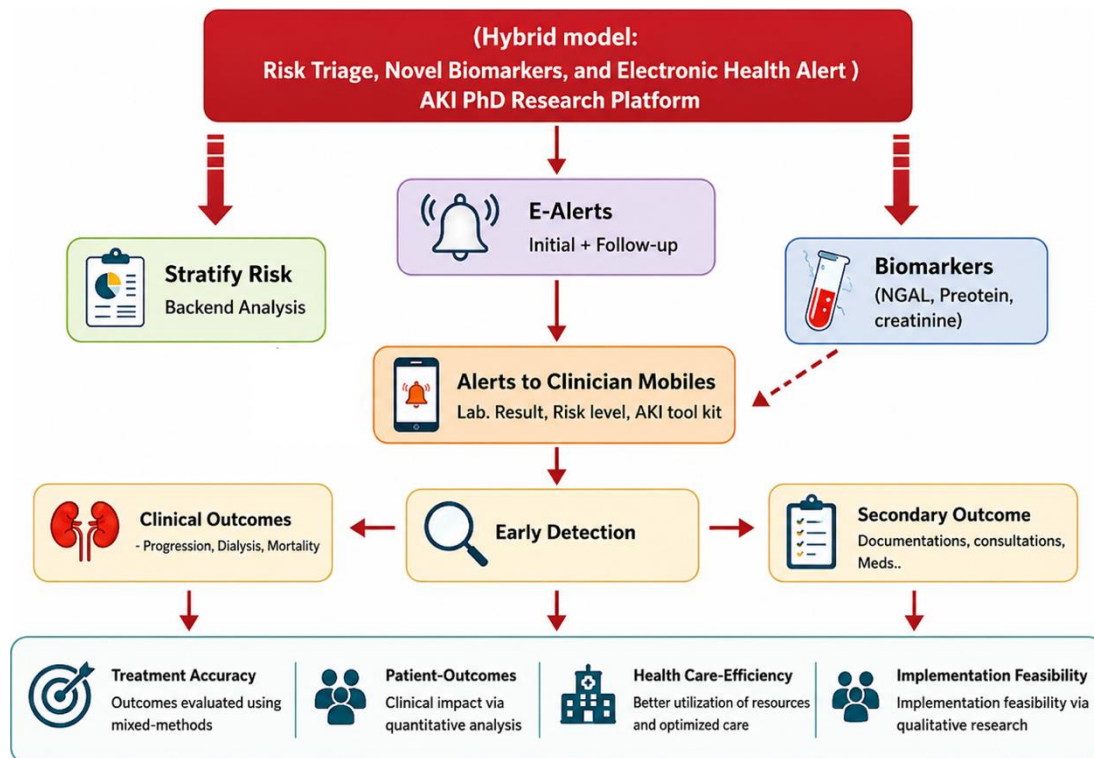


Figure (2.10) Hybrid Conceptual Framework for AKI Management. The framework integrates risk triage, biomarkers, and e-alerts as interlinked components that enhance detection, stratification, and response.

Chapter Three

Methodology

This chapter describes the methodological framework of the study, which follows a mixed-methods design. It is organized into two main sections: the first outlines the quantitative component, followed by the qualitative component. Each section is explained in detail under the subsequent headings.

3.1. Quantitative Part

This section describes the quantitative methodology used to evaluate the effectiveness of a multifaceted intervention on the management of Acute Kidney Injury (AKI) in Southern West Bank Governmental Hospitals. The quantitative design was developed to address the primary research questions through structured data collection and analysis, enabling comparison between intervention and control groups.

3.1.1 Study Design

This study employed a prospective design with a quasi-experimental cohort, using a non-randomized control group. This approach was selected based on practical constraints such as limited resources and hospital workflow.

Quasi-experimental designs are particularly well-suited to real-world clinical research, allowing interventions to be assessed under routine care conditions, while enabling meaningful group comparisons. The inclusion of a control group strengthens the internal validity by providing a benchmark against which the effects of the intervention can be measured (Capili & Anastasi, 2024).

By prospectively following patients in both groups, the study effectively captured the progression of kidney dysfunction along the AKI–AKD–CKD–ESKD continuum, as outlined by KDIGO (2020). This allowed for a comprehensive evaluation of both immediate and longer-term renal outcomes, maintaining strong internal validity via a comparison site, while ensuring external relevance for routine clinical practice in resource-limited settings.

3.1.2 Study Participants

Inclusion Criteria (applied equally to both intervention and control groups):

Patients were included if they met all of the following criteria, following the stepwise selection process illustrated in **Figure 3.1**:

1. Adults (≥ 18 years) admitted to medical, surgical, CCU, or ICU wards.
2. Met the KDIGO criteria for AKI based on serum creatinine and/or urine output (See Table 3.1).
3. AKI was identified using patient data extracted from the Avicenna HIS.

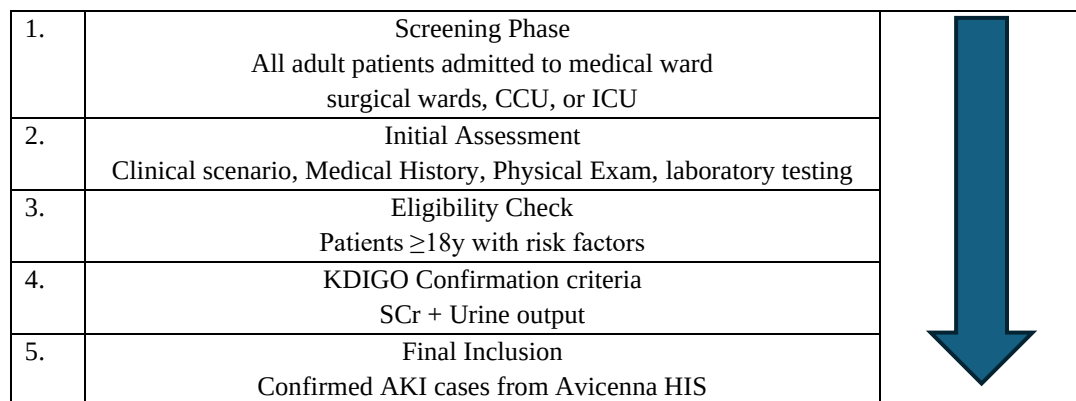


Figure (3.1): Flowchart of Study Participant Selection Based on KDIGO Criteria using the Avicenna HIS system.

Table (3.1): KDIGO Classification Criteria for Staging Acute Kidney Injury

Stage	Serum creatinine criteria	Urine output criteria
Stage 1	Increase in SCr ≥ 0.3 mg/dL within 48 hours or $1.5\text{--}1.9\times$ baseline	<0.5 mL/kg/h for 6–12 hours
Stage 2	$2.0\text{--}2.9\times$ baseline	<0.5 mL/kg/h for ≥ 12 hours
Stage 3	$3.0\times$ baseline or S.cr ≥ 4.0 mg/dL or initiation of RRT	<0.3 mL/kg/h for ≥ 24 hours or anuria for ≥ 12 hours

Source: Kidney Disease: Improving Global Outcomes (KDIGO, 2012)

3.1.3 Exclusion Criteria

The exclusion criteria were applied equally to both the intervention and control groups. Participants were excluded from the study if they met one of the following conditions:

1. Diagnosed with ESRD or on chronic dialysis.
2. History of kidney transplantation.
3. Pregnant women, due to altered renal physiology.

3.1.4 Study Setting

This study was conducted across two governmental hospitals in the southern West Bank region of Palestine: Beit-Jala Hospital (Intervention site) and Hebron Hospital (Control site). These hospitals were selected based on both practical feasibility and their status as the only

governmental referral hospitals in their respective districts. This ensures that the study population represents a comprehensive and typical sample of patients in the southern West Bank. Their comparable service profiles and patient populations also enhanced the validity of the intervention–control comparisons.

To ensure consistency across sites, uniform definitions, diagnostic thresholds (such as KDIGO criteria), and outcome measures (e.g., AKI progression, mortality, dialysis initiation, length of stay) were applied in both hospitals. Data collection was standardized via the Avicenna HIS platform, enabling reliable data extraction and minimizing variability between sites.

Intervention Site: Beit-Jala Hospital

- **Location:** The only governmental hospital in the Bethlehem governorate, offering internal medicine, surgery, and intensive care services.
- **Population:** All adult patients admitted to medical, surgical, ICU, or CCU units.
- **Implementation:** Managed under a pioneering integrated care model that included:
 - Clinical risk triage protocols
 - Use of novel AKI biomarkers (e.g., NGAL, proteinuria, PCR). Notably, NGAL is not part of the Ministry of Health’s official diagnostic test basket; the NGAL kits used in this study were independently purchased and fully funded by the principal researcher.
 - Deployment of an electronic alert system via the Researcher’s HIS platform
- **Environment:** The hospital’s infrastructure, laboratory capacity, and staff readiness supported implementation of the intervention model.

Control Site: Hebron Hospital (“Alia” Hospital)

- **Location:** The only governmental hospital in Hebron city, serving as the control site.
- **Population:** Adult patients admitted to equivalent departments (medical, surgical, ICU, CCU).
- **Standard Care:** Received routine care in accordance with existing clinical protocols, without the intervention components. These practices were documented to allow comparison with the intervention model.
- **Environment:** Existing workflows, staffing levels, and care delivery processes were observed to contextualize the control setting.

3.1.5 Sampling

The determination of sample size was guided by the need to ensure sufficient statistical power to detect clinically meaningful differences in AKI outcomes between the intervention and control groups. The calculation was based on the following assumptions: a 10% improvement in AKI detection or outcomes was considered clinically relevant, with a significance level (α) of 0.05, study power set at 80%, and an allocation ratio of 1:1.

Alternatively, and to align with published evidence, the calculation was also informed by Wu et al. (2018), who reported AKI incidence rates of 2.7% versus 7.9%. Using MedCalc Statistical Software (v.20, Ostend, Belgium), the required sample size under these parameters was estimated at 291 patients per group. To accommodate potential dropouts and incomplete

data, this figure was rounded up to 300 patients per group, giving a planned total of 600 participants.

Due to budgetary and logistical constraints, the final study population comprised 215 patients in the intervention group (Beit-Jala Hospital) and 254 patients in the control group (Hebron Hospital), for a total of 469 patients. Although smaller than initially calculated, this sample size remains adequate for meaningful statistical comparisons. The limitations of reduced power, particularly for secondary and exploratory outcomes, are transparently acknowledged in the discussion.

3.1.6 Study Period

Given the challenges of active outpatient follow-up in Southern West Bank, this study adopted a pragmatic passive-surveillance approach using the Avicenna Hospital Information System (HIS). Clinical outcomes were obtained directly from electronic records during hospitalization and from any subsequent in-network encounters (e.g., readmissions, dialysis, follow-up tests). No direct patient contact after discharge was required. The study was conducted from April 2024 to June 2025 and included the following phases:

Table (3.2). Study Timeline and Key Phases (April 2024 – June 2025)

Phase	Timeline	Key Activities
Preparatory Phase	April – May 2024	Ethical approvals, staff training, protocol calibration, and HIS system integration.
Recruitment & Intervention Phase	June – 31 December 2024	Patient enrollment at Beit-Jala (intervention) and Hebron (control) hospitals.
Follow-up & Analysis Phase	January – March 2025	Follow-up of last enrolled patients; data extraction and preliminary analysis.
Data Entry & Validation	1 April – 1 June 2025	Final data entry, verification, and cleaning to prepare for complete data analysis.

3.1.7 Study Outcomes

All eligible patients were followed from the time of AKI diagnosis until discharge, with outcomes tracked up to 90 days through the Avicenna HIS when available. The study evaluated both clinical and process outcomes to assess the impact of the intervention on AKI management.

Primary Outcomes included AKI progression (worsening of KDIGO stage), initiation of dialysis (RRT), and in-hospital mortality.

Secondary outcomes included documentation of AKI in medical records, length of stay, nephrology consultation timing, medication and fluid management actions, and readmissions within 30 days.

As part of the intervention, risk assessment (triage) was systematically performed, stratifying patients according to clinical scenario, history, physical examination, and laboratory findings to guide management and monitoring.

MAKE90: Additionally, MAKE90 (Major Adverse Kidney Events at 90 days) a composite of death, new dialysis, or persistent renal dysfunction, was included as an exploratory outcome, limited to patients with available in-network follow-up.

Exploratory Biomarker: Outcomes were also assessed in the intervention group, focusing on the diagnostic yield of NGAL, its correlation with AKI progression, RRT initiation, and mortality, as well as the impact of biomarker-informed alerts on provider actions. A full summary of outcomes and operationalized endpoints is presented in Table 3.

Table (3.3): Summary of Study Outcomes, Operationalized Endpoints, and Data Source

Domain	Outcome	Operationalized endpoint (Measurable indicator)	Data source
Primary outcomes	AKI progression	Worsening of KDIGO stage (Stage 1 → 2/3)	Laboratory values
	Initiation of dialysis (RRT)	New RRT during index admission	Orders / patient records
	In-hospital mortality	Death during hospitalization	Hospital records
Secondary outcomes	AKI recognition & documentation	Explicit AKI note in EMR	Chart review
	Length of stay (LOS)	Days from admission to discharge	Hospital records
	Discharge on dialysis	Dialysis-dependent at discharge	Patient records
	30-day readmission	Readmission within 30 days	HIS records
	Risk assessment / triage	Classification based on clinical scenario, labs, exam	AKI PhD Platform
Process measures	Nephrology consultation	Early (<24h) vs late (>24h)	Chart review
	Medication management	Stop/adjust nephrotoxic (NSAIDs, ACEi/ARB, AGs)	Orders
	Fluid management	IV fluid initiation/adjustment/discontinuation	Orders
	Diagnostic work-up	Renal US, urinalysis ordered	Orders
Exploratory outcomes	MAKE90 composite	Death, new RRT, or persistent dysfunction at 90 days	Avicenna HIS (In-network)
	NGAL biomarker yield	Association of NGAL with AKI progression, RRT, mortality	Lab module

3.1.8 Data Collection Methods

To ensure high-quality data collection, the AKI PhD Research Platform incorporated several safeguards. Mandatory fields and drop-down menus minimized missing or inconsistent entries, while all diagnostic definitions and thresholds (e.g., KDIGO criteria) were uniformly applied to ensure consistency. Data were cross-validated against the Avicenna HIS, supplemented by random audits and double-entry checks to maintain accuracy. In addition, the platform included an automated export function that enabled direct transfer of records into Excel and statistical software, thereby preserving data integrity and reducing transcription errors.

3.1.9 Intervention

Platform Structure

To operationalize the intervention, a dedicated electronic tool, the **AKI PhD Research Platform**, was specifically developed for this study in collaboration with a computer science engineer. Unlike routine hospital information systems, the platform was designed exclusively for research purposes, with three key functions: (1) structured data capture, (2) risk triage based on clinical and laboratory inputs, and (3) generation of SMS-based electronic alerts to treating physicians. By standardizing data entry and decision support, the platform enabled consistent documentation across patients and supported timely intervention.

The interface of the platform is illustrated in Figure 3.2, which shows the modules for structured data entry, risk assessment, and patient tracking. Key modules included:

- **Risk Factors and Exposures:** sepsis, major surgery, contrast exposure, trauma, burns, vasopressor use, nephrotoxic medications.
- **Comorbidities (Susceptibilities):** CKD, diabetes, hypertension, obesity, prior AKI, heart/liver/lung disease, cancer.
- **Clinical Examination:** hemodynamic instability, dehydration, edema/ascites, pulmonary congestion, oliguria.
- **Laboratory and Biomarkers:** serum creatinine, eGFR, hemoglobin, urine protein/creatinine, hematuria, NGAL.
- **Medications:** exposure to NSAIDs, aminoglycosides, vancomycin, ARBs, ACE inhibitors, SGLT2 inhibitors, diuretics, cephalosporins, metformin.
- **Interventions and Monitoring:** IV fluids, lab follow-up, radiology follow-up, nephrology consultations.
- **E-Alert Evaluation:** time of alert generation, SMS delivery to physician, provider response time, and subsequent clinical actions.
- **Clinical Outcomes:** AKI stage progression, renal recovery, dialysis initiation, ICU transfer, LOS, mortality, MAKE90 (where in-network data allowed).

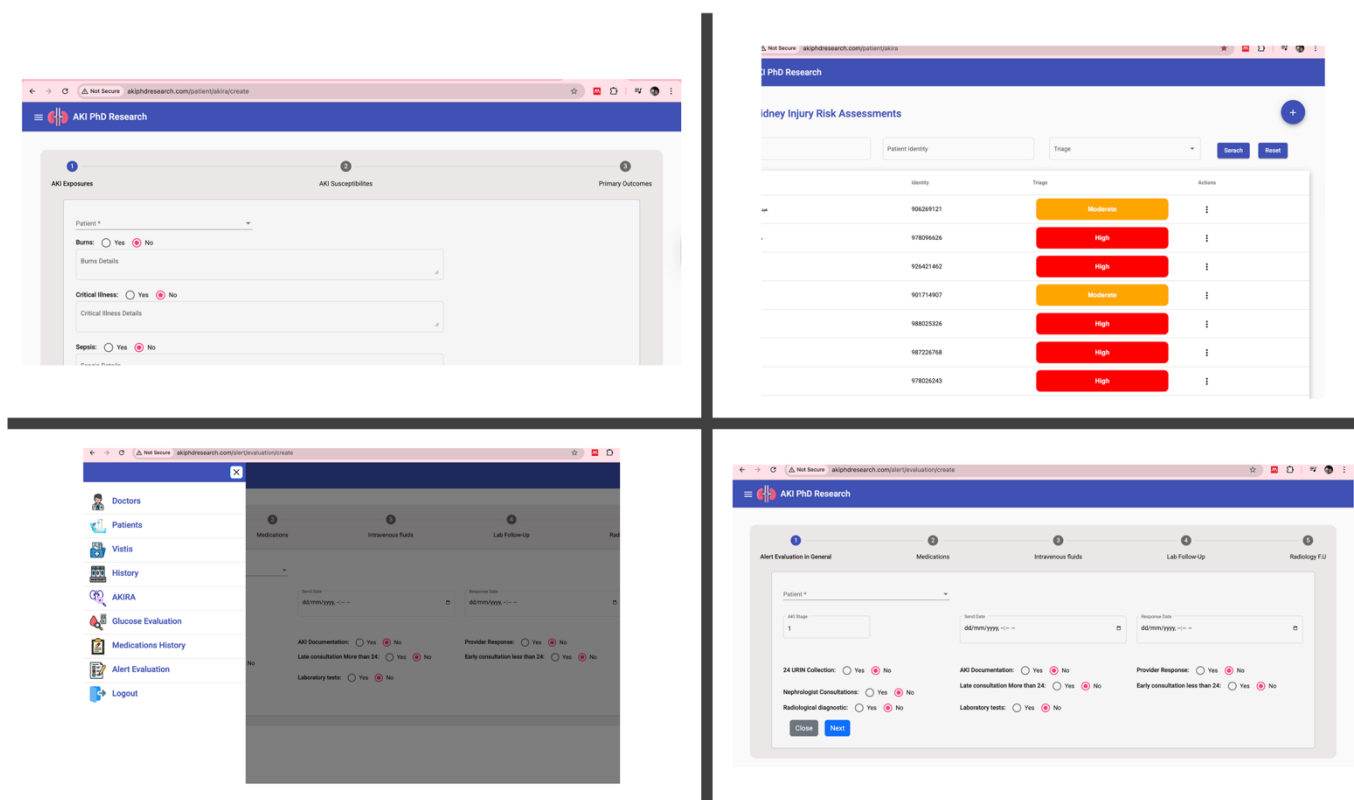


Figure (3.2) Screenshots of the AKI PhD Research Platform showing structured data entry (exposures, susceptibilities, and outcomes), real-time risk assessments, and provider response documentation. The platform was purpose-built for this study to standardize data collection, enable risk triage, and support SMS-based clinical alert.

Workflow and Triage Process:

The intervention implemented in Beit-Jala Governmental Hospital was a multi-component AKI management model designed for this quasi-experimental study (Figure 3.3). It was operationalized through the AKI PhD Research Platform, which enabled structured data entry, AKI staging, integrated biomarker testing, and risk triage.

Triage was conducted in two steps:

Risk triage was performed exclusively at the backend by the research team. It integrated:

- Patient scenario (e.g. ICU, surgery, infection)
- Comorbidities (e.g. CKD, diabetes, cardiovascular disease)
- Clinical signs (e.g. dehydration, edema, oliguria)
- Laboratory results, including serum creatinine and NGAL

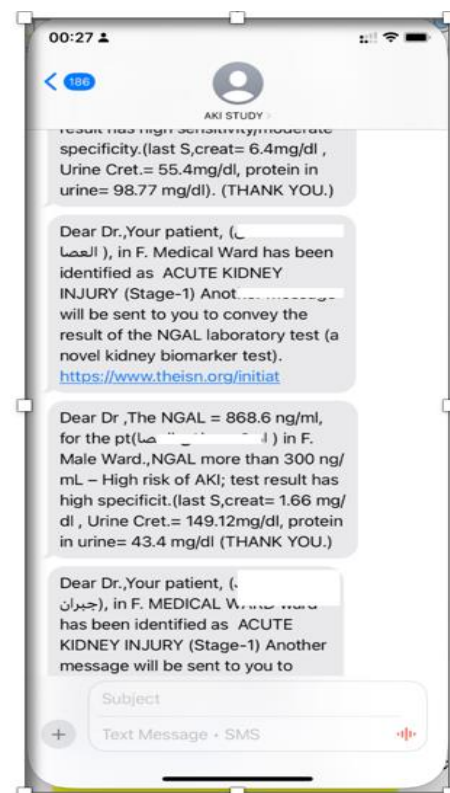


Figure (3.3): Example of SMS-Based E-Alert Notification Following AKI Detection

The triage tool classified patients as low, moderate, or high risk for severe AKI outcomes. However, this triage classification was not shared with clinicians and did not guide real-time decision-making. It served solely as a research variable to assess predictive validity.

NGAL Testing: Diagnostic and Confirmatory Role

In addition to creatinine-based AKI diagnosis, NGAL was used in the intervention group as a diagnostic and severity confirmation tool, with thresholds:

- 50–149 ng/mL = equivocal
- 150–300 ng/mL = Moderate risk / supportive of AKI diagnosis
- ≥ 300 ng/mL = High risk / strong confirmation + severity signal

NGAL was incorporated into triage; this diagnostic information was shared through the second SMS alert

Electronic Alerts (SMS-Based)

Treating physicians received two SMS alerts per patient:

SMS Alert 1: AKI Detection (KDIGO-Based)

- The alert included:
 - AKI stage (1–3), based on KDIGO classification.
 - Patient location.
 - A direct link to the ISN AKI Toolkit (<https://www.theisn.org/initiatives/toolkits/acute-kidney-injury-aki-toolkit>).
- Each stage was mapped to a corresponding clinical risk level (Stage 1 = low risk, Stage 2 = moderate risk, Stage 3 = high risk), facilitating triage prioritization and guiding timely interventions by non-nephrologist physicians.

SMS Alert 2: NGAL Confirmation and Risk Interpretation

- Sent after NGAL testing was completed in the laboratory.
- Included: NGAL level + interpretation (risk category), serum creatinine, urine protein/creatinine, brief clinical message
- Each alert was time-stamped for delivery and response tracking. Alerts were sent directly to physicians via SMS (with WhatsApp backup as needed) within 24 hours of AKI identification.

Provider actions and clinical impact

Although no direct protocolized instructions were mandated, alerts aimed to trigger physician awareness and promote best practices, including:

- **Nephrology referral:**
Consideration of timely nephrology consultation for patients identified as high risk or with confirmed AKI, particularly in cases of worsening kidney function, unclear etiology, or poor response to initial management.

- **Medication review and adjustment:**
Review of current medications with particular attention to potentially nephrotoxic agents. This included consideration of dose adjustment, temporary withholding, or discontinuation (DC) of nephrotoxic drugs (e.g., non-steroidal anti-inflammatory drugs, aminoglycosides, or contrast agents), based on clinical judgment.
- **Fluid management optimization:**
Assessment of the patient's volume status and adjustment of fluid therapy as appropriate, including optimization of intravenous fluid administration or avoidance (discontinuation = DC) of fluid overload, in accordance with standard clinical practice.
- **Renal imaging and diagnostic evaluation:**
Consideration of renal imaging mainly the renal ultrasound.

Physician response times and actions were logged and evaluated for feasibility and adherence. These alerts were generated manually and delivered via SMS.

Target Recipients: Alerts were sent to both general practitioners (GPs) and relevant specialists.

Timing: The alert was issued within 24 hours of detecting the earliest qualifying change indicating potential AKI onset, ensuring timely notification and response.

Control Site Protocol (Routine Care)

At the control site, Hebron Governmental Hospital (Known as Alia Hospital), patients received standard care. There was no structured triage, NGAL testing, or SMS alert system in place. Comparison between intervention and control sites allowed evaluation of both clinical and process outcomes under real-world conditions.

Summary

Component	Intervention group	Control group
AKI Diagnosis	KDIGO (Creatinine/Urine output) + NGAL	KDIGO (Creatinine/Urine output only)
Risk Triage	Backend only, not visible to clinicians	Not performed
SMS Alerts	Two alerts (AKI stage, then NGAL confirmation)	Not used
Provider Actions	Unprompted, clinician-driven	Routine care
Platform Used	AKI PhD Research Platform and <i>AviCenna</i> (Health Information System).	<i>AviCenna</i> (Health Information System)

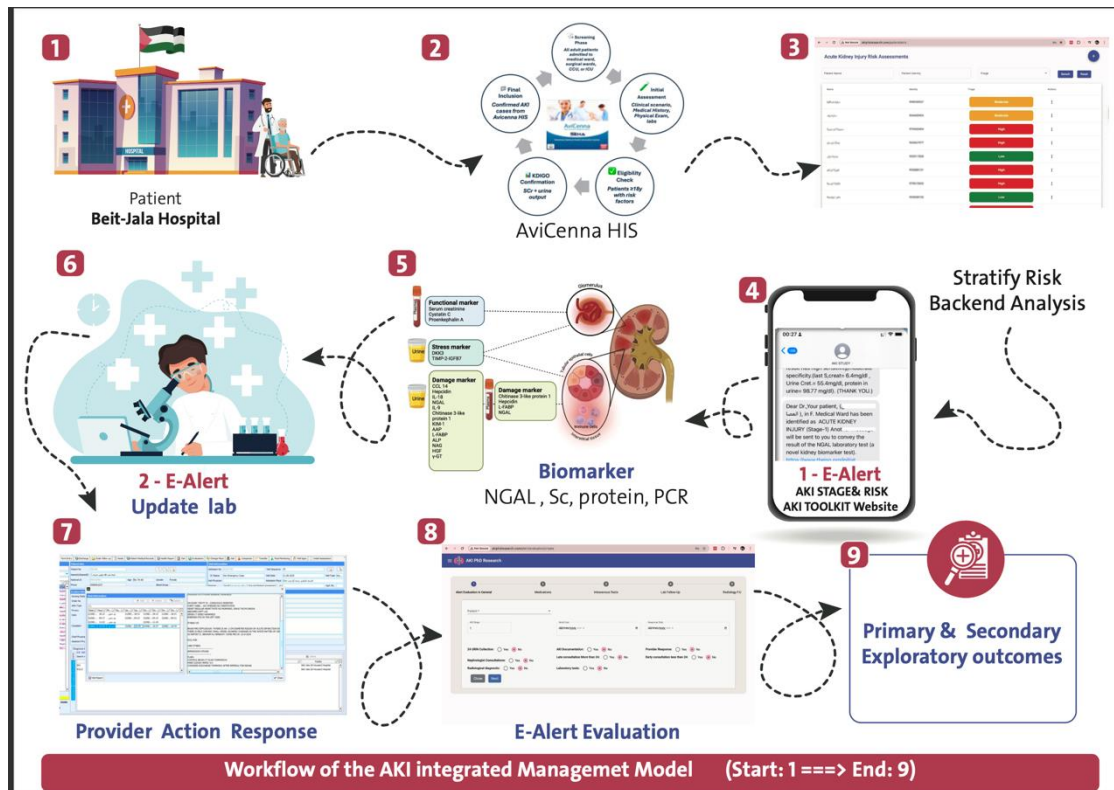


Figure (3.4): Workflow of the AKI integrated management model showing patient triage, biomarker testing, staged e-alerts, provider actions, and patient outcomes over a 90-day follow-up period.

3.1.10 Data Analysis

Statistical analysis was done by SPSS version 28 (IBM Co., Armonk, NY, USA). Numerical data were presented as the mean and standard deviation (SD) and analyzed between groups using an independent t-test or as the median and interquartile range (IQR) and analyzed using the Mann-Whitney test. Testing for normality of distribution was done using the Shapiro-Wilk test. Categorical data were presented as the frequency and percentage and analyzed using the Chi-square test or exact test, as appropriate. ROC curve analysis with sensitivity, specificity, and predictive values was used to assess the diagnostic performance of biomarkers for AKI stages, and cut-off values were selected based on Youden's index. Kaplan Meier curve analysis with log-rank test was performed to assess the overall survival of groups. Cox regression analysis was performed to assess factors associated with failure of recovery over time. Logistic regression analysis was performed to assess factors associated with hemodialysis. A two-tailed P-value <0.05 was considered statistically significant. Statistical analyses were conducted using SPSS version 28 (IBM Corp., Armonk, NY). Numerical variables were assessed for normality using the Shapiro-Wilk test and presented as mean $\pm$ standard deviation (SD) or median with interquartile range (IQR). Categorical variables were summarized as frequencies and percentages.

Group comparisons employed independent samples t-tests, Mann-Whitney U tests, and Chi-square or Fisher's exact tests, depending on the data distribution. Additional analyses included:

- Receiver Operating Characteristic (ROC) curves to evaluate the diagnostic accuracy of biomarkers
- Kaplan–Meier curves and log-rank tests to assess survival
- Cox regression for recovery predictors
- Logistic regression for dialysis prediction

3.1.11 Ethical Considerations

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) and relevant national regulations. Ethical approval for the overall doctoral research project, which included both the quantitative quasi-experimental component and the qualitative interview study, was obtained from the Institutional Review Board (IRB) at the School of Public Health, Al-Quds University (Approval No: 5/24, dated 13 February 2024)(annex 3), and from the Scientific Research Unit at the Palestinian Ministry of Health (Approval dated 28 February 2024).

Informed consent was obtained from all participants before enrollment. For the quantitative study, patients or their legal guardians were provided with full details regarding study objectives, procedures, risks, and benefits, and participation was voluntary. For the qualitative component, nephrologists were informed of their right to withdraw at any stage without penalty, and both verbal and written consent were secured before interviews.

Confidentiality was ensured by coding all personal identifiers, storing data securely, and restricting access to the research team only.

3.1.12 Limitations of the Study

1. Quasi-experimental, non-randomized approach introduces potential selection bias and limits causal inference.
2. Conducted in two hospitals with a smaller-than-planned sample, reducing external validity and statistical power.
3. Alerts were researcher-triggered rather than automated, which may affect scalability and timeliness.
4. Outcomes beyond discharge relied solely on the Avicenna HIS, leading to loss of patients managed outside the network.

3. 2. Qualitative Part

3.2.1. Study Design

A qualitative, exploratory approach was conducted to analyze the perspectives of nephrologists on the feasibility of implementing the NRRT model in hospitals across the West Bank, Palestine. The in-depth interview guide used in this study was specifically developed by the researcher, who reviewed it with experts and has not been previously published (Jawabreh et al., 2025). An English version of the interview guide has been

uploaded as a supplementary file and is cited in the manuscript accordingly. This approach was selected to gain deeper insights into the barriers, facilitators, and recommendations influencing AKI management.

3.2.2. Data Collection

Data collection took place between [January,2024] and [May,2024]. Nephrologists were purposively selected from nephrology departments in Palestinian hospitals located across the West Bank, Palestine. Semi-structured, face-to-face interviews were used as the primary method of data collection. Each interview was conducted in the participant's office or a private hospital room to ensure confidentiality and comfort.

3.2.3 Participant Selection

While AKI is inherently interdisciplinary, this study focused exclusively on board-certified nephrologists due to their central role in clinical decision-making, specialist referral protocols, and nephrology-specific policy development. This focused sampling enabled an in-depth exploration of nephrologists' perspectives on the feasibility of the NRRT. The exclusion of other clinical stakeholders is acknowledged as a limitation, and future research is encouraged to include multidisciplinary views.

3.2.4 Data Saturation and Sample Justification

Data saturation was reached between the 9th and 10th interviews, at which point no new codes or concepts were emerging from the data. This assessment was made through an iterative coding process in which each new transcript was analyzed in comparison with the developing thematic framework. Despite reaching saturation, data collection continued until all 13 board-certified nephrologists practicing in the West Bank had been interviewed. This decision was guided by methodological rigor and supervisory recommendation, ensuring full utilization of the total available population and enhancing the study's depth and contextual variation.

3.2.5 Trustworthiness

Credibility was ensured through triangulation (peer debriefing, expert feedback), member checking, and verbatim transcription. Dependability was enhanced by a detailed audit trail, and confirmability was supported through external review of codes and theme validation. Transferability was considered through rich contextual descriptions of the Palestinian nephrology infrastructure, enabling comparison with similar health systems.

3.2.6 Researcher Reflexivity

The researcher is a healthcare professional with prior clinical and academic experience within the Palestinian public health system. This insider status offered several advantages, including

increased access, contextual sensitivity, and the ability to establish rapport with participants. However, it also introduced potential risks of interpretive bias, power asymmetry, and assumptions of shared understanding during interviews. To address these concerns, the researcher adopted a reflexive stance throughout the study. A structured interview guide with open-ended, neutral questions was used to minimize leading or directive questioning. The researcher maintained a reflexive journal to critically reflect on personal assumptions, emotional responses, and potential influence on data interpretation.

All interviews were conducted with an awareness of role-related dynamics and were followed by peer debriefing sessions with academic supervisors to challenge implicit bias and ensure fidelity to participants' intended meanings. Furthermore, member checking with two participants helped validate early thematic interpretations, while independent review of coding by a secondary analyst contributed to analytic neutrality. These strategies collectively enhanced the study's transparency and reproducibility by making the researcher's position both explicit and methodologically accounted for.

3.2.7 Data Analysis

Transcripts were subsequently analyzed using MAXQDA Analytics Pro Student Version 24.2.0. Thematic analysis followed the systematic framework of identifying meaning units, condensing them into core themes, and refining codes into subthemes and overarching categories. This iterative process was conducted collaboratively with the study supervisor to ensure rigor and alignment with qualitative research standards.

3.2.8 Limitations

Despite the richness of insights, several limitations should be acknowledged. The qualitative nature of the research prioritizes depth over generalizability. Although the sample includes all board-certified nephrologists in the West Bank, it does not capture perspectives from the Gaza Strip, nor does it reflect the views of other stakeholders such as nurses, patients, policymakers, general practitioners, medical specialists, pharmacists, and other frontline healthcare providers.

3.2.9 Ethics Approval and Consent to Participate

This qualitative study is part of a broader doctoral research thesis titled *“Enhancing Acute Kidney Injury Management in Southern Palestinian Governmental Hospitals: Impact of Risk Triage, Novel Biomarkers, and Electronic Health Alerts,”* which comprises three components: a quantitative study, a qualitative study, and a published systematic review (Jawabreh, 2025).

Ethical approval for this specific qualitative component was obtained from the Institutional Review Board (IRB) at the School of Public Health, Al-Quds University (Approval No: 5/24, dated 13 February 2024), and from the Scientific Research Unit at the Palestinian Ministry of Health (Approval dated 28 February 2024).

All participants were nephrology specialists who voluntarily agreed to participate. Informed consent was obtained before conducting any interviews. Participants were informed of the study's objectives, procedures, and their right to withdraw at any point without penalty. Interviews were only conducted after verbal and written consent was secured. This study was conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) and relevant national regulations.

Chapter Four

The Results

Part One: Quantitative Analysis

4.1 Overview of the Quantitative Analysis

This section presents the quantitative findings of the quasi-experimental component of the study. The quantitative analysis was structured around key clinical and process-related outcomes, including:

- Baseline demographic and clinical characteristics
- AKI staging and documentation
- Nephrology consultation and therapeutic adjustments
- Patient outcomes such as dialysis initiation, AKI recovery, mortality, and AKI duration
- Diagnostic performance of biomarkers such as NGAL, SCr, and urinary protein
- Multivariate regression models to identify predictors of AKI recovery and dialysis requirement

4.2 Baseline Characteristics of the Participants

This section presents the baseline demographic, clinical, and laboratory data of the participants in both study arms: the intervention group (Beit-Jala Governmental Hospital, $n = 215$) and the control group (Hebron Governmental Hospital, $n = 254$). These data describe the sample prior to implementation of the AKI management intervention and serve as a foundation for comparing outcomes across groups.

This section presents the baseline demographic, clinical, and laboratory data of the participants in both study arms: the intervention group and the control group. These data describe the sample before implementation of the AKI management intervention and serve as a foundation for comparing outcomes across groups (Table 4.1).

Demographic, clinical, past medical history, and laboratory data are descriptively depicted in Table 4.1. There was a statistically significant difference between the studied groups in terms of gender, with a significantly higher percentage of females in Beit-Jala hospital (intervention) than Hebron hospital (control) (46% vs 36.2%, $P=0.031$). Further, the prevalence of CKD and lung diseases was significantly higher in the intervention group than in the control, being 63.3% vs 52%, $P=0.014$ for the former and 47.4% vs 37.4%, $P=0.028$ for the latter, but the contrary was reported for HTN (72.1% vs 81.1%, $P=0.021$). In the intervention group, the median NGAL was 119.6 (IQR 37.1, 753.4) ng/mL, serum creatinine was 2.04 (1.68, 3.27) mg/dL, creatinine in urine was 60.96 (34.78, 100) mg/dL, and protein in urine was 72.7 (26.91, 262.4) mg/day.

Table (4.1): Baseline characteristics of the participants

Item	Intervention group (n=215)	Control group (n=254)	P-value
Age (years) (mean $\pm$ SD)	66.51 $\pm$ 15.04	66.45 $\pm$ 14.02	0.968
Gender	N (%)	N (%)	
– Male	116 (54%)	162 (63.8%)	0.031
– Female	99 (46%)	92 (36.2%)	
Comorbidities			
– Sepsis	116 (54%)	133 (52.4%)	0.731
– Critical illness	196 (91.2%)	228 (89.8%)	0.608
– Circulatory shock	72 (33.5%)	80 (31.5%)	0.646
– Burns	1 (0.5%)	3 (1.2%)	0.629
– Trauma	14 (6.5%)	20 (7.9%)	0.571
– Cardiac surgery	14 (6.5%)	23 (9.1%)	0.309
– Major noncardiac surgery	35 (16.3%)	51 (20.1%)	0.289
– Nephrotoxic drugs	186 (86.5%)	205 (80.7%)	0.093
– Radiocontrast agents	29 (13.5%)	44 (17.3%)	0.254
– Dehydration	135 (62.8%)	155 (61%)	0.695
– Chronic Kidney Disease (CKD)	136 (63.3%)	132 (52%)	0.014
– hypertension (HTN)	155 (72.1%)	206 (81.1%)	0.021
– Diabetes Mellitus (DM)	126 (58.9%)	155 (61%)	0.637
– Cancer	18 (8.4%)	20 (7.9%)	0.844
– Liver diseases	22 (10.2%)	30 (11.8%)	0.587
– Heart diseases	171 (79.5%)	210 (82.7%)	0.385
– Lung diseases	102 (47.4%)	95 (37.4%)	0.028
– Anemia	143 (66.5%)	152 (59.8%)	0.136
Biomarkers			
– NGAL (ng/mL)	119.6 (37.1, 753.4)	---	---
– Blood creatinine level(mg/dL)	2.04 (1.68, 3.27)	1.84 (1.30, 2.77)	0.18

Chi-square test for categorical variables, independent samples t-test for normally distributed variables, and Mann–Whitney U test for non-parametric data. A two-tailed p -value < 0.05 was considered statistically significant. Numerical data are presented as mean $\pm$ standard deviation (SD) or median (IQR), and categorical data are presented as frequency (%). Statistical significance at P -value <0.05 , CKD: Chronic kidney disease, HTN: Hypertension, DM: Diabetes mellitus, NGAL: Neutrophil gelatinase-associated lipocalin

4.3 Physicians' Responses and Clinical Management Following AKI Detection within the Studied Groups

This section presents the clinical care processes and therapeutic interventions initiated in response to the detection of AKI in the two study groups. Variables include AKI staging at presentation, documentation practices, provider response to AKI alerts, nephrology consultations, medication adjustments (e.g., ACE inhibitors, ARBs, diuretics, nephrotoxic), intravenous fluid (IVF) management, and follow-up laboratory and radiologic investigations. Data were analyzed using Chi-square or Fisher's exact tests for categorical variables and Mann-Whitney U tests for skewed continuous variables. A two-tailed p-value < 0.05 was considered statistically significant.

Table (4.2-A): Clinical Responses in the Studied Groups

Item	Intervention group (n=215)	Control group (n=254)	P-value
General alert response			
AKI Stage n(%)			
Stage 1	144 (67%)	107 (42.1%)	<0.001
Stage 2	31 (14.4%)	50 (19.7%)	
Stage 3	40 (18.6%)	97 (38.2%)	
AKI documented (Yes)	147 (68.4%)	96 (37.8%)	<0.001
NO	68 (31.6%)	158 (62.2%)	
No. Attacks /3 months n (%)			
1	170 (79.1%)	224 (88.2%)	0.029
2	33 (15.3%)	23 (9.1%)	
3	12 (5.6%)	6 (2.4%)	
4	0 (0%)	1 (0.4%)	
Care provider response	164 (76.3%)	No intervention	
Nephrologist consultation			
Late consultation >24	20 (9.3%)	20 (7.9%)	0.581
Early consultation <24	64 (29.8%)	68 (26.8%)	0.472
Medication changes after alert			
ACE			
Use	18 (8.4%)	31 (12.2%)	0.206
Adjust	1 (0.5%)	0 (0.0%)	
DC	14 (6.5%)	21 (8.3%)	
Hold	3 (1.4%)	10 (3.9%)	
ARB			
Use	36 (16.7%)	63 (24.8%)	0.085
Adjust	4 (1.9%)	5 (2.0%)	
DC	24 (11.2%)	35 (13.8%)	
Hold	8 (3.7%)	23 (9.1%)	
Diuretics			
Use	130 (60.5%)	143 (56.3%)	<0.001
Adjust	41 (19.1%)	85 (33.5%)	
DC	85 (39.5%)	51 (20.1%)	
Hold	4 (1.9%)	7 (2.8%)	
NSAIDs			
Use	6 (2.8%)	6 (2.4%)	0.372
DC	6 (2.8%)	4 (1.6%)	

Table (4.2-B): Clinical responses in the studied groups

Hold	0 (0%)	2 (0.8%)	
Cephalosporins			
Use	166 (77.2%)	113 (44.5%)	<0.001
Adjust	30 (14%)	14 (5.5%)	
DC	136 (63.3%)	99 (39%)	
SGLT2 Inhibitors			
Use	14 (6.5%)	13 (5.1%)	0.180
Adjust	1 (0.5%)	0 (0%)	
DC	13 (6%)	10 (3.9%)	
Hold	0 (0%)	3 (1.2%)	
Metformin			
Use	11 (5.1%)	39 (15.4%)	<0.001
DC	8 (3.7%)	34 (13.4%)	
Hold	3 (1.4%)	5 (2%)	
Aminoglycoside			
Use	30 (14.0%)	11 (4.3%)	0.002
Adjust	14 (6.5%)	3 (1.2%)	
DC	14 (6.5%)	7 (2.8%)	
Hold	2 (0.9%)	1 (0.4%)	
IV Fluids changes			
IVF use	136 (63.3%)	196 (77.2%)	0.001
IVF status			
Use	130 (60.5%)	193 (76%)	
Adjust	34 (15.8%)	122 (48%)	
DC	95 (44.2%)	65 (25.6%)	
Hold	1 (0.5%)	6 (2.4%)	
IVF amount	1500 (0, 2000)	1500 (150, 2000)	0.055
Laboratory follow-up			
Creatinine	210 (97.7%)	234 (92.1%)	0.008
Serum electrolytes	204 (94.9%)	234 (92.1%)	0.231
Urine analysis	165 (76.7%)	150 (59.1%)	<0.001
24 urine collection	126(58.6%)	121(47%)	0.023
Radiology follow-up			
Ultrasound performed	63 (29.3%)	78 (30.7%)	0.741

Numerical data are presented as mean $\pm$ SD or median (IQR), and categorical data are presented as frequency (%), Statistical significance at P-value<0.05, ACE: Angiotensin-Converting Enzyme, ARB: Angiotensin Receptor Blocker, NSAIDs: Nonsteroidal Anti-Inflammatory Drugs, IVF: Intravenous Fluid, DC: Discontinue.

In view of the general alert response, AKI 1 was the predominant stage in both groups, with proportions of 67% in the intervention group vs 42.1% in the control group. In comparison, 14.4% vs 19.7% elicited AKI 2 and 18.6% vs 38.2% elicited AKI 3, with a statistically significant difference between groups ($P<0.001$). As for AKI history, the prevalence was significantly higher in the intervention group than in the control (68.4% vs 37.8%, $P<0.001$) and the majority of both groups (79.1% of intervention vs 88.2% of control) had 1 attack/3 months, denoting a statistically significant difference ($P=0.029$). Moreover, the rate of provider response was more than two-thirds in the intervention group (76.3%) compared to none in the control group ($P < 0.001$). Notably, the rate of early nephrologist consultation (<24 hours) was slightly higher in the intervention group than in the control (29.8% vs 26.8%), with no significant difference.

A statistically significant difference was detected between groups in diuretics' (Adjustment in 19.1% of intervention group vs 33.5% of control, discontinuing in 39.5% vs 20.1% and holding in 1.9% vs 2.8, $P<0.001$), Cephalosporins (adjustment in 14% of intervention vs 5.5% of control and discontinuing in 63.3% vs 39%, $P<0.001$), Metformin (discontinuing in 3.7% vs 13.4% and holding in 1.4% vs 2%, $P<0.001$) and Aminoglycoside administration (adjustment in 6.5% vs 1.2%, discontinuing in 6.5% vs 2.8% and holding in 0.9% vs 0.4%, $P=0.002$). The rate of IVF use was significantly lower in the intervention group than the control (63.3% vs 77.2%, $P=0.001$), with significantly different IVF status (adjustment in 15.8% vs 48%, discontinuing in 44.2% vs 25.6%, and holding in 0.5% vs 2.4%, $P<0.001$). Creatinine and urine analysis were performed at significantly higher rates in the intervention group than in the control, being respectively 97.7% vs 92.1% ($P=0.008$) and 76.7% vs 59.1% ($P<0.001$).

4.4 Primary Clinical Outcomes: AKI Progression, Recovery, Dialysis, and Mortality

This section reports on the primary clinical outcomes used to evaluate the effectiveness of the enhanced AKI management model, which included an electronic alert system (e-alert), biomarker monitoring, and structured provider response. Outcomes were compared between the intervention group (Beit-Jala Hospital) and the control group (Hebron Hospital).

- Key outcome indicators included:
- Progression of AKI (from Stage 1 to 2, or 2 to 3)
- Need for dialysis initiation
- Recovery from AKI
- All-cause in-hospital mortality
- AKI duration (number of days)
- Length of hospital stay (LOS)

Statistical comparisons were made using Chi-square tests for categorical outcomes and Mann–Whitney U tests for continuous outcomes, given the non-normal distribution of time variables.

Table (4.3): Outcomes of the Studied Groups

Item	Intervention group (n=215)	Control group (n=254)	P-value
AKI progression	N (%)	N (%)	
Stage 1	201 (93.5%)	244 (96.1%)	0.207
Stage 1 to 2	135 (62.8%)	157 (61.8%)	0.827
Stage 2 to 3	84 (39.1%)	106 (41.7%)	0.558
Dialysis initiation	17 (7.9%)	42 (16.5%)	0.005
Mortality	52 (24.2%)	55 (21.7%)	0.515
Recovery	71 (33%)	52 (20.5%)	0.002
AKI period (days)	4 (3, 6)	5 (3, 8)	<0.001
Length of stay (days)	9 (5, 15)	10 (5, 16)	0.272

Statistical comparisons were made using Chi-square tests for categorical outcomes and Mann–Whitney U tests for continuous outcomes, given the non-normal distribution of time variables. Numerical data are presented as mean $\pm$ SD or median (IQR), and categorical data are presented as frequency. Significance was set at $P < 0.05$.

AKI progression from stage 1 to 2 was evidenced in more than half of both groups (62.8% of the intervention group vs 61.8% of the control group), while from stage 2 to 3 was evidenced in 39.1% vs 41.7%, with no statistically significant differences. Hemodialysis was initiated at a significantly lower rate in the intervention group than in the control (7.9% vs 16.5%, $P=0.005$). The incidence of mortality was comparable between both groups (24.2% in the intervention group and 21.7% in the control group), with a significantly higher recovery rate in the intervention group (33% vs 20.5%, $P=0.002$). Additionally, the AKI period was significantly shorter in the intervention group ($P<0.001$), showing a median (IQR) of 4 (3, 6) vs 5 (3, 8) days. Both groups had similar LOS, with a median (IQR) of 9 (5, 15) days in the intervention group and 10 (5, 16) days in the control group. **(Table 4.3)**

4.5 Associations between risk triage level and AKI stage in the intervention Group

This section explores the association between risk-based triage levels and the severity of AKI, as classified by KDIGO staging criteria, within the intervention group (Beit-Jala Hospital). As part of the enhanced AKI management model, patients were triaged into three risk levels, low, moderate, and high, based on predefined criteria including clinical risk factors and biomarker values (e.g., NGAL).

Evaluating how these triage levels correlate with AKI stage provides insight into the predictive value and clinical validity of the stratification tool used in the intervention model.

Table (4.4): Associations between triage result and AKI stage in Beit-Jala hospital

Item	Triage			P-value
	Low (n=11)	Moderate (n=54)	High (n=150)	
AKI stage	N (%)	N (%)	N (%)	
Stage 1	9 (81.8%)	47 (87%)	88 (58.7%)	0.001
Stage 2	1 (9.1%)	6 (11.1%)	24 (16%)	
Stage 3	1 (9.1%)	1 (1.9%)	38 (25.3%)	

Data are presented as frequency (%), Statistical significance at $P\text{-value}<0.05$ using chi-square testing

Our investigation revealed a statistically significant association between triage level and AKI stage ($P=0.001$), with 81.8% of low triage group, 87% of the moderate triage group and 58.7% of the high triage group eliciting AKI stage 1, 9.1%, 11.1% and 16% eliciting stage 2 and 9.1%, 1.9%, and 25.3% eliciting stage 3.

4.6 Diagnostic Performance of Biomarkers for Predicting AKI Severity in the Intervention Group

This section evaluates the diagnostic accuracy of several biomarkers in predicting the severity of acute kidney injury (AKI) in patients admitted to Beit-Jala Hospital (intervention group).

The biomarkers analyzed included:

- Neutrophil gelatinase-associated lipocalin (NGAL)
- Serum creatinine
- Urine creatinine
- Urine protein excretion

- Protein-to-creatinine ratio (PCR)

The diagnostic value of each marker was assessed using receiver operating characteristic (ROC) curve analysis, calculating:

- Sensitivity
- Specificity
- Positive Predictive Value (PPV)
- Negative Predictive Value (NPV)
- Area Under the Curve (AUC)

Cut-off values were selected based on Youden's index for each biomarker. The performance indicator ($J = \text{Sensitivity} + \text{Specificity} - 1$) was used to determine the effectiveness of the diagnostic test, optimizing the balance between sensitivity and specificity. The model is statistically significant at a p-value *less than* 0.05.

Table (4.5): Diagnostic performance of biomarkers in the prediction of AKI stages in Beit-Jala hospital (intervention hospital) by Youden's index

Item	Cut-off	Sensitivity	Specificity	PPV	NPV	AUC	P-value
AKI stage 1							
– NGAL (ng/mL)	≤101	58.33	74.65	82.4	46.9	0.696	<0.001
– S. creatinine (mg/dL)	≤2.56	77.78	67.61	83.0	60.0	0.785	<0.001
– Creatinine in urine (mg/dL)	≤80.7	71.53	45.07	72.5	43.8	0.567	0.115
– Protein in urine (mg/day)	≤129.9	68.06	53.52	74.8	45.2	0.610	0.008
– PCR	≤0.39	31.94	83.10	79.3	37.6	0.567	0.102
AKI stage 2							
– NGAL (ng/mL)	>22.3	96.77	17.39	16.5	97.0	0.501	0.981
– S. creatinine (mg/dL)	>1.71	90.32	31.52	18.2	95.1	0.552	0.261
– Creatinine in urine (mg/dL)	>100	32.26	77.17	19.2	87.1	0.510	0.862
– Protein in urine (mg/day)	≤26.34	38.71	77.72	22.6	88.3	0.561	0.292
– PCR	≤5.44	96.77	23.37	17.5	97.7	0.571	0.176
AKI stage 3							
– NGAL (ng/mL)	>158.9	87.50	65.71	36.8	95.8	0.785	<0.001
– S. creatinine (mg/dL)	>2.69	87.50	78.86	48.6	96.5	0.873	<0.001
– Creatinine in urine (mg/dL)	>109.8	35.00	84.00	33.3	85.0	0.590	0.090
– Protein in urine (mg/day)	>66.79	85.00	53.14	29.3	93.9	0.711	<0.001
– PCR	>0.4	97.50	33.14	25.0	98.3	0.655	0.001

PPV: Positive predictive value, NPV: Negative predictive value, AUC: Area under the curve, Statistical significance for the test at P-value<0.05. PCR: Protein creatinine ratio.

ROC curve analysis revealed that NGAL, serum creatinine, and protein in urine were significant diagnostic indices of AKI stage 1, respectively, with AUC of 0.696, 0.785, and 0.610, and P-value <0.001, <0.001, and 0.008 as: The ≤101 ng/mL NGAL cut-off point gave sensitivity of 58.33%, specificity of 74.65%, PPV of 82.4% and NPV of 46.9%, the ≤2.56 mg/dL serum creatinine gave sensitivity of 77.78%, specificity of 67.61%, PPV of 83% and NPV of 60% and the ≤129.9 mg/day protein in urine gave sensitivity of 68.06%, specificity of 53.52%, PPV of 74.8% and NPV of 45.2%. None of the included biomarkers was a significant predictor of AKI stage 2. As for AKI stage 3, NGAL, serum creatinine, protein in

urine, and PCR were significant predictors, respectively with AUC of 0.785, 0.873, 0.711, and 0.655, and P-value <0.001, <0.001, <0.001, and 0.001 as: The >158.9 ng/mL NGAL cut-off point evidenced sensitivity of 87.5%, specificity of 65.71%, PPV of 36.8% and NPV of 95.8%, the >2.69 mg/dL serum creatinine showed sensitivity of 87.5%, specificity of 78.86%, PPV of 48.6% and NPV of 96.5%, the >66.79 mg/day protein in urine showed sensitivity of 85%, specificity of 53.14%, PPV of 29.3% and NPV of 93.9% and the >0.4 PCR showed sensitivity of 97.5%, specificity of 33.14%, PPV of 25% and NPV of 98.3%. The ROC curves corresponding to these biomarkers for predicting AKI stages are illustrated in Figures 4.1–4.7.

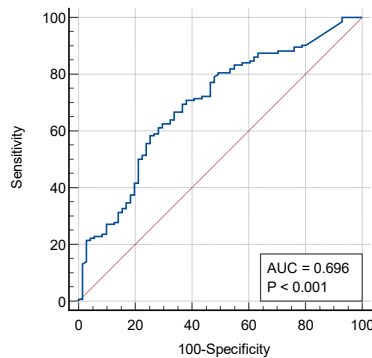


Figure (4.1): ROC curve of NGAL for the prediction of AKI stage 1

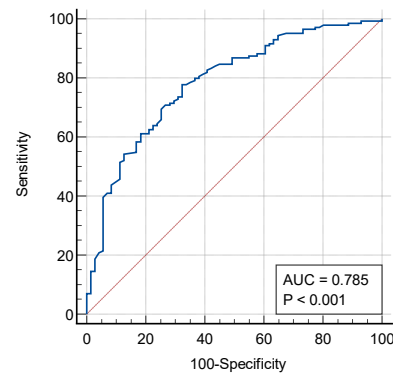


Figure (4.2): ROC Curve of Serum Creatinine for The Prediction of AKI Stage 1

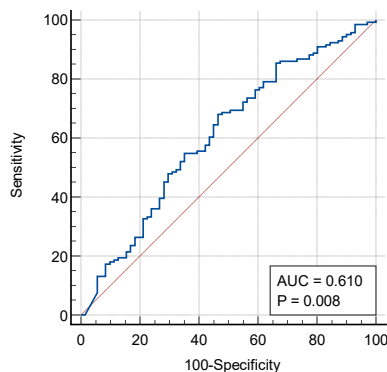


Figure (4.3): ROC Curve of Protein in Urine for The Prediction of AKI Stage

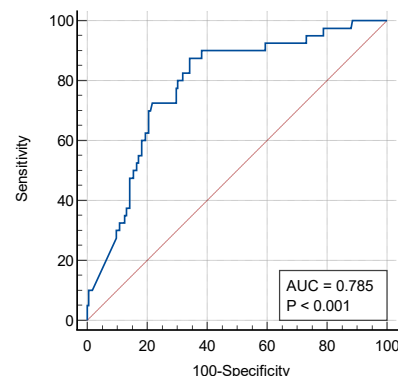


Figure (4.4): ROC Curve of NGAL for the Prediction of AKI Stage

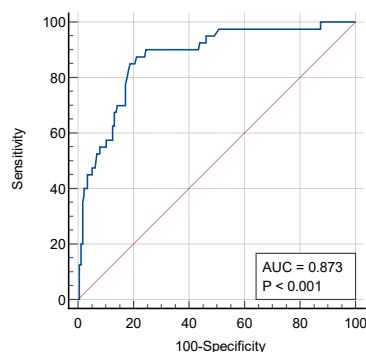


Figure (4.5): ROC Curve of Serum Creatinine for the Prediction of AKI stage 3

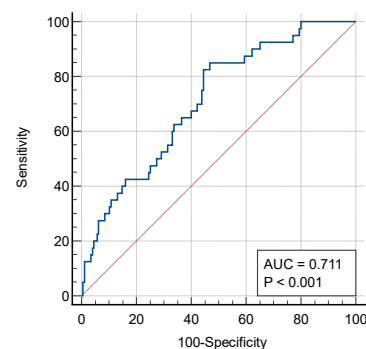


Figure (4.6): ROC Curve of Protein in Urine for the Prediction of AKI Stage 3

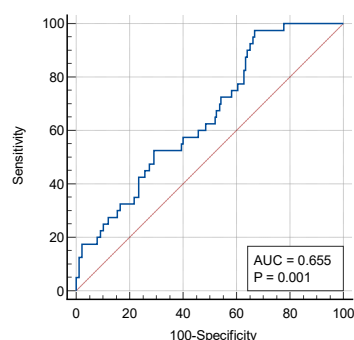


Figure (4.7): ROC Curve of PCR for the Prediction of AKI Stage 3

4.7 Overall Survival Analysis Between the Intervention and Control Groups

This section presents the comparison of overall survival between patients in the intervention group (Beit-Jala Hospital) and the control group (Hebron Hospital) using Kaplan–Meier survival analysis and the log-rank test.

Survival time was defined as the time from AKI diagnosis to death (event) or discharge (censored). The primary objective was to assess whether the enhanced AKI management model, including e-alerts and structured care interventions, had a statistically significant impact on patient survival compared to standard care.

Hazard ratios (HR) and 95% confidence intervals (CI) were calculated using Cox regression analysis.

Table (4.6): In-hospital survival analysis of the studied groups after completion of cohort follow-up

Group	N of events (%)	N. censored (%)	Median survival (Days)	HR (95%CI)	Log-rank P-value
Intervention	52 (24.2%)	163 (75.8%)	25	1.33 (0.9 to 1.97)	0.156
Control	55 (21.7%)	199 (78.4)	38	Ref	

HR: Hazard ratio, Statistical significance at P-value<0.05

Based on Kaplan–Meier survival curves with log-rank testing, there was no statistically significant difference in overall survival between the intervention and control groups (**P** = 0.156). Although the intervention group had a lower median survival (25 days vs. 38 days), this difference did not reach significance. Cox regression yielded a hazard ratio of 1.33 (95% CI: 0.90–1.97), further indicating no significant survival benefit. The Kaplan–Meier survival curves comparing overall survival between the intervention and control groups are presented in Figure 4.8.

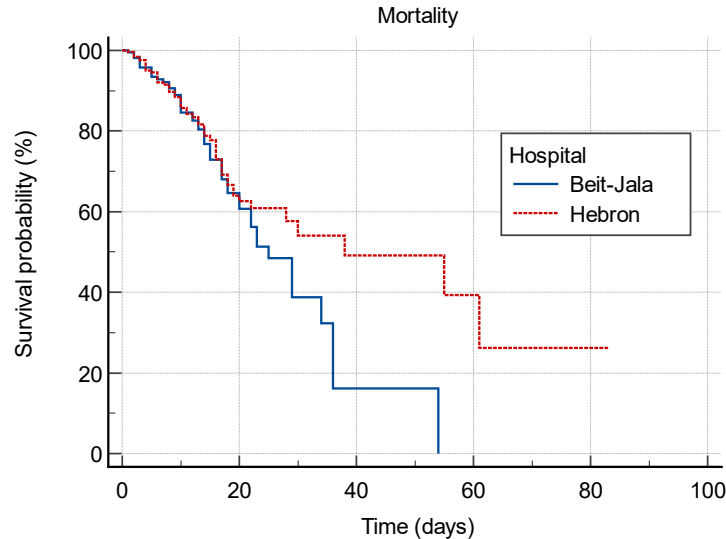


Figure (4.8): Kaplan Meier Curve for Overall Survival Analysis of the Studied Groups

4.8 Factors Associated with Recovery Failure from AKI Among Intervention Group

This section evaluates which clinical, biomarker, and management-related factors are associated with recovery failure from acute kidney injury (AKI) over time among patients in the intervention group using Cox proportional hazards regression.

The univariate model was first used to explore crude associations, and variables with $p < 0.20$ were subsequently included in the multivariable model to adjust for confounders. Hazard Ratios (HRs) with 95% Confidence Intervals (CIs) were calculated, and $p < 0.05$ was considered statistically significant.

Table (4.7-A): Cox Regression Analysis for Factors Associated with Recovery from AKI over time Among the Intervention Group

Item	Univariate analysis			Multivariable analysis		
	HR	95% CI	P-value	HR	95% CI	P-value
Age (years)	1.01	1 to 1.02	0.154	1.01	0.99 to 1.02	0.424
Gender						
Male	Ref					
Female	0.9	0.65 to 1.26	0.544			
Comorbidities						
Sepsis	0.85	0.61 to 1.19	0.346			
Critical illness	1.42	0.58 to 3.47	0.446			
Circulatory shock	1.27	0.9 to 1.77	0.168	1.18	0.82 to 1.7	0.362
Burns	1.49	0.21 to 10.7	0.692			
Trauma	1.17	0.57 to 2.4	0.668			
Cardiac surgery	0.74	0.37 to 1.46	0.381			
Major noncardiac surgery	1.33	0.87 to 2.04	0.188	1.26	0.78 to 2.04	0.35
Nephrotoxic drugs	1	0.62 to 1.63	0.998			
Radiocontrast agents	0.83	0.52 to 1.34	0.445			
Dehydration	1.02	0.72 to 1.44	0.931			
CKD	0.97	0.66 to 1.41	0.871			
HTN	1.05	0.71 to 1.56	0.809			
DM	0.72	0.51 to 1.01	0.058	0.69	0.48 to 0.99	0.045
Cancer	0.8	0.44 to 1.45	0.47			

Table (4.7-B): Cox Regression Analysis for Factors Associated with Recovery from AKI over time Among the Intervention Group

Liver diseases	1.01	0.61 to 1.68	0.963			
Heart diseases	0.88	0.57 to 1.36	0.563			
Lung diseases	0.89	0.64 to 1.24	0.489			
Anemia	0.83	0.58 to 1.18	0.291			
Biomarkers						
NGAL (ng/mL)	0.9999	0.9997 to 1.0001	0.382			
S. creatinine (mg/dL)	0.99	0.91 to 1.09	0.901			
Creatinine in urine (mg/dL)	1.002	0.999 to 1.005	0.201			
Protein in urine (mg/day)	0.9999	0.9997 to 1.0001	0.277			
General alert response						
AKI Stage						
1	Ref			Ref		
2	1.41	0.88 to 2.26	0.157	1.42	0.86 to 2.36	0.17
3	1.16	0.77 to 1.73	0.483	1.1	0.7 to 1.73	0.683
Attacks /3 months						
1	Ref			Ref		
2	0.93	0.61 to 1.41	0.726	1.03	0.66 to 1.61	0.88
3	0.62	0.33 to 1.16	0.137	0.62	0.32 to 1.21	0.16
AKI documented	1.07	0.75 to 1.52	0.726			
Provider response	0.87	0.59 to 1.27	0.463			
Early Consultation <24	0.87	0.61 to 1.23	0.423			
Medication Changes						
ACE						
None	Ref			Ref		
Adjust	0.37	0.05 to 2.66	0.322	1.31	0.08 to 22.78	0.852
DC	1.13	0.53 to 2.44	0.747	0.83	0.33 to 2.12	0.698
Hold	2.75	0.87 to 8.71	0.085	1.5	0.43 to 5.21	0.519
ARB						
Item	Univariate analysis			Multivariable analysis		
	HR	95%CI	P-value	HR	95%CI	P-value
None	Ref			Ref		
Adjust	0.36	0.09 to 1.48	0.157	0.32	0.04 to 2.35	0.264
DC	2.23	1.25 to 3.96	0.006	2.12	1.07 to 4.22	0.031
Hold	2.54	1.1 to 5.84	0.029	2.04	0.83 to 5.02	0.119
Diuretics						
None	Ref					
Adjust	0.84	0.53 to 1.33	0.453			
DC	0.84	0.57 to 1.23	0.365			
Hold	0.63	0.15 to 2.58	0.516			
NSAIDs						
None	Ref					
Hold	1.1	0.35 to 3.45	0.875			
Cephalosporins						
None	Ref					
Adjust	0.94	0.55 to 1.61	0.818			
DC	0.86	0.58 to 1.27	0.449			
SGLT2 Inhibitors						
None	Ref					

Table (4.7-C): Cox Regression Analysis for Factors Associated with Recovery from AKI over time Among the Intervention Group

Adjust	0.79	0.11 to 5.7	0.818			
DC	1.09	0.51 to 2.35	0.82			
Metformin						
None	Ref			Ref		
DC	0.75	0.24 to 2.37	0.628	0.67	0.21 to 2.16	0.5
Hold	2.73	0.86 to 8.64	0.088	1.6	0.42 to 6.05	0.487
Aminoglycoside						
None	Ref			Ref		
Adjust	0.52	0.25 to 1.07	0.075	0.51	0.25 to 1.07	0.074
DC	0.71	0.37 to 1.36	0.303	0.79	0.4 to 1.55	0.491
Hold	0.67	0.16 to 2.71	0.57	0.4	0.09 to 1.78	0.228
IV Fluids changes						
IVF use	1.19	0.84 to 1.67	0.332			
IVF status						
None	Ref					
Adjust	1.1	0.67 to 1.78	0.713			
DC	1.17	0.81 to 1.69	0.401			
Hold	0.35	0.05 to 2.56	0.3			
IVF amount	1	1 to 1	0.724			

HR: Hazard ratio, CI: Confidence interval, Statistical significance at P-value<0.05

In univariate Cox regression analysis, ARB administration was significantly associated with recovery from AKI, as patients whose ARB was discontinued or held showed significantly higher hazard of recovery failure than those not receiving ARB, respectively with HR (95%CI) of 2.23 (1.25 to 3.96, P=0.006) and 2.54 (1.1 to 5.84, P=0.029).

Only variables with P-values<0.2 (a p-value < 0.20 were considered eligible for inclusion in the multivariable model. This more liberal threshold was intentionally used to avoid premature exclusion of potentially important predictors and confounders that may demonstrate independent associations after adjustment.) in the univariate model were included in the multivariable model, as appropriate, denoting that DM and ARB administration were significantly associated with recovery as diabetic patients showed significantly lower hazard of recovery failure than non-diabetic ones (HR=0.69, 95%CI: 0.48 to 0.99, P=0.045) and patients whose ARB was discontinued showed significantly higher hazard of recovery failure than those not receiving ARB (HR=2.12, 95%CI: 1.07 to 4.22, P=0.031).

Table (4.8): Multivariable Cox Regression Analysis for Factors Associated with Recovery Failure from AKI in the Intervention Group

Variable	Adjusted HR	95% CI	P-value
Diabetes mellitus (DM)	0.69	0.48 – 0.99	0.045
ARB discontinuation	2.12	1.07 – 4.22	0.031

ARB, angiotensin receptor blocker; CI, confidence interval; DM, diabetes mellitus; HR, hazard ratio.

4.9 Factors Associated with In-Hospital Mortality Among Intervention Group Patients

This section presents the logistic regression analysis assessing the predictors of in-hospital mortality among patients in the intervention group (Beit-Jala Hospital). The analysis included

both univariate and multivariable logistic regression models, with factors entered into the multivariable model if their univariate p-value was <0.20.

Table (4.9): Logistic Regression Analysis of Predictors of In-Hospital Mortality- Intervention Group

Variables	Univariate analysis				Multivariable analysis			
	Unadjusted OR	95%CI		P-value	Adjusted OR	95%CI		P-value
Age	1.01	0.99	1.04	0.199	1.01	0.99	1.04	0.337
Sepsis	5.89	2.7	12.87	<.001	3.06	1.15	8.1	0.025
Circulatory Shock	13.65	6.43	28.95	<.001	13.26	5.05	34.8	<.001
Dehydration	2.09	1.04	4.22	0.039	0.36	0.12	1.07	0.066
Biomarker	1	1	1	0.005	1	1	1	0.613
Creatinine	1.14	0.99	1.33	0.076	1.03	0.83	1.28	0.767
Creatinine in Urine	1.01	1	1.01	0.027	1	1	1.01	0.115
AKI Stage								
1								
2	0.76	0.27	2.16	0.61	0.62	0.17	2.24	0.464
3	3.24	1.54	6.83	0.002	1.28	0.43	3.86	0.655
Attacks /3months								
1								
2	1.4	0.6	3.27	0.442	1.51	0.52	4.41	0.449
3	5.21	1.56	17.39	0.007	9.85	1.94	50.11	0.006
IVF	1.59	0.81	3.14	0.177	1.82	0.71	4.7	0.216

OR: Odds ratio, CI: Confidence interval, Statistical significance at P-value<0.05

The univariate logistic regression analysis identified the following as significant predictors of in-hospital mortality:

- Sepsis (OR = 5.89, p < 0.001)
- Circulatory shock (OR = 13.65, p < 0.001)
- Dehydration (OR = 2.09, p = 0.039)
- AKI stage 3 compared to stage 1 (OR = 3.24, p = 0.002)
- ≥3 AKI attacks in 3 months (OR = 5.21, p = 0.007)
- Higher NGAL and urine creatinine levels also showed statistically significant but modest associations with mortality.

In the multivariable model, after adjusting for potential confounders:

- Circulatory shock remained a strong and independent predictor of mortality (OR = 13.26, 95% CI: 5.05–34.80, p < 0.001). Sepsis was also independently associated with mortality (OR = 3.06, 95% CI: 1.15–8.10, p = 0.025).
- Patients with three or more AKI attacks over 3 months had nearly 10-fold higher odds of mortality (OR = 9.85, p = 0.006), indicating the cumulative burden of kidney injury.

Other variables, including biomarkers, AKI stage, creatinine, and IVF use did not retain statistical significance in the adjusted model.

This analysis highlights that sepsis, circulatory shock, and recurrent AKI episodes are key drivers of increased mortality among patients in the intervention group. These findings underscore the need for early detection, aggressive management of hemodynamic instability,

and preventive strategies to reduce recurrent AKI episodes as part of an enhanced AKI care model.

4.10 Outcomes Stratified by Nephrology Consultation

This section evaluates the impact of nephrology consultation on key clinical outcomes, including recovery, dialysis initiation, mortality, and AKI duration, in both the intervention and control groups.

Table (4.10) Impact of nephrology consultation on clinical outcomes in intervention and control groups

Nephrology Consult	Group	Recovery (%)	Dialysis Initiation (%)	Mortality (%)	AKI-Duration (Median, Q1–Q3)
No	Intervention	46 (36%)	2 (2%)	28 (22%)	4 (3, 5)
	Control	45 (27%)	11 (7%)	40 (24%)	4 (3, 7)
	P-value	0.102	0.036	0.660	0.200
Yes	Intervention	29 (28%)	15 (17%)	24 (27%)	4.5 (3, 7)
	Control	7 (8%)	31 (35%)	15 (17%)	7 (5, 12)
	P-value	<0.001	0.007	0.094	<0.001

Comparison of recovery rates, dialysis initiation, mortality, and AKI duration between intervention and control groups, stratified by whether nephrology consultation occurred. Data presented as percentages or medians (Q1–Q3). Statistical significance assessed using Chi-square and Mann–Whitney U tests, with significance set at $P < 0.05$.

Among Patients Who did not Receive A Nephrology Consult

The recovery and mortality rates were comparable between the intervention and control groups. However, the dialysis initiation rate was significantly lower in the intervention group (2% vs. 7%, $P = 0.036$), indicating possible early detection and upstream interventions facilitated by the e-alert system, even without specialist input.

Among Patients Who Received a Nephrology Consult

The intervention group had significantly higher recovery rates (28% vs. 8%, $P < 0.001$) and lower dialysis initiation rates (17% vs. 35%, $P = 0.007$) compared to the control group.

There was no statistically significant difference in mortality ($P = 0.094$), but the AKI duration was significantly shorter in the intervention group (4.5 vs. 7 days, $P < 0.001$).

These findings suggest that the combination of an e-alert system and timely nephrology consultation within the hybrid model may have synergistic effects in improving AKI recovery and reducing the need for dialysis.

This subgroup analysis underscores the added value of nephrology consultation in the context of the hybrid AKI management model. The integration of digital alerts and specialist response appears to enhance outcomes, particularly for recovery and AKI duration, reinforcing the importance of multidisciplinary collaboration.

Part Two: Qualitative Analysis

This study investigated the perspectives of 13 nephrologists working in Palestinian hospitals across the West Bank, Palestine, on the feasibility and implementation of the NRRT model.

The findings are organized into three primary categories: facilitators, barriers, and recommendations, each represented in Table 1 through corresponding key themes and descriptive insights. The table outlines five enabler themes that support the NRRT implementation, five barrier themes that hinder its adoption, and three strategic recommendation themes aimed at enhancing nephrology care and addressing AKI management in the Palestinian context.

Table (4.11): Summary of Key Facilitators, Barriers, and Recommendations for NRRT Implementation in Palestine

Category	Key Themes	Description
Facilitators	MOH Strategic Policies	Robust government leadership, policy frameworks, and structured nephrology care integration.
Facilitators	Prevention-Driven Health System	Early detection, proactive health policies, and risk-based interventions to reduce AKI burden.
Facilitators	Multidisciplinary Collaboration & Nephrologist Early Engagement	Involvement of nephrologists, pharmacists, radiologist, nurses, and other specialists to ensure timely interventions.
Facilitators	Institutional Endorsement for Nephrology Care	Hospital-based monitoring systems, intake/output charting, and daily creatinine tracking for high-risk patients.
Facilitators	Advancing Technological Innovation	Implementation of AI-driven diagnostics, novel biomarkers (e.g., Cystatin C, NGAL), and electronic alert systems for early AKI detection.
Barriers	Systemic Governance and Policy Barriers	Lack of nephrology-specific policies, fragmented health governance, and insufficient regulatory frameworks.
Barriers	Financial and Operational Constraints	Limited funding, outdated dialysis machines, and poor infrastructure for nephrology services.
Barriers	Human Resource Insufficiency	Shortage of nephrologists, lack of residency programs, and migration of specialists due to low salaries.
Barriers	Prevention Strategies and Awareness Challenges	Poor health literacy, delayed nephrology consultations, and inadequate prevention efforts in primary care.
Barriers	Collaborations and Surveillance System Challenges	Lack of coordination among healthcare providers, absence of a national renal disease registry, and inconsistent patient tracking.
Recommendations	Policy and Governance Reforms	Strengthen nephrology policies, increase funding, implement national strategies, and establish a renal disease registry.
Recommendations	Capacity Building and Education	Expand residency programs, provide structured training for healthcare professionals, and enhance nephrology education.
Recommendations	Public Awareness and Prevention Strategies	Integrate prevention programs in primary care, establish nephrology-specific clinics, and enhance public education on kidney disease management.

Facilitators for NRRT Implementation

Successful implementation of the NRRT model in Palestinian hospitals depends on several key enablers. Five facilitating themes were identified: MOH Strategic Policies, Prevention-Driven Health System, Multidisciplinary Collaboration and Nephrologist Early Engagement, Institutional Endorsement for Nephrology Care, and Advancing Technological Innovation (see Figure 3). These themes reflect the structural, professional, and technological foundations essential for sustaining NRRT interventions and improving nephrology care.

1. MOH Strategic Policies

A strong policy framework and effective leadership from the Ministry of Health (MOH) were consistently recognized as essential drivers for NRRT implementation. Nephrologists emphasized the pivotal role of the MOH in spearheading systemic reforms, ensuring sustainability, and fostering a coordinated approach to nephrology care. Leadership commitment was seen as a prerequisite for overcoming implementation barriers. One nephrologist highlighted this, stating:

"The Ministry of Health alone can establish this system." (Participant no. 8: 35).

In addition, centralized training workshops under MOH supervision were identified as a critical strategy for equipping healthcare providers with the necessary skills. Standardized training ensures uniform nephrology management practices across hospitals. Another participant elaborated:

"If you want to implement it, you need to coordinate and establish a center at the Ministry of Health where workshops are held in all hospitals for nurses and doctors." (Participant no. 4: 29).

2. Prevention-Driven Health System

Nephrologists advocated for integrating nephrology into a broader preventive health model, highlighting the importance of early detection, risk assessment, and proactive management of AKI. Shifting toward proactive policies is essential in reducing AKI incidence and its associated burdens. As one participant highlighted,

"If this system is implemented, it will have a great impact, and we will quickly see its benefits, particularly how effective AKI management reduces the duration of hospitalization, improves survival rates for many patients..." (Participant no. 13: 27).

Primary healthcare was seen as a cornerstone of this strategy, particularly in facilitating early-stage CKD identification and long-term monitoring. Participants stressed the need for strengthened infrastructure, such as consistent follow-up protocols and regulated medication



Figure (4.9) Key Facilitators to NRRT Implementation in the Palestinian Health System. This diagram illustrates five core enablers supporting the successful adoption of the Nephrology Rapid Response Team (NRRT) model.

dispensing, to operationalize prevention. As one nephrologist explained, effective integration requires:

"They want to activate a preventive health system... patients with chronic kidney disease should have regular follow-ups and undergo basic tests consistently. Pharmacies should be prohibited from selling medications arbitrarily without a prescription." (Participant no.11: 55).

3. Multidisciplinary Collaboration & Nephrologist Early Engagement

The role of multidisciplinary collaboration was another fundamental facilitator. Early involvement of nephrologists and interdisciplinary teamwork was considered essential for managing AKI. However, in the Palestinian healthcare context, early nephrologist consultations are often unavailable due to a shortage of nephrology specialists, a lack of structured referral systems, and an overburdened healthcare workforce.

Nephrology consultations are delayed or even overlooked due to the absence of nephrologists in certain regions. The heavy workload of the few available specialists limits their ability to provide timely consultations, often leading to late-stage referrals when patients require dialysis or critical care interventions. As one nephrologist remarked,

"Providing nephrology specialists is essential to manage AKI effectively, increasing recovery chances and preserving patients' health. Residency programs are crucial" (Participant no. 4: 29).

Strengthening early multidisciplinary consultation was viewed as a low-cost, high-impact reform to improve AKI prognosis and reduce late-stage interventions.

4. Institutional Endorsement for Nephrology Care

Institutional endorsement emerged as a significant enabler for implementing the NRRT model, particularly through the standardization of basic monitoring practices. Nephrologists consistently emphasized that simple, low-cost measures such as intake and output charting, regular patient weighing, and daily creatinine testing could serve as foundational tools for early detection and timely AKI management. One nephrologist illustrated this point:

"It is not difficult to take an intake and output chart for any patient. For high-risk patients or those on nephrotoxic medications, conducting daily creatinine lab tests is also simple. These practices do not require high costs, creativity, or significant effort." (Participant no. 3: 51).

These basic monitoring practices, though simple and low-cost, were viewed as foundational enablers of the NRRT implementation. When supported by institutional commitment and embedded into routine workflows, they offer a practical path toward early AKI detection and consistent, preventive nephrology care.

5. Innovation and Technology Integration: Enabling Early Detection

Participants emphasized the need to integrate innovative, technology-driven tools to improve the early detection and management of kidney diseases. Two key innovations emerged: the use of novel biomarkers, particularly cystatin C, and the implementation of electronic alert systems. Cystatin C was recognized as a more sensitive indicator than creatinine, capable of detecting renal dysfunctions that traditional tests may miss. Likewise,

electronic alert systems were identified as pivotal for the early identification and management of AKI.

As one nephrologist succinctly explained across different points in the interview: -
"One of the most important biomarkers is cystatin C. It sometimes detects issues that creatinine cannot reveal... An automated alert system could ensure timely detection, prompting action before progression becomes irreversible, if integrated effectively with regulations." (Participant no. 1: 56)

In resource-constrained settings like Palestine, participants stressed that the successful implementation of these tools depends on a broader hospital strategy, including staff training, clearly defined clinical pathways, and strong regulatory oversight to ensure sustainability and impact. To avoid the risk of alarm fatigue, which can occur when alerts are excessive or poorly integrated, participants emphasized the importance of designing systems that prioritize clinical relevance and prompt appropriate action.

Barriers to NRRT Implementation

The implementation of the NRRT model in Palestinian hospitals could face several systemic and operational barriers. These Obstacles span across governance (e.g., lack of policy coherence and weak leadership), financial constraints (e.g., insufficient funding for nephrology services), resource limitations (e.g., shortage of nephrologists and inadequate diagnostic tools), and awareness deficiencies (e.g., limited knowledge among healthcare providers and patients about AKI management). Five key themes summarizing these barriers are presented in Figure 4, reflecting the complex interplay of structural and intermediary determinants within the healthcare system.



Figure (4.10). Key Barriers to NRRT Implementation in the Palestinian Health System

1. Weak Systemic Governance and Policy Gaps

Structural weaknesses in health governance emerged as a central barrier to NRRT implementation. Nephrology care was described as fragmented, shaped by short-lived initiatives, reactive planning, and limited long-term investment. Participants repeatedly emphasized that Ministry of Health (MOH) programs often lacked continuity, leaving services exposed to shifting political agendas and financial shortfalls. One participant remarked,

“The Ministry of Health initiates programs, but unfortunately, they rarely complete them 100%.” (Participant no. 9:65)

This lack of sustainability reflects a broader governance dilemma in which nephrology remains marginalized, with no structured policies guiding decision-making or ensuring equitable service distribution.

2. Financial and Operational Constraints

Chronic underfunding and misallocated health budgets were cited as direct impediments to nephrology development. The frustration among participants was palpable, as they linked the dominance of reactive care (dialysis) to a lack of strategic investment in prevention, diagnostics, and early-stage interventions.

One nephrologist sharply criticized the Government of Palestine (GoP) for failing to allocate sufficient funds to the Ministry of Health (MOH), stating:

“They don’t allocate a proper budget for the Ministry of Health... With an adequate budget, we could conduct proper testing and avoid unnecessary dialysis procedures.” (Participant no. 11: 74-75).

Beyond infrastructure limitations, low salaries and overwhelming workloads are driving a wave of physician migration, further weakening the already fragile nephrology workforce. One nephrologist described the reality of Palestinian specialists leaving the country in search of better financial and professional stability:

“Some doctors go abroad and don’t return because the salary is 7,000 NIS (~\$2,000), and they are overburdened with patients.” (Participant no. 13: 45-46).

The brain drain forms a real barrier to implementing structured, team-based models like our proposed NRRT. It deprives the system of the specialized workforce essential for coordinated and preventive nephrology care.

3. Nephrology Workforce Shortage

The implementation NRRT model in Palestinian hospitals is hindered by an acute shortage of nephrologists, an issue that has reached an unacceptable level. Dialysis centers often operate without specialist oversight, creating unsafe care environments and violating basic clinical standards. Participants highlighted a systemic failure to scale training programs alongside service expansion.

One participant vividly described this systemic gap:

“Dialysis centers opened... but where are the nephrology specialists? Ideally, there should be a plan to ensure every center has a specialist, but unfortunately, that’s not the case.” (Participant no. 9: 24).

The absence of nephrologists in dialysis units is an abnormal and unacceptable condition, highlighting a dangerous disconnect between nephrology service expansion and workforce planning. Participants further noted that this workforce gap is compounded by the absence of a formal nephrology residency program and training opportunities in Palestine. Without addressing this imbalance, participants questioned how consistent and timely nephrology care could be delivered.

4. Weak Prevention and Public Awareness

Participants criticized the underutilization of primary care centers for the early detection of kidney disease. Nephrology is typically addressed at advanced stages, with limited public education and provider training on the early detection of AKI risk. One nephrologist critically observed:

"In our context, ... Patients are only referred to a nephrologist when they reach the stage of needing dialysis." (Participant no. 3: 29).

Beyond healthcare provider practices, misconceptions about kidney health among patients were also identified as barriers. Many individuals held simplistic or incorrect beliefs about kidney disease prevention, assuming that drinking water alone could maintain kidney health. As one nephrologist noted:

"Some people think drinking too much or too little water affects kidney health, but that's not true if the kidneys are functioning normally." (Participant no. 4: 29).

These gaps in awareness, limited emphasis on preventive care, and delays in nephrology referrals reflect ongoing challenges in integrating nephrology services within the broader healthcare system.

5. Collaborations and Surveillance System Challenges

A fundamental flaw in the current healthcare system, as revealed by participants, is the lack of coordination between primary and secondary healthcare services, fragmenting patient management and leading to disjointed care pathways. Patients often navigate a maze of healthcare providers—the Ministry of Health (MOH), military medical services, relief agencies, and UNRWA—each operating independently, without a centralized treatment plan or communication channel. One nephrologist reflected on this uncoordinated system:

"Healthcare services are being provided in multiple places, but there is no harmony or coordination between the primary healthcare centers." (Participant no. 10: 28).

This healthcare fragmentation creates delays in patient management, duplication of efforts, and inconsistent medication regimens. Patients receive conflicting prescriptions and undergo unnecessary duplicate tests due to the absence of a shared clinical record system.

Closely tied to this fragmentation is the absence of a national renal disease registry, which significantly limits strategic planning for kidney care. Without a centralized data repository, nephrologists lack critical tools for monitoring patient trajectories, assessing population-level burden, and informing clinical decision-making. One participant underscored this challenge:

"... A proper registry system would help us follow patients better, especially as their numbers grow. Unfortunately, we don't have any statistics at all." (Participant no. 7:40–41)

This data vacuum hinders evidence-based decision-making, making it impossible to allocate resources efficiently or develop national strategies for kidney disease management. The

failure to establish a real-time surveillance system for CKD and AKI cases reflects a systemic oversight that continues to undermine nephrology services at every level.

Nephrologists' Insights: Strategic Recommendations for NRRT Implementation

Grounded in their lived experiences and professional realities, nephrologists provided strategic recommendations to overcome the systemic barriers hindering the effective implementation of the NRRT model. Figure 5 illustrates and synthesizes the recommendations, which emerged organically from nephrologists' daily experiences and direct engagement with the systemic challenges of the Palestinian healthcare system.

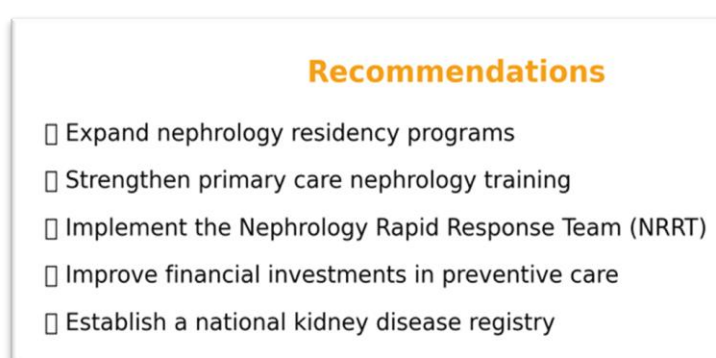


Figure (4.11). Key Policy and System-Level Recommendations to Strengthen Nephrology Care Delivery in Palestine

Within the complex and resource-limited healthcare landscape, nephrologists articulated pragmatic solutions, highlighting the need for systemic transformation in nephrology care. Their recommendations consolidate into three interdependent themes, each addressing a critical aspect of health system reform.

The following section provides an in-depth exploration of these recommendations, capturing the nuanced perspectives and frontline realities of nephrologists as they reimagine nephrology care within a constrained yet resilient healthcare system.

1. Policy and Governance Reforms: A Call for Systemic Change

Nephrologists consistently emphasized the need for comprehensive reforms in health governance to strengthen nephrology care. Their narratives revealed a fragmented system lacking strategic direction, sustainable funding, and cohesive referral mechanisms, factors that collectively undermine patient outcomes and limit the feasibility of NRRT implementation.

A central recommendation was the expansion of structured primary care services through the family medicine program. This was viewed as essential for shifting from dialysis-centered care toward early detection and prevention-based strategies. One participant articulated this vision through a more structured and patient-centered model:

"The Family Medicine program in Palestine needs to expand significantly and should serve as the first line of defense in managing such cases. These physicians are the ones who see patients first, refer them when necessary, and follow up on their conditions. This ensures a structured and coordinated approach to patient care." (Participant P. no. 9: 36).

Strengthening frontline care and referral coordination, alongside implementing a national nephrology strategy, was seen as foundational for enhancing system responsiveness and ensuring the long-term viability of nephrology reforms.

2. Capacity Building and Education: Strengthening the Foundations of Nephrology Care

A foundational recommendation was to strengthen the nephrology workforce through structured residency programs, continuous medical education, and general physician upskilling. Participants highlighted the need for both specialist and generalist training to improve early detection and AKI management. A nephrologist highlighted the dual necessity of medical training and a structured tracking system:

"General physicians must be trained on how to act as the first line of defense in managing kidney diseases. Additionally, there should be a kidney disease registry to ensure proper tracking and management of these cases." (Participant no. 9: 69).

This emphasis on education and capacity building reflects a deep awareness among nephrologists that closing the knowledge gap is pivotal to improving patient outcomes. Without a skilled and well-trained workforce, nephrology services will continue to struggle, leaving AKI and CKD patients vulnerable to mismanagement and late-stage referrals. Participants envisioned a future where continuous medical education, structured residency programs, and a well-established nephrology registry would not just enhance individual skills but fortify the entire healthcare system, ensuring better patient care despite resource limitations.

3. Public Awareness and Prevention Strategies: A Shift Toward Proactive Nephrology Care

Nephrologists called for wide-scale public education and early intervention campaigns to reduce the rising burden of kidney disease. These would target both community misconceptions and systemic neglect in the early stages of care. A notable proposal was the creation of nephrology-specific outpatient clinics segmented by condition: CKD, AKI, and transplant to provide tailored treatment and improve follow-up. One participant articulated the necessity of this structured approach:

"Another important point is to have specialized clinics within government institutions: separate clinics for CKD and AKI. Managing chronic kidney disease is different from managing acute kidney injury because AKI patients have a good chance of kidney recovery. Therefore, in my opinion, nephrology services should be divided into three distinct clinics for optimal effectiveness—for kidney transplants, AKI, and CKD. (Participant no. 13: 17)

Integrating preventive nephrology into primary care and restructuring service models to reflect disease progression were seen as transformative strategies to improve long-term care and reduce dialysis dependency.

Chapter Five

Discussion and Recommendations

This chapter synthesizes the quantitative and qualitative findings to evaluate the feasibility and effectiveness of the integrated AKI detection and management model and the contextual factors that influenced its implementation in Palestinian hospitals. The quantitative analysis examined clinical and process outcomes related to AKI care, while the qualitative findings provided insight into implementation challenges, workflow adaptation, and professional perspectives on feasibility. Together, these results offer a clearer understanding of how the intervention performed in practice and why certain patterns emerged.

5.1 Epidemiological Profile and Risk Factors of AKI

The demographic and clinical characteristics of this cohort underscore the multifactorial etiology of AKI in Palestine and LMICs. The mean age was approximately 66 years in both the intervention and control groups, highlighting the increased vulnerability of older adults, likely due to age-related nephron decline and increased comorbidity burden.

A notable demographic pattern was the predominance of males among AKI cases. This finding aligns with the global meta-analysis by Neugarten & Golestaneh (2018), which reported that men face a higher risk of hospital-acquired AKI (OR 1.23, 95% CI: 1.11–1.36), particularly in ICU and non-cardiac surgical settings. These results challenge earlier guidelines (KDIGO, 2012) that considered female sex a greater susceptibility factor (Khwaja, 2012). Biological mechanisms such as hormonal influence, immune modulation, and differential tubular repair may partly explain the disparity, alongside sociocultural factors like occupational exposure and delayed care-seeking. Consistent with this, the unpublished Palestinian MoH data show that males constitute most dialysis patients nationwide, supporting the notion of higher AKI incidence and faster progression to ESKD among men.

Comparable demographic patterns were observed in recent local studies, including Damin Abukhalil et al. (2024), who reported a median age of 65 years and 54% male prevalence among AKI hospital admissions in Palestine.

Hypertension and Diabetes Mellitus: Dual Drivers of Susceptibility

Hypertension (72.1%) and diabetes mellitus (58.9%) were the most common, consistent with the metabolic and vascular burden driving kidney disease across the Eastern Mediterranean region. HTN was significantly more prevalent in controls (81.1%, $p = 0.021$), suggesting that uncontrolled blood pressure may exacerbate renal hemodynamic instability, increase AKI severity, and delay recovery (Cerdá et al., 2017).

Diabetic nephropathy, though not statistically different between groups, remains a major structural substrate for AKI, predisposing to microvascular ischemia and oxidative stress during acute illness (Ostermann et al., 2025). The coexistence of diabetes, hypertension, and CKD creates a synergistic triad, each exaggerating the risk and impeding recovery, mirroring the “renal–cardiometabolic syndrome” increasingly reported in LMICs (Luyckx et al., 2024). This local pattern aligns with national epidemiological data. According to the 2022 National STEPS Survey (Palestinian Ministry of Health, 2024), 21.8% of Palestinian adults reported hypertension and 19.9% reported diabetes, with rates increasing sharply after age 44. These findings reveal an intersection between the chronic NCD and AKI risk, particularly in settings marked by fragmented health systems and limited resources. Pre-renal etiologies, particularly sepsis and dehydration, were the dominant causes, affecting over half and two-thirds of patients, respectively, which is consistent with global LMIC data, where community and hospital-acquired AKI remain interrelated.

AKI– CKD – ESKD Continuum

The high prevalence of CKD in our research, exceeding 60% in both intervention and control groups, reinforces the concept that AKI in Palestine commonly arises in the context of underlying renal impairment. This observation supports the increasingly recognized continuum between AKI, CKD, and ESKD, rather than viewing them as independent conditions. KDIGO’s 2024 consensus statement emphasizes that CKD is the primary susceptibility factor for AKI, wherein a decline in nephron reserve, chronic inflammation, and microvascular injury exaggerate risk from even modest hemodynamic or nephrotoxic insults (Kellum & Zarbock, 2025).

This “AKI on CKD” or AKI on top of CKD, as the Palestinian physicians documented in patients’ EMR, phenomenon reflects not only individual-level biological vulnerability but also broader system-level challenges. National data from the Palestinian Ministry of Health (2025) indicate a 108% increase in ESKD cases since 2015, with over 3,500 patients now receiving dialysis. These trends suggest that unrecognized or inadequately managed AKI episodes are accelerating progression toward ESKD, particularly in the absence of robust post-discharge follow-up and a national renal registry (Palestinian Ministry of Health, 2024). The CKD prevalence in this cohort is markedly higher than regional and global estimates, far surpassing the Middle East average of 8.17% and typical figures reported in low- and middle-

income countries (Bello AK et al., 2023). This disparity likely reflects systemic inequities in the Palestinian healthcare system, including the severe shortage of nephrology specialists, fewer than thirteen across the West Bank, and the absence of unified national protocols for CKD and AKI management (Palestinian Ministry of Health, 2023; Jawabreh et al., 2025). The qualitative findings highlighted that this workforce limitation, combined with limited-fragmented referral pathways and a lack of standardized post-AKI follow-up, continues on reactive rather than proactive-preventive nephrology care. Without a national renal registry, formal CKD surveillance, or structured primary-care integration, early kidney disease often progresses silently to ESKD. Similar challenges have been documented in other LMICs by the ISN Global Kidney Health Atlas (Bello et al., 2023), underscoring how workforce shortages and policy gaps remain the principal barriers to implementing prevention-driven nephrology.

The KDIGO guidelines emphasize longitudinal surveillance following AKI, recommending continued renal function monitoring to detect incomplete recovery or progression to CKD (Khwaja, 2012). However, these guidelines pose logistical challenges in overburdened systems. AKI affects approximately 1.5% of the general population annually (Sawhney et al., 2018), and nephrology access is severely limited in Palestine; it is unrealistic to expect nephrologists alone to manage all post-AKI care. Indeed, fewer than 10% of patients surviving hospitalization with AKI globally receive nephrology follow-up within three months (Silver & Siew, 2017).

Epidemiologically, AKI and CKD form a bidirectional, self-perpetuating cycle. Patients with pre-existing CKD are at significantly higher risk of AKI, and those with AKI face increased likelihood of incomplete recovery, persistent dysfunction, or rapid progression, now conceptualized as acute kidney disease (Chawla & Kimmel, 2012; Lameire et al., 2021). This transitional phase highlights the importance of early identification, longitudinal monitoring, and the integration of renal care across systems, particularly in resource-limited settings such as Palestine.

Nephrotoxic Drug Exposure and Preventable Triggers

Nephrotoxic drug exposure was remarkably high (86.5% vs 80.7%), emphasizing a preventable risk factor that persists in LMIC hospitals where pharmacovigilance systems are limited. Commonly implicated medications included aminoglycosides, ACE inhibitors, and intravenous contrast, often administered without serial renal monitoring. This pattern aligns with the WHO AKI Roadmap findings that 20–30% of hospital-acquired AKI in low-resource settings is linked to medication-related toxicity (Zhu et al., 2023). Notably, radiocontrast exposure (13.5%), though lower than global averages, still represents a significant avoidable cause, especially given the lack of standardized prophylaxis protocols. The integration of e-alert–based nephrotoxin review within the hybrid intervention directly targeted this gap, prompting medication reassessment and likely contributing to the observed reduction in dialysis initiation.

Our findings echo concerns raised by Damin Abukhalil et al. (2024), who reported nephrotoxic drug exposure in 68.7% of AKI cases, predominantly NSAIDs, ACE inhibitors/ARBs, diuretics, and antibiotics. Both studies reveal broadly and often

inappropriate nephrotoxin use, particularly in community settings where most medications are accessible without adequate renal monitoring.

Lung disease (47.4% vs. 37.4%, $p = 0.028$) and critical illness (91.2%) were also prominent contributors in our sample, suggesting multi-organ interactions as key mechanisms of AKI. Damini Abukhalil et al. (2024) similarly identified pulmonary disease in 21.9% of cases, linking hypoxia and systemic inflammation to renal injury. This supports the medical condition known as pulmonary-renal syndrome, where cytokine-mediated endothelial dysfunction and reduced oxygen delivery aggravate tubular stress (Husain-Syed et al., 2024). Collectively, these data reveal that AKI in Palestine arises within a predictable chronic comorbidity, nephrotoxin exposure, and system-level gaps in preventive renal care. Our study builds upon and extends the findings of Abukhalil et al. (2024) by demonstrating how integrating risk profiling, biomarkers, and e-alert systems can transform this epidemiologic understanding into actionable prevention and early management.

From an epidemiologic standpoint, both national and cohort-level Palestinian data converge on several critical themes. Community-acquired AKI predominates, frequently triggered by dehydration, infection, and inappropriate drug exposure. Hypertension, diabetes, and chronic kidney disease (CKD) consistently emerge as the core triad of susceptibility, while nephrotoxic agents, particularly ACE inhibitors/ARBs, represent the most modifiable risk factor, with inappropriate use persisting even during hospitalization.

In contrast to most regional studies that rely solely on serum creatinine (S.cr) and urine output, the present research incorporated NGAL and other early-detection biomarkers, representing a step forward in enabling the identification of subclinical AKI that traditional markers may overlook. The median NGAL concentration in the intervention group was 119.6 ng/mL, reaching >700 ng/mL in severe cases. These results confirm NGAL's utility for early renal stress detection and align with global evidence advocating multimarker integration for improved diagnostic timing and precision (Virzì et al., 2025; Ostermann et al., 2025).

5.2 Impact of the E-Alert on Care Processes

The implementation of a real-time e-alert system in our study resulted in a demonstrable improvement in AKI detection, documentation, and care quality, consistent with emerging international evidence that digital decision-support tools can enhance process measures, even in resource-limited settings. Quantitatively, the intervention group showed a clear shift toward earlier AKI stages, with Stage 1 predominating (67.0% vs 42.1% in controls) and a marked reduction in Stage 3 cases (18.6% vs 38.2%, $p < 0.001$). This redistribution reflects the alert's capacity to facilitate timelier identification and response, consistent with findings by Wilson et al. (2015, 2021). The overall documentation rate doubled (68.4% vs 37.8%, $p < 0.001$), signaling the emergence of a more transparent and accountable record-keeping culture, an essential precondition for any learning health system model in nephrology.

Beyond recognition, alerts translated into measurable behavioral change at the point of care. In our study, clinician response rate of 76.3 % is comparable to or exceeds that seen in prior AKI e-alert systems, where response or acceptance rates typically range from ~50 % to ~70 %, depending on design and context resembling 69 % provider acceptance, 57 % behavior

change in decision-support systems, or high deferment rates in UK pop-up alerts (Bani-Saad et al., 2019; Shi et al., 2022).

Process audits revealed significant improvements in medication safety: discontinuation of nephrotoxic cephalosporins (63.3% vs 39.0%, $p < 0.001$) and adjustment of aminoglycosides (13.0% vs 4.0%, $p = 0.002$) were markedly higher in the intervention group. Comparable trends were observed for diuretics and metformin, consistent with evidence that e-alerts prompt proactive renal-dose modification and drug cessation (Wilson et al., 2015a, 2023a; Y. Wu et al., 2018). These medication-related actions are widely recognized as alternative indicators of safer renal practice, underscoring that process adherence often precedes outcome gains.

Notably, the intervention group displayed a more individualized approach to fluid therapy. Although intravenous fluids were administered less frequently (63.3% vs 77.2%, $p = 0.001$), clinicians were twice as likely to discontinue fluids when clinically appropriate (44.2% vs 25.6%, $p < 0.001$). This pattern suggests a paradigm shift from routine resuscitation toward tailored volume management, an essential determinant of renal recovery and mortality (Kim et al., 2017).

In contrast, radiological evaluation (renal ultrasound) showed no significant difference between groups (29.3 % vs 30.7 %, $p = 0.741$). This aligns with international data indicating that e-alerts seldom influence imaging behavior, as radiology requests are usually guided by structural suspicion rather than biochemical triggers. Both Li et al. (2024) and Perry Wilson et al. (2021) observed similar neutrality in imaging outcomes, noting that alerts improve biochemical surveillance but do not alter low-yield investigations such as ultrasound unless hydronephrosis or obstruction is suspected.

Laboratory follow-up improved correspondingly, with higher rates of repeat creatinine testing (97.7% vs 92.1%, $p = 0.008$), urinalysis (76.7% vs 59.1%, $p < 0.001$), and 24-hour urine collections (58.6 % vs 47 %, $p = 0.023$). Such adherence to monitoring protocols aligns with global standards for AKI surveillance (Fu et al., 2024; Wilson et al., 2015) and signals progressive normalization of best practice within Palestinian hospitals.

The meta-analysis by Tome et al. (2022) and the systematic review by Fu et al. (2024) both concluded that laboratory follow-up is one of the most consistent process improvements attributable to e-alert systems, even when clinical outcomes remain unchanged.

From a public-health standpoint, the greater use of 24-hour urine collection and urine analysis in the intervention group suggests a broader shift from reactive to preventive nephrology practice.

Early detection of proteinuria or persistent oliguria can inform timely nephrology referral and predict progression risk, an aspect strongly emphasized by KDIGO 2012 and reinforced in the KDIGO LMIC Controversies Conference (Jha et al., 2016) as a cost-effective surveillance strategy where advanced diagnostics are limited. Therefore, the present findings illustrate that even simple alert prompts can translate into more complete renal investigations without additional infrastructure investment.

These findings indicate that the e-alert system prompted more systematic biochemical reassessment and renal monitoring processes that are crucial for staging AKI, detecting recovery, and guiding medication or fluid adjustments. This enhanced monitoring closely mirrors patterns observed in large multicenter evaluations of electronic AKI surveillance.

5.2.1 Alert Fatigue

The implementation of the AKI e-alert and triage system achieved a high and clinically meaningful level of provider responsiveness. Nearly three-quarters of alerts prompted documented clinical action, an encouraging result given the high patient load and resource constraints of the participating hospitals. This response rate aligns with international evaluations of AKI e-alert systems, where engagement typically ranges between 60–75% (Perry Wilson et al., 2021; Selby et al., 2021). Thus, the system demonstrated substantial success in promoting awareness and early response among frontline clinicians.

Despite these advances, approximately one in four alerted cases lacked a documented provider response. At face value, this might imply non-compliance; yet the qualitative findings reveal a deeper organizational story. Nephrologists consistently described structural and cultural barriers that hindered timely translation of alerts into action, chronic workforce shortages, competing clinical demands, and the absence of mandatory follow-up pathways. Several participants remarked that although the system “made AKI visible,” limited accountability rendered it informational rather than operational. These perspectives mirror implementation barriers identified globally in digital health adoption, where technological success often precedes institutional (Carpenter-Song et al., 2024).

Moreover, alert fatigue expanded by high patient loads and frequent non-prioritized messages further diminished responsiveness, as clinicians learned to triage notifications selectively amid competing clinical demands. These behavioral dynamics were reinforced by nephrologists’ qualitative accounts of limited clinical autonomy, poor cross-departmental communication, and an absence of clear escalation pathways, all of which diluted the intended urgency of the e-alert system. Thus, while the quantitative data quantify a 24% non-response rate, the qualitative strand explains why, revealing that the constraint was not technological inefficacy but organizational misalignment and resource exhaustion. This mixed-method synthesis emphasizes that digital innovations, when introduced into structurally fragile systems, require concurrent investment in workflow integration, team-based accountability, and behavioral reinforcement if they are to translate recognition into timely therapeutic action.

5.3 Operational impact of the AKI Risk-Triage

The AKI risk-triage model developed in this study represents a structured, context-adapted framework for identifying patients at heightened risk of severe AKI outcomes within low-resource hospital settings. Grounded in the KDIGO “susceptibility–exposure–injury” paradigm (KDIGO, 2023), the model integrates patient history, clinical presentation, comorbidities, and laboratory findings into a composite classification system, categorizing patients as low, moderate, or high risk.

Despite its non-clinical implementation, the model demonstrated clear construct validity. A significant association was observed between triage risk level and AKI stage at diagnosis ($P = 0.001$). Specifically, 25.3% of patients in the high-risk category presented with Stage 3

AKI, compared to just 9.1% in the low-risk group. This gradient strongly supports the model's potential to stratify patients by likelihood of disease severity and suggests value for future predictive integration in real-time clinical systems.

Unlike the two-stage SMS alert system, which delivered KDIGO-based AKI diagnosis and later biomarker results to treating clinicians, the triage model functioned exclusively at the backend. It was not intended to guide immediate clinical action in this phase but rather to support analytic exploration and inform future decision-support tool development.

These findings are consistent with the results of Malhotra et al. (2017), who developed an ICU-based AKI prediction model incorporating comorbidities and acute insults, achieving an AUC of 0.81. Similarly, a recent meta-analysis by Feng et al. (2023) Feng et al. (2023), found strong pooled discriminatory performance (C-statistic ≈ 0.80) across over 150 AKI prediction models, particularly when risk tools incorporated both chronic and acute parameters.

In contrast, the triage model operated in the background as an analytic layer. While not seen by providers, its alignment with AKI stage supports its use as a predictive research tool that could inform future early-warning systems. This distinction addresses the ADQI 27 framework, which urges movement beyond static alerts toward layered, risk-informed models that are both human-involved and digitally supported (K. B. Kashani et al., 2023).

These findings support recommendations from the ISN's Oby25 campaign, which calls for early AKI recognition and intervention as a global health equity priority (Mehta et al., 2015). The 2023 ISN Global Kidney Health Atlas also highlights the urgent need for scalable early-warning tools, especially in LMICs (Bello AK et al., 2023).

Furthermore, our triage model aligns with the adaptive maturity model proposed by Ponce & Balbi (2016), who emphasized human-involved, locally contextual tools in AKI care. By relying on composite clinical and laboratory markers, our system offers a more nuanced and effective alternative to serum creatinine alone, which is a key limitation in LMIC nephrology. The triage model holds promise for future real-time clinical use. With further validation and stakeholder input, particularly from nephrologists and national decision-makers, it could be embedded within a national AKI prevention protocol. This would allow high-risk patients to be flagged proactively and prioritized for early monitoring and intervention.

Such integration would not only close the loop between risk prediction and clinical action but also operationalize global best practices in a scalable and equitable way. The dual-layered approach demonstrated in this study, analytic triage informing backend risk and SMS alerts guiding front-line action, represents a closed-loop digital nephrology system adapted to the realities of LMIC healthcare.

5.4 Diagnostic and Prognostic Performance of NGAL

5.4.1 Predictive Performance of NGAL across AKI Severity

Our study demonstrates that embedding NGAL into a hybrid triage and SMS-based e-alert system meaningfully enhances early detection and risk stratification for AKI within a resource-constrained hospital setting. Traditional markers such as serum creatinine and urine output remain the cornerstone of KDIGO AKI diagnosis, but their delayed kinetics and baseline dependency limit responsiveness in acute clinical scenarios. By contrast, NGAL acts

as an early structural biomarker, rising within 2–4 hours of ischemic or nephrotoxic insult (Ostermann et al., 2024; Schrezenmeier et al., 2017), thereby enabling timely therapeutic decisions, especially when combined with clinical triage data.

Comparative performance and Contextual Value

In our cohort, both NGAL and S.cr demonstrated statistical significance in predicting AKI stages 1 and 3. At Stage 1, S.cr yielded the highest AUC (0.785), while NGAL offered higher specificity (74.65%) and thus fewer false positives, reducing over-alerting in cases of transient creatinine fluctuations. At Stage 3, NGAL's sensitivity (87.5%) and negative predictive value (95.8%) facilitated safer clinical de-escalation, reinforcing its role as a “rule-out” tool. While S.cr showed slightly higher discriminative power ($\Delta\text{AUC} \approx 0.09$), NGAL consistently outperformed proteinuria-based indices, confirming its superiority among structural biomarkers.

NGAL's predictive accuracy is further supported by recent studies. In an ICU cohort in Saudi Arabia, Albeladi & Algethamy (2017) found that u-NGAL predicted the need for renal replacement therapy (RRT) with exceptional accuracy (AUC = 0.93), particularly when measured on Day 2. Likewise, Brogi et al. (2024) observed a 99% sensitivity for AKI detection using NGAL at ICU admission, underscoring its real-time diagnostic potential. These results affirm NGAL's utility not only for early identification but also for forecasting AKI trajectory and severity.

Structural–Functional Integration

Consistent with ADQI 28 recommendations (Ostermann et al., 2020), our hybrid approach aligned functional (S.cr) and structural (NGAL) markers with clinical triage. This integration enabled dynamic and context-aware classification of injury types, including “subclinical AKI” (NGAL⁺/S.cr⁻), which would otherwise be missed. This 2×2 model of biomarker-function pairing, as advocated by Albert et al. (2020), allowed for earlier nephrology consultation, optimized fluid management, and nephrotoxin stewardship. As a result, our intervention group experienced reduced dialysis initiation (17% vs. 35%) and shorter AKI duration (median 4.5 vs. 7 days, $p < 0.001$).

Implementation Insights and Global Context

NGAL's diagnostic performance is not absolute; it is influenced by systemic inflammation, sepsis, and variable assay thresholds. However, combining NGAL with clinical risk profiles, as in our triage-alert model, mitigates these limitations. This mirrors global findings where NGAL's predictive value improves when integrated with risk scores or other markers, such as the Renal Angina Index (RAI), as shown by Goldstein et al. (2020) and Neyra et al. (2019). Furthermore, Lumlertgul et al. (2020) reported that while uNGAL alone had moderate performance for long-term kidney outcomes (MAKE30 AUC = 0.66), combining it with clinical parameters improved predictive accuracy (AUC = 0.74). These findings emphasize that NGAL's utility is maximized in layered, multimodal frameworks, precisely the design adopted in our intervention.

Pragmatic Relevance in LMICs

Despite concerns about cost and access, NGAL can be deployed effectively in low-resource environments through selective, protocol-driven usage. The Palestinian experience highlights that biomarker-enhanced AKI care is not confined to high-income settings. Our SMS-triggered, triage-anchored, and NGAL-scaled up system represents a scalable, low-tech pathway with high clinical return. This aligns with ADQI and KDIGO's vision for democratizing precision nephrology through context-sensitive innovation, rather than infrastructure-heavy automation.

Interpretive and Operational Implications

Our findings support the emerging ADQI 28 consensus that AKI evaluation must integrate clinical risk triage (susceptibility and exposure) with stress/damage biomarkers (e.g., NGAL, TIMP-2•IGFBP7) and functional markers (creatinine, UO) to move recognition earlier along the injury continuum (Ostermann, Zarbock, Goldstein, Kashani, Macedo, et al., 2020). By embedding NGAL in a triage + alert loop, this study offers a pragmatic implementation of that ideal in a constrained health system. It exemplifies how precision diagnostics can be democratized when embedded in low-cost, SMS-based tools rather than dependent on full EHR automation.

However, interpretation must remain context aware. NGAL can rise in systemic inflammation, limiting its specificity in septic patients. The manual triage component mitigated this by integrating clinical context vital signs, infection source, and exposure history into decision-making. Future algorithmic iterations could automate this composite judgment through AI-assisted scoring to refine specificity further.

The integration of NGAL within a hybrid triage–e-alert system represents a paradigm shift in AKI detection for low-resource hospitals. It bridges the gap between delayed functional metrics and early structural injury markers, translating biomarker science into real-world impact. By merging human judgment, laboratory precision, and digital communication, this model moves Palestinian kidney care from reactive to preventive and precision-oriented practice. Despite geopolitical and infrastructural constraints, the results demonstrate that innovation grounded in contextual realism, not resource abundance, can deliver Q1-level outcomes. The Palestinian experience provides a replicable template for LMICs aiming to embed biomarker-enhanced, digitally enabled renal surveillance within their health systems.

Triangulation with Qualitative Findings

The qualitative component (Jawabreh et al., 2025) deepens the interpretation of these quantitative gains. Nephrologists described technological innovation and biomarker adoption as critical enablers of early detection, emphasizing that “biomarkers detect what creatinine cannot.” They envisioned NGAL as a decision-trigger embedded within alerts to prompt earlier intervention. This aligns with our data showing faster clinical responses and improved renal recovery in the intervention group. Moreover, the qualitative theme of “multidisciplinary collaboration and early nephrologist engagement” directly corresponds to the observed increase in nephrology consultation and nephrotoxin stewardship, underscoring how digital and behavioral innovations intersect to improve care processes.

Thus, the integration of NGAL was not only diagnostically superior but culturally and operationally congruent with clinicians' perceptions of feasible reform. It served as the "missing link" between detection and action, bridging laboratory data, clinician behavior, and system design.

5.5 Impact of the Hybrid Model on AKI Primary Outcomes

Our study provides the first empirical or practical validation of a hybrid AKI management model in a low- and middle-income country (LMIC) setting. Despite operating under significant structural and economic constraints, the intervention achieved clinically and operationally meaningful improvements across most renal-specific outcomes. The intervention group experienced a 50% reduction in dialysis initiation (7.9% vs 16.5%, $p = 0.005$), a significant rise in recovery rate (33.0% vs 20.5%, $p = 0.002$), and a shorter AKI duration (median 4 vs 5 days, $p < 0.001$).

5.5.1 Renal Recovery and Dialysis Reduction

The superior recovery rate and reduced dialysis initiation observed in the intervention group validate the translational efficacy of the triage–alert–biomarker framework. The alerts acted as behavioral triggers, prompting medication review, volume optimization, and early nephrology referral. These findings parallel multicenter data from (Kolhe et al., 2016; Li et al., 2024), where structured AKI alerts linked with care bundles halved dialysis dependence through faster therapeutic intervention. In Palestine's context, where nephrology coverage is limited, the hybrid model functioned as an alternative clinical safety net, compensating for specialist shortages by standardizing early response.

The mechanisms underlying these gains are consistent with global evidence showing that digital prompts alone rarely change outcomes unless coupled with actionable pathways. By embedding alerts within a biomarker confirmation (NGAL), this study operationalized the KDIGO "Susceptibility–Exposure–Injury" model (Ostermann et al., 2024). The process mirrors that reported by Tome et al. (2022) and Wang et al. (2024), where alerts improved AKI recognition and provider response (e.g., discontinuation of nephrotoxins, repeat creatinine testing), leading to earlier recovery. Thus, the present results extend these observations to an LMIC environment, demonstrating that a low-cost analog-to-digital adaptation can yield equivalent process benefits without sophisticated infrastructure.

5.5.2 Interpreting Mortality Neutrality

The absence of mortality difference (24.2% vs 21.7%, $p = 0.515$) aligns with global evidence that e-alert systems seldom influence short-term survival because mortality in AKI is dominated by comorbid sepsis, multi-organ failure, and late presentation (Fu et al., 2024; Wilson et al., 2015). However, the observed reduction in AKI persistence and dialysis dependence indicates substantial renal-specific survival benefits and may curb long-term CKD and ESKD progression effects that exceed the timeframe of acute hospitalization. As the KDIGO Controversies Conference (Jha et al., 2016) highlighted, incremental gains in

early AKI recognition can have disproportionate downstream benefits in resource-limited systems.

5.5.3 Interpretation of Hospital Length of Stay (LOS) Findings

Although the reduction in hospital length of stay (LOS) between groups did not reach statistical significance (median 9 vs 10 days, $p = 0.272$), its clinical relevance remains substantial in the operational context of Palestinian governmental hospitals. These facilities operate at chronically high occupancy rates, often exceeding 90%, with prolonged patient turnover times that limit access for new admissions. Within such settings, even a one-day reduction in hospitalization can translate into meaningful system-level efficiency, freeing beds for critically ill patients, reducing nursing workload, and lowering per-patient care costs. This interpretation aligns with Tome et al. (2022) and Wilson et al. (2015), who reported that marginal reductions in LOS following AKI alert implementation, while not always statistically significant, represent tangible operational gains in overburdened public health systems.

Importantly, an absence of statistical significance does not imply poorer performance. Chen-Xu et al. (2024) demonstrated that LOS may increase when more comprehensive AKI care bundles are used, yet clinical outcomes such as mortality and renal recovery improve. In this context, a slightly longer or unchanged LOS may reflect safer monitoring, more complete medical optimization, and adherence to best-practice care rather than inefficiency. Thus, LOS should be interpreted as an indicator of hospital productivity and quality of clinical management rather than a purely statistical endpoint.

Health System and Policy Implications

Within the Palestinian health system, these findings carry strong policy resonance. Each avoided dialysis initiation and every shortened AKI episode translate directly into reduced hospital costs, fewer bed blockages, and decreased long-term renal replacement therapy dependence. The model therefore enhances *health system resilience* by alleviating the growing CKD–ESKD burden, estimated to have doubled nationally since 2015. Moreover, by achieving these results with minimal digital infrastructure, the hybrid model exemplifies “appropriate technology innovation” for LMICs, where clinical precision must coexist with economic feasibility.

5.5.4 Strategic and Global Significance

The study’s success under conflict-related constraints underscores that transformative nephrology reform in LMICs is not contingent upon high-cost automation, but upon *contextual intelligence* integrating human triage, biomarker science, and adaptive communication. The findings substantiate the ISN 0by25 Initiative, affirming that preventable AKI mortality can be reduced through locally adapted, low-cost solutions. As such, the Palestinian model offers a scalable framework for other fragile or under-resourced health systems seeking to embed AKI surveillance within routine hospital practice.

The magnitude of these results is particularly striking given the context. Unlike prior randomized trials in high-income settings, this study demonstrated that a low-cost, context-adapted digital-biomarker triad combining e-alerts, structured triage, and NGAL guidance

can deliver tangible renal protection without dependence on advanced electronic infrastructure. These findings extend global evidence (J. J. Chen et al., 2024; Tome et al., 2022; Wang et al., 2024; Y. Wu et al., 2018) by showing that clinical process optimization through alerts can be successfully replicated in LMIC hospitals, where manual data collection, delayed diagnostics, and limited nephrology coverage are routine barriers.

The reduction in dialysis initiation mirrors the results of Li et al. (2024) and Wu et al. (2018), where e-alerts combined with care bundles and enhanced provider awareness led to earlier preventive actions, such as medication adjustments and optimization of fluid therapy. Likewise, the meta-analysis by Tome et al. (2022) found that alert implementation significantly improved AKI recognition and process measures (e.g., cessation of nephrotoxins, repeat creatinine testing), which are intermediate factors contributing to improved renal recovery. These parallels suggest that even in a low-resource environment, digital alert systems can achieve substantial process-to-outcome translation when supported by clinician responsiveness.

Despite these global observations, the current study's findings of shorter AKI duration and greater recovery are significant. They reflect incremental but practical clinical improvements relevant to LMIC contexts. The KDIGO Controversies Conference emphasized that in resource-limited settings, even modest gains in early AKI recognition, reduced dialysis burden, and shortened AKI duration translate into major economic and public health benefits. Furthermore, by reducing unnecessary dialysis exposure and promoting recovery, the alert system likely contributes to lower long-term CKD transition risk, a crucial outcome not captured within the short-term hospital stay (Jha et al., 2016).

5.6.1 The Role of Early Nephrology Consultation

This study provides compelling evidence that early nephrology consultation maximizes the clinical effectiveness of e-alert-driven AKI management. Stratified analysis revealed that, although e-alerts alone improved certain outcomes, the combination of alerts with timely nephrology input yielded the most pronounced benefits.

Among patients who did not receive nephrology consultation, the intervention still conferred partial benefits, including a significant reduction in dialysis initiation (2% vs. 7%, $p = 0.036$), despite comparable recovery (36% vs. 27%) and mortality rates (22% vs. 24%). This indicates that even in the absence of specialist oversight, alerts heightened clinical vigilance and triggered earlier preventive measures such as fluid review or nephrotoxin discontinuation. Such findings parallel the reports of Wilson et al. (2015) and Wu et al. (2018), who observed that alert systems enhance process-of-care metrics and delay progression to severe AKI even when specialist engagement is limited.

Synergistic Benefit of Early Specialist Involvement

When nephrology consultation was integrated, the magnitude of improvement increased substantially. Compared with controls, the intervention group showed higher recovery (28% vs. 8%, $p < 0.001$), lower dialysis initiation (17% vs. 35%, $p = 0.007$), and a shorter AKI duration (median 4.5 vs. 7 days, $p < 0.001$). Mortality was lower in the intervention cohort (27% vs. 17%), though not statistically significant ($p = 0.094$), likely reflecting multifactorial

determinants of death in critically ill populations. These results are consistent with international studies, which show that nephrology involvement within 24–48 hours of AKI recognition reduce dialysis dependence and improves renal recovery (Silver et al., 2023; Wilson et al., 2023; Park et al., 2018).

This synergy between early e-alert detection and specialist input supports a “human-in-the-loop” decision model, in which digital alerts serve as catalysts for timely expert assessment rather than replacements for clinical judgment. In resource-constrained systems such as Palestine’s, where nephrologists are scarce and caseloads are high, this model optimizes limited expertise by ensuring that consultation is both targeted and timely. Similar frameworks linking AI-assisted alerts to expert review have demonstrated reduced AKI duration and improved provider response times in tertiary settings (Tran et al., 2024).

From a system-design perspective, the findings highlight the value of embedding context-aware digital pathways that guide non-specialists toward evidence-based actions while escalating complex cases to nephrology teams. This approach mirrors hybrid clinical models adopted in the (Wilson et al., 2021), where the combination of e-alerts and structured nephrology consultation produced superior renal outcomes compared with automated alerts alone.

In low- and middle-income settings, where nephrology workforce shortages are common, the demonstrated synergy between alerts and consultations has strong policy implications. It supports the development of AKI response systems; wherein digital alerts provide broad surveillance coverage and structured escalation ensures that nephrology input is reserved for high-risk cases. This not only maximizes specialist efficiency but also democratizes access to nephrology-informed care across general wards. By linking automation to expert intervention, the hybrid model delivers both technological scalability and clinical precision, a balance critical for sustainable AKI care in Palestine and comparable LMICs.

5.6.2 Triangulation with Qualitative Insights

The quantitative evidence presented here converges strongly with the qualitative perspectives of Palestinian nephrologists reported in (Jawabreh et al., 2025). Clinicians repeatedly emphasized that delayed consultation and fragmented communication between general wards and specialists were key contributors to late AKI recognition and preventable deterioration. They described the e-alert and triage framework as a potential “equalizer,” enabling earlier identification of at-risk patients and prompting timely escalation to nephrology teams—precisely the mechanism demonstrated by the statistical findings in this study. Moreover, nephrologists noted that workforce scarcity and heavy caseloads often precluded bedside review of every AKI case, reinforcing the necessity of a tiered response model in which digital alerts guide general practitioners and reserve specialist input for high-risk scenarios.

Together, these strands of evidence validate the hybrid model as both clinically effective and contextually feasible within Palestine’s constrained health-system infrastructure. The triangulated findings illustrate how technology-assisted triage operationalizes nephrologists’ preventive vision, transforming early recognition into actionable care processes that reduce dialysis initiation, accelerate renal recovery, and strengthen system responsiveness. This alignment between empirical data and practitioner insight underscores the translational

integrity of the model, bridging digital innovation, human expertise, and real-world health-system reform.

The ability of the e-alert system to trigger targeted consultations rather than generalized alerts appears to enhance responsiveness, reduce unnecessary interventions, and shorten AKI duration, mirroring outcomes seen in recent AI-assisted AKI detection models that improved response and reduced duration (Tran et al., 2024).

These findings emphasize the complementary role of clinical decision support and specialist involvement. Prior studies from high-income settings, such as Selby et al. (2019) and Wilson et al. (2021), similarly reported improved outcomes when alerts were paired with structured nephrology engagement. In resource-limited contexts, this dual model could optimize both early recognition and treatment precision, balancing technological scalability with clinical expertise.

5.7 Factors Influencing AKI Recovery in the Context of E-Alert

The evolving concept of Acute Kidney Disease (AKD) as an intermediary phase between AKI and CKD has underscored the clinical urgency of timely recovery assessment and intervention. Our analysis revealed two significant predictors of recovery from acute kidney injury (AKI): diabetes mellitus (DM) and ARB (angiotensin receptor blocker) discontinuation. Interestingly, diabetic patients in our intervention group had a *lower hazard of recovery failure* compared to non-diabetics (HR = 0.69, 95% CI: 0.48–0.99, $P = 0.045$). This finding contrasts with prior studies that show diabetes as a strong risk factor for both the development and poor recovery of AKI. Kaur et al. (2023) and Chen et al. (2024) report that diabetes increases susceptibility to AKI due to vascular damage and impairs repair mechanisms, thus delaying recovery. The unexpected result in our cohort may be explained by structured care protocols such as early nephrology consultation and tighter control of medications possibly resulting in better outcomes for diabetic patients. This aligns with observations by Vakhshoori et al. (2025), who noted that clinical interventions and early detection significantly improve renal outcomes.

More consistently with existing literature, we found that ARB discontinuation was associated with a *higher hazard of AKI recovery failure* (HR = 2.12, 95% CI: 1.07–4.22, $P = 0.031$). This supports a growing body of evidence suggesting that continuation or timely resumption of RAS blockers (ACEi/ARB) post-AKI improves long-term outcomes. A systematic review by (J. Y. Chen et al., 2021) found that ACEi/ARB use post-AKI reduced mortality and the risk of recurrent AKI and CKD progression, despite a higher risk of hyperkalemia. Likewise, Tomson & Tomlinson (2019) emphasized that the automatic discontinuation of these agents, especially in patients with comorbidities like heart failure or proteinuria, may cause more harm than good. Physiologically, RAS blockers help by reducing intraglomerular pressure and fibrosis, promoting better recovery. Therefore, our findings reinforce the need for careful, individualized decisions regarding medication changes during AKI episodes, rather than blanket discontinuation of ARBs.

Nonetheless, digital interventions like automated e-alerts—while improving timely medication review may not independently influence clinical outcomes unless embedded within a comprehensive care strategy. The randomized trial by Wilson et al. (2023) found no significant improvement in hard outcomes despite higher medication discontinuation rates in the alert group, suggesting that alerts alone are insufficient to drive recovery. Our cohort study supports this notion, as despite improved detection and medication adjustments via alert systems, key recovery determinants such as comorbid diabetes and pharmacologic modulation appeared to have a more substantial impact. Therefore, integrating e-alerts with real-time clinical decision support, timely nephrology consultation, and patient-specific risk profiles, particularly in diabetics, may be crucial to translating alerts into action.

Taken together, these insights call for a paradigm shift toward individualized, biomarker-informed, and diagnosis-specific post-AKI care. For high-risk populations like diabetic patients, the balance between renal protection and therapeutic risk must be carefully navigated, emphasizing early follow-up, continued RAS inhibition where appropriate, and intelligent alert systems that facilitate, not merely notify, clinical action.

5.8 Predictors of Mortality Among AKI Patients

The multivariable logistic regression analysis revealed that circulatory shock and sepsis were the strongest independent predictors of mortality among patients with AKI. Patients presenting with circulatory shock had over thirteenfold higher odds of death (adjusted OR = 13.26, 95% CI: 5.05–34.8, $p < 0.001$), whereas those with sepsis had threefold higher odds (adjusted OR = 3.06, 95% CI: 1.15–8.1, $p = 0.025$). These findings are consistent with global evidence indicating that hemodynamic instability and infection-driven multi-organ dysfunction are leading causes of AKI-related mortality.

The present findings, which identify circulatory shock and sepsis as the strongest independent predictors of mortality among AKI patients, are strongly supported by recent literature. The 28th Acute Disease Quality Initiative (ADQI) consensus report emphasized that sepsis-associated acute kidney injury (SA-AKI) is not only the most frequent AKI phenotype in critical care but also one of the most lethal, owing to its complex interplay of dysregulated inflammation, endothelial dysfunction, and microcirculatory derangements. These mechanisms contribute to renal ischemia and poor recovery, frequently culminating in renal replacement therapy and death (Zarbock et al., 2023). This is corroborated by a comprehensive systematic review and meta-analysis that found sepsis and septic shock to be among the most consistent and strongest predictors of AKI-related mortality. The study reported a pooled mortality rate of 43.7% in patients with SA-AKI and identified septic shock as an especially high-risk context for AKI onset and poor outcomes (Liu et al., 2020). Moreover, in cases of cardiogenic shock, early AKI significantly increased 30-day all-cause mortality. A prospective registry study demonstrated that patients with early AKI during cardiogenic shock had nearly double the mortality risk, particularly when renal replacement therapy was required, underscoring the prognostic weight of circulatory collapse in AKI trajectories (Schupp et al., 2024). Together, these sources confirm that systemic hypoperfusion (shock) and inflammatory injury (sepsis) are central mechanisms linking critical illness to renal injury and mortality.

The significant association between recurrent AKI episodes and mortality further supports the hypothesis that repetitive renal insults amplify cumulative injury and reduce renal resilience. Patients with three or more AKI attacks in the preceding three months had nearly tenfold higher odds of mortality (adjusted OR = 9.85, 95% CI: 1.94–50.11, $p = 0.006$).

Recurrent acute kidney injury (AKI) has emerged as a critical determinant of poor prognosis, with mounting evidence linking it to increased mortality and chronic disease progression. Rodríguez et al. (2018) conducted a four-year retrospective study of 359 AKI survivors and found that 34% experienced recurrent AKI, which was independently associated with significantly higher risks of developing chronic kidney disease (HR: 2.2, 95% CI: 1.09–4.3, $p = 0.003$) and mortality (HR: 4.5, 95% CI: 2.7–7.5, $p < 0.001$), especially in those with diabetes, ischemic heart disease, or elevated creatinine during the first AKI episode (Rodríguez et al., 2018). Complementing this, Sako et al. (2019) showed that early recurrence of AKI within 21 days of the first event was associated with a significantly higher all-cause mortality rate (33.8 vs 6.2 deaths per 100 person-years) compared to late or non-recurrent AKI, highlighting the importance of vigilant post-AKI monitoring during the high-risk window (Sako et al., 2019). Similarly, in a cohort of ICU patients with severe sepsis, patients with recurrent AKI episodes had markedly worse outcomes, including increased 30-day and 1-year mortality, emphasizing that repeated renal insults in the critical care setting lead to cumulative renal damage and systemic vulnerability (Rodrigo et al., 2017). These findings collectively reinforce the hypothesis that recurrent AKI is not merely a marker but a driver of long-term adverse outcomes and justify implementing structured follow-up and prevention strategies.

Interestingly, while dehydration and elevated serum creatinine were associated with higher mortality in univariate analysis, these associations lost significance after adjustment, suggesting that the acute hemodynamic state and infection severity outweighed baseline renal parameters in determining survival. Similarly, AKI stage 3 was significant in the univariate model but attenuated in multivariate analysis, likely due to confounding by the high prevalence of sepsis and shock among those patients.

Overall, the results emphasize that systemic factors rather than renal biomarkers alone drive mortality in AKI, underscoring the importance of integrating hemodynamic stabilization, infection control, and multi-disciplinary care into AKI management protocols. When contextualized with earlier findings on biomarker performance (Tables 5 and 6), it becomes evident that NGAL and serum creatinine serve best as diagnostic and staging tools, whereas clinical parameters such as shock and recurrent AKI are more predictive of patient survival. Integrating both biological and clinical indicators within an electronic AKI alert framework may provide a more comprehensive approach to risk stratification and targeted intervention.

5.9 AKI Detection and Management: Quantitative Summary

The quantitative findings of this study collectively demonstrate that the integrated AKI detection and management model yielded substantial process and clinical improvements across multiple domains of care. Implementation of the e-alert system significantly enhanced AKI recognition, documentation, and provider response, translating into earlier-stage detection, increased recovery rates, reduced dialysis initiation, and shortened AKI duration,

all without adding undue alert fatigue. The inclusion of NGAL testing alongside serum and urinary protein-creatinine ratio improved diagnostic discrimination, particularly for subclinical and Stage 3 AKI, confirming the added value of multimarker strategies in low-resource environments. Furthermore, stratified analysis revealed that outcomes were most favorable when alerts were paired with timely nephrology consultation, underscoring the synergistic effect of human expertise and digital support. Despite these measurable gains, mortality remained largely unchanged, reflecting the multifactorial nature of death in acutely ill patients and emphasizing the influence of systemic constraints beyond the renal domain. Overall, the quantitative data validate the feasibility and clinical relevance of an adaptive, triage-driven, biomarker-informed AKI surveillance model that can deliver meaningful kidney-specific benefits within the realities of a constrained healthcare system.

Nephrologists' Perspectives on Implementing AKI Care Models

This novel qualitative research provides a deeply contextualized epistemological lens, offering perspectives that quantitative metrics often fail to capture. Through the opinions of Palestinian nephrologists working within a resource-limited healthcare landscape, this study explores the complex interplay between systemic defects, technical barriers, and the potential for transformative nephrology care reforms in Palestine.

By exploring facilitators, barriers, and strategic recommendations, this qualitative analytical research goes beyond identifying challenges; it maps pathways for health reform, providing a locally grounded yet globally informed perspective on improving AKI management. The findings are consistent with international guidelines, such as KDIGO (Kidney Disease: Improving Global Outcomes). Rather than imposing a global standard, this research contextualizes these recommendations within the constraints, realities, and opportunities unique to the Palestinian healthcare system.

Nephrologists consistently asserted the MoH central role in leading systemic efforts to improve nephrology services. As the principal provider of nephrology care under the national health insurance framework, the MoH ensures free coverage for patients diagnosed with End-Stage Kidney Disease (ESKD). While this reflects commendable political will, participants highlight powerfully that embedding preventive strategies aimed at reducing the prevalence of CKD and AKI could significantly enhance the sustainability of health services and cost-effectiveness. The participants also recognize gaps in governance and policy implementation, noting that fragmented policies and the deprioritization of nephrology services undermine systemic efficiency. These observations align with previous research (Thomas et al., 2020; John Sperati et al., 2019), which confirms the need for cohesive national nephrology strategies to ensure long-term service stability.

From the nephrologists' perspective, addressing these governance barriers requires a concerted effort by the MoH to institutionalize nephrology services within the broader public health framework. Strengthening governance structures through policy coherence, regulatory enforcement, and strategic resource allocation was seen as fundamental in fostering a more sustainable, prevention-driven nephrology model. Participants advocated for embedding standardized nephrology protocols within primary care, ensuring that early detection, risk

assessment, and early referrals become vital components of the healthcare system rather than reactive responses.

A severe shortage of nephrology specialists in the West Bank and Gaza Strip presents a critical barrier to AKI and CKD management, significantly limiting timely intervention efforts. Alarming, only 13 board-certified nephrologists are responsible for overseeing nephrology care across the 16 cities in the West Bank, a figure grossly insufficient to meet the escalating burden of ESKD. This shortage is exacerbated by the reality that several hospitals operate hemodialysis units without a nephrologist, leaving general practitioners to manage complex renal cases without specialist oversight. The MoH Annual Health Report (2023) underscores the need for workforce expansion and strategic intervention, as dialysis patient numbers have doubled from 1,014 in 2015 to 2,300 patients in 2025. Establishing nephrology residency programs, incentivizing specialization, and integrating structured nephrology training into general medical education were identified as critical facilitators to bridge the gap in nephrology expertise.

From a public health and policy view, addressing these workforce challenges demands systemic reforms that extend beyond hospital settings into primary healthcare facilities. These findings align with those Tam-Tham et al. (2016), who similarly reported workforce shortages and collaboration gaps in CKD management within primary care. The NRRT model presents a viable mechanism for enhancing early multidisciplinary collaboration, ensuring that nephrologists are strategically allocated to high-risk cases while primary care physicians receive the necessary training to manage early-stage kidney disease. By prioritizing preventive nephrology services, strengthening early detection policies, and implementing structured workforce policies, the Palestinian healthcare system can antidote the painful maximization in dialysis dependency while improving overall renal health outcomes.

Participants highlighted that inadequate MoH budgets and high out-of-pocket patient costs limit investments in critical infrastructure, workforce development, and diagnostic technologies. These financial barriers frequently slow down patients' access to essential care, perpetuating inequities. Consistent with findings by Abdel-Kader et al. (2014), tackling these financial barriers through strategic resource reallocation and health reforms is essential to ensuring sustainability and equity in nephrology care.

Beyond cost containment, which counts \$ 50 million annually, a strong recommendation emerged for enhancing financial investments in preventive nephrology services (Palestinian Ministry of Health, 2023). Addressing modifiable ESKD risk factors, such as diabetes and hypertension, through early screening, structured patient follow-up, and nephrology integration into primary care, could stop disease progression and reduce long-term dialysis demand. This prevention-based approach, such as the NRRT, is critical in ensuring a more cost-effective, sustainable, and equitable nephrology care.

The Palestinian health system remains heavily skewed towards curative care, consuming 75.5% of the total health budget, while preventive services receive a mere 1.5%. This disproportionate focus not only rising healthcare costs but also limits the sustainability of essential operational services. By reallocating resources and prioritizing preventive care initiatives, the Palestinian MoH can align its nephrology practices with global benchmarks,

reinforcing its leadership in proactive healthcare delivery (Palestinian Central Bureau of Statistics & Ministry of Health, 2024).

The investment in enhancing awareness among both healthcare providers and patients, alongside developing a countable responsiveness primary healthcare system, emerged as a milestone for addressing kidney health challenges. Participants highlighted significant deficits in knowledge and understanding of AKI and CKD. Many primary care providers lacked adequate training, leading to delays in diagnosis and treatment. Moreover, misconceptions about kidney health, such as reliance on hydration as a preventive measure, were common among patients, compounding these challenges. These findings align with Nash et al. (2018) and Williams et al. (2024), who emphasized the importance of educational programs to improve awareness and adherence to guidelines.

Further insights from Carpenter-Song et al. (2024) offer a nuanced perspective on implementing AKI prevention strategies within interdisciplinary frameworks. They identified several systemic barriers to successful implementation, such as workflow disruptions, staff turnover, and limited leadership buy-in.

The NRRT model, if effectively implemented, presents a viable pathway for transforming AKI management, ensuring timely nephrology consultations, structured patient monitoring, and improved care coordination. However, its success depends on strong policy frameworks, financial restructuring, and the integration of multidisciplinary collaboration within the broader healthcare system.

By redirecting financial resources toward preventive nephrology services and enhancing primary care engagement, the Palestinian healthcare system can achieve greater sustainability, improved patient outcomes, and a more equitable distribution of nephrology resources. The findings of this study call for a strategic realignment of health policies that balances immediate patient needs with long-term nephrology care sustainability, ultimately fostering a resilient and prevention-driven healthcare model.

Transferability and Relevance to Global Contexts

The findings of this study, while contextually grounded in Palestine, resonate with global nephrology care priorities, particularly in LMICs facing similar systemic challenges. As documented in the ISN–Global Kidney Health Atlas (ISN–GKHA, 2023), global inequities in nephrology care persist, with severe shortages in nephrology specialists, limited funding, and inconsistent access to high-quality kidney replacement therapy (KRT). The Atlas emphasizes context-sensitive, preventive models—such as telemedicine, task-shifting, and team-based care—as essential for equitable nephrology advancement (Bello et al., 2023).

Kalyesubula et al. (2024) similarly advocate for the integration of kidney care into broader health systems, emphasizing political will and scalable interventions. Mehta et al. (2015), in the ISN’s Oby25 Initiative, reinforce this by proposing health system integration, enhanced tracking, and point-of-care diagnostics to reduce preventable AKI deaths. The feasibility of such models is exemplified by Evans et al. (2025), whose multicountry evaluation proved that low-cost AKI management using symptom-based risk scores and on-site diagnostics significantly improved early detection and outcomes.

Furthermore, Ravyn et al. (2022) highlight facilitators such as institutional support and clinician education that directly strengthen NRRT viability, while Luyckx et al. (2024) call

for system-level reforms to close persistent knowledge-to-practice gaps. Together, these findings confirm the global relevance of locally generated strategies like NRRT, particularly for LMICs lacking robust infrastructure or universal coverage.

Collectively, these international perspectives enhance the contextual relevance and potential transferability of this study's findings to other low-resource settings. Rather than endorsing a one-size-fits-all solution, they underscore the growing momentum in LMICs toward preventive nephrology strategies that emphasize early AKI detection and system integration. As reflected in participant narratives, timely intervention was viewed not simply as a clinical preference but as a practical and resource-sensitive response in environments where long-term dialysis remains financially and logistically constrained.

This qualitative strand delves into the perspectives of nephrologists on the feasibility and implementation of the NRRT model in Palestinian governmental hospitals. Insights gathered align with the WHO Social Determinants of Health framework, emphasizing how structural determinants such as governance and resource allocation impact healthcare delivery. By incorporating the perspectives of practicing nephrologists, this research sheds light on systemic, operational, and resource-related challenges that hinder the optimization of health care services. The findings underscore the central role of the MoH in spearheading systemic reforms, with a focus on policy coherence, resource allocation, and fostering a preventive care paradigm. Proactive measures such as nephrologist-led interventions, primary care integration, and technology adoption emerged as key enablers for enhancing nephrology care, aligning with global guidelines like KDIGO.

Integrated Interpretation of Quantitative and Qualitative Findings

This triangulated interpretation is the crowning of a multi-phase research agenda designed to address critical gaps in the nephrology implementation literature. Previous global studies on AKI e-alert systems, predominantly carried out in high-income countries (HICs), have yielded mixed results, with limited impact on primary outcomes such as dialysis initiation or mortality. These trials often lacked contextual adaptation and were quantitative only, overlooking the structural and behavioral conditions that form provider response. As documented in a systematic review and meta-analysis by Jawabreh (2025), the dominant outcomes in e-alert research have focused on technological deployment, without addressing the organizational dynamics necessary for clinical effectiveness.

This exploratory sequential mixed-methods design advances the science by integrating not only quantitative outcome data, but also the lived perspectives of nephrologists practicing in a complicated, low-resource setting. In doing so, it provides the first triangulated evaluation of an AKI e-alert model that is both contextually grounded and system-aware. Quantitatively, the intervention yielded significant improvements in AKI recognition, documentation, and early management, resulting in reduced dialysis rates, higher recovery, and shorter AKI duration. However, nearly one-quarter of alert-triggered cases lacked a recorded provider response. On its own, this might suggest technological failure or clinical disengagement. Yet the qualitative findings contextualize this outcome: nephrologists attributed the response gap not to clinical indifference, but to systemic fragility, massive understaffing, absence of protocols, and weak accountability structures (Jawabreh et al., 2025).

This interpretation reshapes the “response gap” as a reflection of institutional capacity, not alert design. It also confirms predictions made in the pre-implementation qualitative study, where nephrologists anticipated that workforce shortages and lack of policy integration would limit the operational impact of even well-designed digital systems (Jawabreh et al., 2025). Similarly, the intervention’s quantitative data show that early nephrology consultation remarkably enhanced outcomes: patients who received early consultation experienced higher recovery (28% vs. 8%) and lower dialysis initiation (17% vs. 35%). These findings are reinforced by qualitative insights describing delayed referrals, fragmented care pathways, and the absence of a formal referral hierarchy, all exacerbated by the fact that only thirteen nephrologists currently serve across the West Bank.

The biomarker component, especially NGAL, also demonstrated quantifiable gains in early-stage risk stratification and dialysis avoidance. Yet nephrologists viewed biomarkers not as standalone diagnostics, but as part of a broader “triage–education–alert” continuum. NGAL was seen as a clinical booster helping front-line physicians recognize renal vulnerability earlier and adjust nephrotoxin use accordingly. The “activation effect” observed quantitatively thus reflects the enabling role of NGAL in raising situational awareness among non-specialists, as supported by nephrologists.

In summary, this triangulated synthesis moves the field beyond purely technical assessment (Jawabreh, 2025; Jawabreh et al., 2025) of AKI e-alert systems. It illustrates that while digital and biomarker innovation can improve process-level outcomes, sustainable impact depends on institutional readiness, professional training, and governance infrastructure. Within the literature, this study fills a critical implementation gap by offering the first empirically grounded, context-sensitive AKI detection model adapted to an LMIC setting. It emphasizes the central conclusion of (Jawabreh, 2025; Jawabreh et al., 2025): that meaningful transformation in renal care cannot rely on alerts alone, but must be embedded within prevention-driven, multidisciplinary, and policy-supported frameworks. This insight now forms the conceptual bridge to the final chapter, which moves from interpretation to prescription, outlining the reforms required to scale this model nationally.

Chapter Six

Conclusions and Recommendations

Building upon the integrated evidence from both quantitative and qualitative strands, this section translates the study's insights into actionable, policy-relevant recommendations. The findings revealed that while the hybrid model improved early AKI recognition, recovery, and care processes, its long-term sustainability is limited by structural weaknesses in governance, workforce shortages, and fragmented infrastructure. Accordingly, this section transitions from what worked to what is needed: constructing the institutional, educational, and technological frameworks required to sustain and scale these gains within a resilient, prevention-oriented kidney care system.

A central insight from the qualitative study is that nephrologists do not view technology or diagnostics as sufficient in isolation. Instead, they stressed that system-level preparedness, early detection in high-risk populations, and continuity between AKI and CKD care are essential for meaningful reform. Several participants highlighted the contradiction in Palestine's current health financing structure: although ESKD services are provided free of charge, this financial commitment leaves little room for investment in early-stage CKD prevention and AKI, particularly in diabetics, hypertensives, and socioeconomically vulnerable groups. As one nephrologist noted, *"Dialysis is free, but we are paying for it with our prevention."* This paradox underscores the need to reallocate resources upstream, toward risk reduction and early intervention.

The following recommendations are structured across five interrelated pillars, each informed by nephrologists' perspectives and aligned with international nephrology frameworks such as KDIGO, the ISN 0by25 initiative, and the WHO Global Kidney Health strategy.

1. Systemic and Policy Recommendations

The sustainability and scalability of the integrated AKI management model require structural reform at the governance level. Triangulated evidence from this study revealed that fragmented policymaking, limited nephrology representation in decision-making, and weak coordination across hospitals hinder consistent delivery of AKI and CKD services. Addressing these constraints is reflected in the following recommendations:

- Exploring the establishment of a national AKI–CKD–ESKD registry system by the (MoH) to enable real-time monitoring of kidney disease progression and outcomes.
- Integrate nephrology into national NCD Policy, ensuring CKD is managed alongside diabetes and hypertension in primary and secondary care.

- Develop a national AKI response framework, guided by the ISN 0by25 model and tailored to Palestine's system capacities.
- Secure dedicated financing for preventive nephrology, reallocating a portion of dialysis expenditure toward upstream CKD care, risk screening, and outpatient follow-up services.
- Institutionalize multidisciplinary care teams, with nephrologists, nurses, pharmacists, and laboratory staff collaborating on standardized care bundles and quality audits.

2. Capacity Building and Workforce Development

Nephrologists described a critical shortage of trained professionals as a major barrier to early detection and continuity of care. Many highlighted that dialysis units lack nephrology oversight, and primary care lacks the tools or training to identify early-stage CKD. These gaps require coordinated workforce actions, outlined below:

- The Ministry of Health should consider launching a national nephrology workforce strategy to forecast demand and deploy specialists based on epidemiological burden.
- Introduce residency and fellowship programs in nephrology in partnership with academic institutions.
- Implement Task-Shifting models, training general physicians and nurses to screen, refer, and manage early AKI and CKD cases using protocols.
- Expand continuous medical education and digital literacy, particularly in biomarkers such as NGAL interpretation, AKI/CKD staging, and e-alert response.
- Introduce incentive mechanisms, including salary improvements, academic promotions, and dual practice policies, to retain specialists.

3. Prioritizing CKD and High-Risk Groups within a Free-ESKD Care Model

A novel contribution of this study is the emphasis placed by nephrologists on redirecting attention toward upstream prevention, especially given the country's financial commitment to free dialysis. Despite this, CKD remains underdiagnosed, and diabetics, hypertensives, and cardiovascular patients often present late. The following policy actions are recommended:

- The Ministry of Health should consider establishing CKD clinics within public hospitals, operating alongside dialysis and transplant units.
- Mandate Routine CKD screening in primary care, especially for diabetics and hypertensives, with creatinine/eGFR and urine protein tests.
- Develop a CKD risk Stratification tool, adapted for PHC use, with referral thresholds based on local epidemiology.
- Integrate CKD Pathways into family medicine and NCD clinics, embedding nephrology protocols into chronic care workflows.
- Use the Free-ESKD model as leverage, demonstrating the cost-efficiency of prevention to justify upstream investment and donor engagement.

4. Technological Innovation and Digital Infrastructure

The intervention showed that simple technologies such as SMS alerts and biomarker integration can yield substantial clinical benefits. Nephrologists stressed that sophistication is not required; contextual fit is. Accordingly, the following recommendations are proposed:

- The Ministry of Health should consider deploying an “EHR-Light” infrastructure, linking laboratory systems, alerts, and clinical notes or e-health and telecommunication system.
- Embed NGAL and creatinine results into clinical pathways, with automated decision cues to support non-specialists.
- Establish a national AKI–CKD alert network, leveraging SMS/WhatsApp channels to notify providers in real-time.
- Expand the AKI PhD platform nationally, integrating it into training, reporting, and surveillance.
- Develop digital governance frameworks, ensuring patient privacy, data security, and interoperability.

5. Translating Evidence into Sustainable Clinical Pathways

The Nephrology Rapid Response and Triage (NRRT) model tested in this study is an implementable tool. The following strategic recommendations are proposed:

- Formalize the NRRT as national policy, with MoH-approved guidelines and AKI response teams in every hospital.
- Bridge AKI and CKD Care, by integrating outpatient nephrology follow-up and automatic flags for high-risk discharges.
- Use mixed-methods findings to develop implementation tools, such as SOPs, process maps, and training modules.
- Align with global and regional kidney health initiatives, facilitating cross-border collaboration and resource mobilization.
- Implement a phased national rollout, starting with institutionalization, followed by digital integration, workforce development, and national scale-up.

Conclusions

This mixed-methods investigation examined whether a locally designed, resource-sensitive AKI management model could strengthen early detection and improve outcomes within Palestinian governmental hospitals. The quantitative findings showed clear clinical gains, including reduced dialysis initiation, improved recovery rates, and shorter AKI duration. Qualitative insights complemented these results by highlighting the contextual conditions required for effective implementation, particularly the importance of governance support, coordinated care pathways, and adequate workforce capacity. Together, the strands converge on a central conclusion: meaningful improvement in AKI care is achievable in constrained settings when clinical innovation is coupled with system readiness. These findings underscore the potential for scalable, prevention-oriented kidney care models that align with national priorities and global nephrology frameworks.

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Appendix (1) : Patient Consent Form for Participation in a Research Study



كلية الصحة العامة – برنامج الدكتوراة في الصحة العامة نموذج موافقة للمشاركة في دراسة بحثية

عزيزي / عزيزتي المريض/ة في مستشفى بيت جالا الحكومي،

أنتم مدعوون للمشاركة الطوعية في بحث بعنوان:

((تقييم نظام تصنيف درجة الخطورة للمرضى والفحوصات المخبرية التنبؤية مع التنبيه الإلكتروني على كيفية معالجة الإصابات بالفشل الكلوي الحاد داخل المستشفيات الحكومية في جنوب فلسطين.))

الباحث: بلال عبد الرحمن جوايرة.

الجامعة: جامعة القدس / كلية الصحة العامة – برنامج الدكتوراة في الصحة العامة.

مقدمة: مرض الفشل الكلوي الحاد يعتبر البداية لمرض الفشل الكلوي المزمن إذا لم يتم كشفه مبكراً وعلاجه في الوقت المناسب. أنتم مدعوون للمشاركة في هذه الدراسة حول تحسين آلية الكشف المبكر والتشخيص المستعجل للمرضى المصابون بالفشل الكلوي الحاد ومنع تقدم المرض. قبل أن تقرر المشاركة، من المهم أن تفهم سبب إجراء البحث وما سيتضمنه. الرجاء قضاء بعض الوقت لقراءة المعلومات التالية بعناية.

غرض الدراسة: تهدف هذه الدراسة إلى معرفة تأثير نظام تصنيف درجة الخطورة للمرضى والفحوصات المخبرية التنبؤية مع التنبيه الإلكتروني على كيفية معالجة الإصابات بالفشل الكلوي الحاد داخل المستشفيات الحكومية في جنوب فلسطين.

الموافقة في المشاركة: إذا وافقت على المشاركة في هذا البحث، سيطلب منك تقديم بعض المعلومات الشخصية الصحية وإجراء فحوصات مخبرية عن طريق إعطاء عينة دم أو عينة بول بهدف إعطاء تقييم مبكر لوظيفة الكلى. وتشمل هذه الدراسة أيضاً مراقبة حالتك الصحية وأي علاجات تتلقاها أثناء إقامتك في المستشفى.

المخاطر والفوائد: لا يوجد مخاطر محتملة لهذه الدراسة على صحتك. الفوائد المحتملة تشمل تحسين معالجة ومتابعة الإصابات بالفشل الكلوي الحاد وبالتالي المساهمة في تحقيق نتائج صحية ذات جودة عالية. التكلفة المالية للفحوصات المخبرية ستكون على حساب الباحث.

السرية: مشاركتك في هذه الدراسة سرية. سيتم استخدام المعلومات التي تم جمعها لأغراض البحث فقط ولن يتم الكشف عنها لأي شخص غير مرتبط بالدراسة.

المشاركة الطوعية: مشاركتك في هذه الدراسة طوعية بالكامل. لديك الحق في الانسحاب في أي وقت دون أي عواقب.

الموافقة: بالتوقيع على هذا النموذج، فإنك توافق على المشاركة في الدراسة.

مزيد من المعرفة والاستفسار حول هذه الدراسة يرجى التواصل مع أ.د معتصم حمدان، أستاذ السياسات الصحية في جامعة القدس mhamdan@staff.alquds.edu علماً بأننا سنقوم بتزويدكم بنسخة من هذه الدراسة عند نشرها في المجالات العلمية المحكمة.

لقد قرأت وفهمت المعلومات المقدمة أعلاه. لقد أتيحت لي الفرصة لطرح الأسئلة، وقد تم الإجابة على جميع أسئلي بما يرضيني. أوافق على المشاركة في هذه الدراسة البحثية.

توقيع المشارك: ----- التاريخ: -----.

الباحث: بلال عبد الرحمن نمر جوابرة، طالب دكتوراة في كلية الصحة العامة / جامعة القدس.

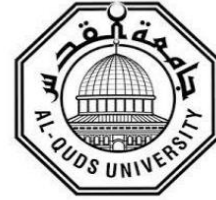
رقم النقال: 0599277850 أو 0566277850

بريد الكتروني: bilaljawabreh@gmail.com

Appendix (2) : Physicians' consent form for participation in a research study

Deanship of Graduate Studies

Al-Quds University



**"Enhancing Acute Kidney Injury Management in Southern Palestinian Governmental Hospitals:
Impact of Risk Triage, Novel Biomarkers, and Electronic Health Alerts"**

An Interventional Study

Thesis Authored by

Bilal Jawabreh

Academic Supervision Provided by

Prof. Motasem Hamdan

Jerusalem-Palestine

Tue Jan. 31 – Rajab 20

2024/1445



كلية الصحة العامة – برنامج الدكتوراة في الصحة العامة
نموذج موافقة للمشاركة في دراسة بحثية

حضرة الطبيب المحترم في مستشفى بيت جالا الحكومي،

أنتم مدعوون للمشاركة الطوعية في بحث بعنوان:

((تقييم تأثير دمج بروتوكولات تصنيف درجة المخاطر، الفحوصات المخبرية التنبؤية، والمنبه الإلكترونية على آلية تحسين معالجة الإصابة بالفشل الكلوي الحاد داخل المستشفيات الحكومية في جنوب فلسطين.))

"Enhancing Acute Kidney Injury Management in Southern Palestinian Governmental Hospitals: Impact of Risk Triage, Novel Biomarkers, and Electronic Health Alerts". (An Interventional Study)

الباحث: بلال عبد الرحمن جوابرة.

الجامعة: جامعة القدس / كلية الصحة العامة – برنامج الدكتوراة في الصحة العامة.

مقدمة: مرض الفشل الكلوي الحاد (Acute Kidney Injury) يعتبر البداية ل الفشل الكلوي المزمن (ESRD) إذا لم يتم كشفه مبكراً وعلاجه في الوقت المناسب. أنتم مدعوون للمشاركة في هذه الدراسة حول تحسين آلية الكشف المبكر والتشخيص المستعجل للمرضى المصابون بالفشل الكلوي الحاد. قبل أن تقرر المشاركة، من المهم أن تفهم سبب إجراء البحث وما سيتضمنه. الرجاء قضاء بعض الوقت لقراءة المعلومات التالية بعناية.

غرض الدراسة: تهدف هذه الدراسة إلى تقييم تأثير دمج بروتوكولات تصنيف المخاطر، والمؤشرات الحيوية الجديدة، والتنبيهات الصحية الإلكترونية على إدارة الإصابة الحادة بالكلية داخل المستشفيات الحكومية الجنوبية الفلسطينية.

Objectives: This study aims to systematically assess the impact of integrating risk triage protocols, novel biomarkers, and electronic health alerts on AKI management within Southern Palestinian Governmental Hospitals. The study will focus on enhancing early detection, accurate categorization, and timely intervention for AKI cases.

الموافقة في المشاركة: إذا وافقت على المشاركة في هذا البحث، ستتضمن مشاركتك في الرد على التنبيهات الإلكترونية على جهازك المحمول ومتابعة الباحث للخطة الطبية بعد وصول المنبه الإلكتروني والتعاون مع الباحث في طلب عمل فحوصات تقييمية تنبؤية (Novel Biomarkers laboratory Test).

المخاطر والفوائد: المخاطر ضئيلة وتتعلق في المقام الأول بمخاوف تتعلق سرية البيانات، والتي سيتم حمايتها بشكل متقن. تشمل الفوائد المساهمة في تحسين معالجة ومتابعة الإصابة بالفشل الكلوي الحادة وبالتالي تحقيق نتائج صحية ذات جودة عالية. التكلفة المالية للفحوصات المخبرية ستكون على حساب الباحث.

السرية: مشاركتك في هذه الدراسة سرية. موضوع الاستجابة للمنبه ليس إلزامي وهو أمر خاص بالطبيب المشرف على علاج المريض وهوية الأطباء وكيفية الاستجابة للمنبه الإلكتروني من عدمها ستكون قيد السرية التامة. المعلومات التي تخص المرضى وتم جمعها ستكون أيضاً لأغراض البحث فقط ولن يتم الكشف عنها لأي شخص غير مرتبط بالدراسة.

المشاركة الطوعية: مشاركتك في هذه الدراسة طوعية بالكامل. لديك الحق في الانسحاب في أي وقت دون أي عواقب.

الموافقة: بالتوقيع على هذا النموذج، فإنك توافق على المشاركة في الدراسة.

مزيد من المعرفة والاستفسار حول هذه الدراسة يرجى التواصل مع أ.د معتمد حمدان، أستاذ السياسات الصحية في جامعة القدس mhamdan@staff.alquds.edu علماً بأننا سنقوم بتزويدكم بنسخة من هذه الدراسة عند نشرها في المجلات العلمية المحكمة.

لقد قرأت وفهمت المعلومات المقدمة أعلاه. لقد أتيت لي الفرصة لطرح الأسئلة، وقد تم الإجابة على جميع أسئلتي بما يرضيني. أوافق على المشاركة في هذه الدراسة البحثية.

توقيع المشارك: ----- التاريخ: -----.

الباحث: بلال عبد الرحمن نمر جوابرة، طالب دكتوراة في كلية الصحة العامة / جامعة القدس.
رقم النقال: 0599277850 أو 0566277850
بريد الكتروني: balaljawabreh@gmail.com

Appendix (3): Ethical Approval

Al-Quds University
Jerusalem
School of Public Health



جامعة القدس
القدس
كلية الصحة العامة

التاريخ: 2024/2/13

الرقم: REF. 5/24

عزيري الطالب بلال جوايرة المحترم
برنامج الدكتوراة في الصحة العامة

الموضوع: موافقة لجنة أخلاقيات البحث العلمي

قامت اللجنة الفرعية لأخلاقيات البحث التابعة لكلية الصحة العامة بمراجعة مشروع الرسالة بعنوان:

“Enhancing Acute Kidney Injury Management in Southern Palestinian Governmental Hospitals: Impact of Risk Triage, Novel Biomarkers, and Electronic Health Alerts”

المقدم من (مشرف البحث/أ.د. معصم حمدان).

يعتبر مشروعك مستوفياً لمتطلبات أخلاقيات البحث في جامعة القدس.

نتمنى لكم كل التوفيق في تسيير المشروع.

ملاحظة: في حالة الحاجة الى موافقة من اللجنة المركزية في الجامعة، تستطيع التقدم باستخدام هذه

الموافقة على الرابط <https://research.alquds.edu/en/ethics/48-how-to-apply.html>

رئيسة اللجنة الفرعية لأخلاقيات البحث

كلية الصحة العامة

د. نهى الشريف

نسخة/ أعضاء لجنة البحث

نسخة/ الملف

Jerusalem Branch/Telefax 02-2799234

Gaza Branch/Telefax 08-2644220 -2644210

P.O. box 51000 Jerusalem

فرع القدس / تليفاكس 02-2799234

فرع غزة / تليفاكس 08-2644220-2644210

ص.ب. 51000 القدس

Appendix (4): REC approval letter

Al-Quds University
Jerusalem
Deanship of Scientific Research



جامعة القدس
القدس
عمادة البحث العلمي

Research Ethics Committee
Committee's Decision Letter

Date: May 31, 2025
Ref No: 562/REC/2025

Dears Prof. Motasem Hamdan, Dr. Salam khatib, Mr. Bilal Jawabreh,

Research ethics application. After reviewing your submission titled: "Implementing a Nephrology Rapid Response Model for Acute Kidney Injury: Challenges & Facilitators (Qualitative Study)", the Research Ethics Committee (REC) at Al-Quds University confirms that your application aligns with our ethics guidelines, which are based on the principles outlined in the Declaration of Helsinki.

Please note that this approval does not replace other required permissions, such as for sample shipment or data sharing. We also request a copy of your final report or publication when available.

This approval is valid for two Years. If your research extends beyond this period, a renewal request will be necessary. The approval remains valid as long as there are no changes to the research protocol.

Sincerely,

Suheir Ereqat, PhD
Associate Professor of Molecular Biology

Research Ethics Committee Chair

Cc. Prof. Hanna Abdel Nour - President
Cc. Members of the committee
Cc. file

Abu-Dies, Jerusalem P.O.Box 20002
Tel-Fax: #970-02-2791293

research@admin.alquds.edu

أبوديس، القدس ص.ب. 20002
تلفاكس : #970-02-2791293

Appendix (5): A Qualitative Study of Nephrologists' Perspectives on Implementing a Nephrology Rapid Response Model for Acute Kidney Injury

Jawabreh et al. *BMC Nephrology* (2025) 26:534
<https://doi.org/10.1186/s12882-025-04449-w>

BMC Nephrology

RESEARCH

Open Access



A qualitative study of nephrologists' perspectives on implementing a nephrology rapid response model for acute kidney injury

Bilal Jawabreh^{1*}, Salam Khatib² and Motasem Hamdan¹

Abstract

Introduction Acute kidney injury (AKI) poses major health and economic burdens, especially in low-resource settings like Palestine. This study explores nephrologists' perspectives on implementing the Nephrology Rapid Response Team (NRRT) model, highlighting key barriers, facilitators, and strategic priorities to improve AKI care.

Study Design A qualitative, exploratory study design was employed to gain in-depth nephrologists' perspectives on the feasibility of implementing the Nephrology Rapid Response Team (NRRT) model in Palestinian hospitals.

Methods Thirteen board-certified nephrologists were recruited using purposive sampling. Semi-structured interviews were conducted between January and May 2024, with data transcribed verbatim and analyzed thematically using MAXQDA Analytics Pro software. Thematic analysis identified key facilitators, barriers, and recommendations. Rigorous methodological strategies ensured the credibility, dependability, and transferability of the findings.

Results Five enablers themes emerged that could facilitate integration of the model: strategic backing from the Ministry of Health, a growing orientation toward prevention-driven healthcare policies, enhanced multidisciplinary collaboration with early nephrologist engagement, institutional endorsement through hospital-based systems, and the progressive adoption of technological innovations such as electronic alert systems and novel biomarkers. On the other hand, five dominant barrier themes emerged. These include systemic governance and policy fragmentation, financial and operational limitations, a pronounced shortage of nephrology specialists, insufficient awareness and prevention frameworks, and weak collaboration and surveillance systems—particularly the lack of a national renal registry. Despite these obstacles, nephrologists expressed optimism, offering three central recommendations to support sustainable implementation. These include systemic policy and governance reforms, investments in nephrology education and training programs, and the expansion of public awareness and prevention strategies through primary care engagement. Together, these strategies represent a foundational roadmap for overcoming structural challenges and AKI care delivery through the NRRT model.

Conclusions This study highlights the Ministry of Health's critical role in leading reforms for NRRT implementation, emphasizing prevention, technology, and capacity-building as priorities to improve nephrology care.

*Correspondence:

Bilal Jawabreh
bilaljawabreh@gmail.com

Full list of author information is available at the end of the article



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Clinical trial number Not applicable.

Keywords Acute kidney injury, Nephrology rapid response team, Nephrology qualitative research, Nephrology Public health policies, Multidisciplinary collaboration

Background

Acute kidney injury (AKI), characterized by a sudden decline in kidney function, is a significant contributor to patient morbidity and mortality in hospital settings. It is linked to prolonged hospital stays and a tenfold increase in inpatient mortality. Additionally, AKI independently elevates the risk of progressing to chronic kidney disease (CKD), end-stage kidney disease (ESKD), cardiovascular complications, and a heightened susceptibility to infections [1]. AKI affects an estimated 13.3 million people annually, with 85% of cases occurring in developing countries. Beyond direct kidney-related complications, AKI also increases the likelihood of requiring long-term hemodialysis and raises the risk of recurrent hospitalizations due to multi-organ failure. AKI is believed to contribute to approximately 1.7 million deaths each year [2].

According to the Palestinian Ministry of Health's (MOH) Annual Reports until 2025, more than 3,500 patients across the Gaza Strip and West Bank (including 2,300 in the West Bank alone) currently suffer from ESKD [3]. While not all cases of ESKD are directly secondary to AKI, the growing burden of AKI contributes significantly to disease progression, long-term dialysis dependence, and health system strain. As shown in Fig. 1, dialysis-dependent patients in the West Bank alone have increased by 108% over the past decade from 1,014 in 2015 to 2,300 in 2025. Escalated worsening epidemiological trajectory trend, unfortunately, coincides with the absence of a centralized renal registry in Palestine to capture the incidence, etiology, or outcomes of AKI. This critical surveillance gap hinders timely diagnosis, delays appropriate care, and restricts evidence-based national planning.

From a financial perspective, the economic impact of nephrology care in Palestine is profound. A study by Younis et al. [4] estimated the average cost of a kidney transplant at \$16,277 in the first year, with annual hemodialysis costs reaching \$16,085 per patient. With more than 2,300 dialysis-dependent patients in the West Bank alone, the combined annual cost of dialysis services is projected to exceed \$50 million. Such figures reflect a broader international trend highlighted by Jha et al. [5] that shows exponential increases in treatment costs as CKD advances.

These clinical and economic realities reinforce a strategic imperative: shifting nephrology care in LMICs, including Palestine, from reactive, late-stage interventions to proactive and preventive strategies. Structured screening programs, AKI risk stratification, and

multidisciplinary nephrology response teams offer a path to reducing the progression of kidney disease and alleviating both human and financial suffering. Given these challenges, there is momentous need for early detection and robust public health policies to mitigate AKI progression and improve long-term prognosis inspired from the 5-R approach proposed by the ISN (International society of Nephrology)'0 death by 2025 project: risk assessment, recognition, response, renal support and rehabilitation, the first three Rs concern the prevention area.

The Nephrology Rapid Response Team (NRRT) is a multidisciplinary model designed to enhance early detection, risk stratification, and timely intervention for AKI. As illustrated in Fig. 2, the NRRT framework outlines a structured pathway for managing AKI within the first 12–48 hours, integrating electronic alert systems, laboratory assessments, and team-based care to ensure rapid nephrology consultation. This model, adapted from Rizo-Topete et al. [6], emphasizes AKI risk assessment through clinical evaluation, history, examination findings, and laboratory data. The NRRT framework follows a structured AKI Risk Assessment (ARA) model, which evaluates clinical scenarios, patient history, physical examination findings, and laboratory results, including biomarker-based risk identification. This approach facilitates rapid intervention, minimizes the reliance on invasive treatments like dialysis, and strengthens post-AKI monitoring to prevent chronic kidney disease (CKD) progression [6]. However, before adopting this model in Palestinian hospitals, it is crucial to understand the specific barriers and facilitators nephrologists encounter in managing AKI, in addition to exploring general recommendations to enhance the quality of nephrology care.

This study aims to explore the perspectives of nephrologists on implementing the NRRT model in Palestinian hospitals. By examining the facilitators, barriers, and general recommendations for NRRT implementation, this research seeks to provide valuable insights for policymakers. Such insights can guide the development of a national strategy to improve AKI management, reduce its associated morbidity, mortality, and healthcare costs, and enhance nephrology services in Palestine.

Methods

Study design

A qualitative, exploratory approach was conducted to analyze the perspectives of nephrologists on the feasibility of implementing the NRRT model in hospitals across the West Bank, Palestine. The in-depth interview

DIALYSIS TRENDS IN THE WEST BANK: PATIENT NUMBERS AND MORTALITY (2015-2025)

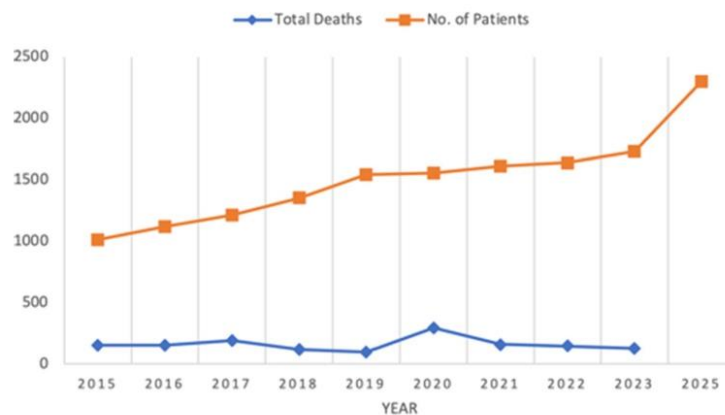


Fig. 1 Trends in dialysis utilization and mortality in the west bank (2015–2025). Source: Palestinian ministry of health [3]. Data for 2024–2025 derived from official unpublished records

guide used in this study was specifically developed by the author for this research, which was reviewed by experts and has not been previously published. An English version of the interview guide has been uploaded as a supplementary file and is cited in the manuscript accordingly. This approach was selected to gain deeper insights into the barriers, facilitators, and recommendations influencing AKI management.

Data collection

Data collection took place between [January, 2024] and [May, 2024]. Nephrologists were purposively selected from nephrology departments in Palestinian hospitals located across the West Bank-Palestine. Semi-structured, face-to-face interviews were used as the primary method of data collection. Each interview was conducted in the participant's office or a private hospital room to ensure confidentiality and comfort.

Participant selection

While AKI is inherently interdisciplinary, this study focused exclusively on board-certified nephrologists due to their central role in clinical decision-making, specialist referral protocols, and nephrology-specific policy development. This focused sampling enabled an in-depth exploration of nephrologists' perspectives on the feasibility of the NRRT. The exclusion of other clinical stakeholders is acknowledged as a limitation, and future research is encouraged to include multidisciplinary views.

Data saturation and sample justification

Data saturation was reached between the 9th and 10th interviews, at which point no new codes or concepts were emerging from the data. This assessment was made through an iterative coding process in which each new transcript was analyzed in comparison with the developing thematic framework. Despite reaching saturation, data collection continued until all 13 board-certified nephrologists practicing in the West Bank had been interviewed. This decision was guided by methodological rigor and supervisory recommendation, ensuring full utilization of the total available population and enhancing the study's depth and contextual variation.

Trustworthiness

Credibility was ensured through triangulation (peer debriefing, expert feedback), member checking, and verbatim transcription. Dependability was enhanced by a detailed audit trail, and confirmability was supported through external review of codes and theme validation. Transferability was considered through rich contextual descriptions of the Palestinian nephrology infrastructure, enabling comparison with similar health systems.

Researcher reflexivity

The researcher is a healthcare professional with prior clinical and academic experience within the Palestinian public health system. This insider status offered several advantages, including increased access, contextual

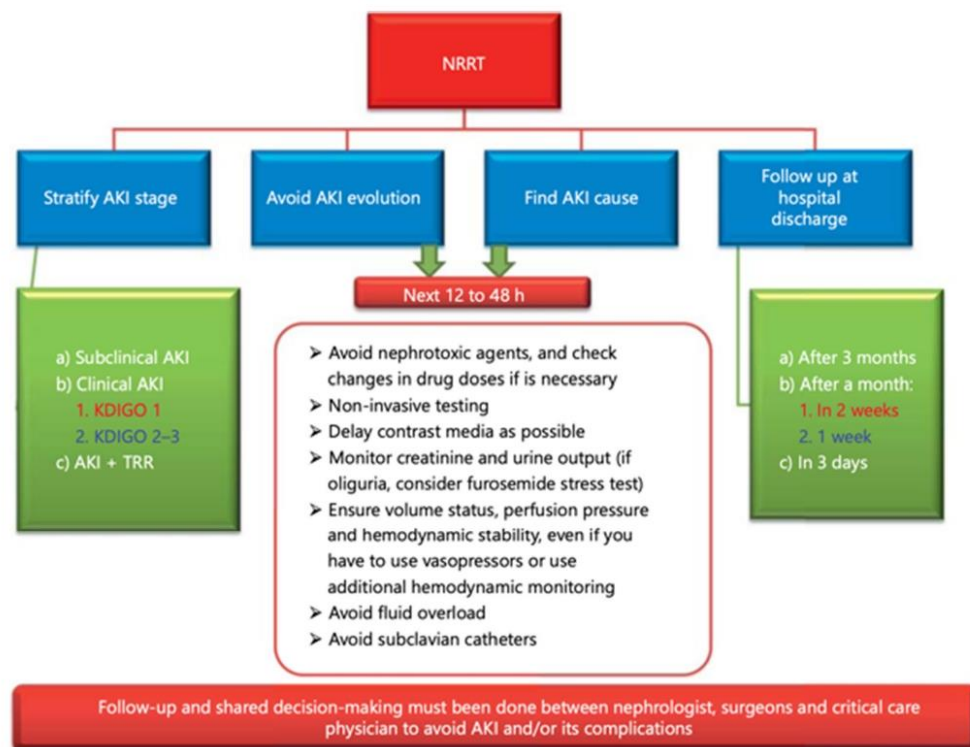


Fig. 2 Structure of the nephrology rapid response team (NRRT) Model. This figure outlines the NRRT pathway for early AKI detection, including risk stratification, use of biomarkers, electronic alert systems, and multidisciplinary nephrology intervention

sensitivity, and the ability to establish rapport with participants. However, it also introduced potential risks of interpretive bias, power asymmetry, and assumptions of shared understanding during interviews. To address these concerns, the researcher adopted a reflexive stance throughout the study. A structured interview guide with open-ended, neutral questions was used to minimize leading or directive questioning. The researcher maintained a reflexive journal to critically reflect on personal assumptions, emotional responses, and potential influence on data interpretation.

All interviews were conducted with an awareness of role-related dynamics and were followed by peer debriefing sessions with academic supervisors to challenge implicit bias and ensure fidelity to participants' intended meanings. Furthermore, member checking with two participants helped validate early thematic interpretations, while independent review of coding by a secondary analyst contributed to analytic neutrality. These strategies collectively enhanced the study's transparency and

reproducibility by making the researcher's position both explicit and methodologically accounted for.

Data analysis

Transcripts were subsequently analyzed using MAXQDA Analytics Pro Student Version 24.2.0. Thematic analysis followed the systematic framework of identifying meaning units, condensing them into core themes, and refining codes into subthemes and overarching categories. This iterative process was conducted collaboratively with the study supervisor to ensure rigor and alignment with qualitative research standards.

Results

This study investigated the perspectives of 13 nephrologists working in Palestinian hospitals across the West Bank, Palestine, on the feasibility and implementation of the NRRT model. The findings are organized into three primary categories: facilitators, barriers, and recommendations, each represented in Table 1 through

Table 1 Summary of key facilitators, barriers, and recommendations for NRRT implementation in Palestine

Category	Key themes	Description
Facilitators	MOH Strategic Policies	Robust government leadership, policy frameworks, and structured nephrology care integration.
Facilitators	Prevention-Driven Health System	Early detection, proactive health policies, and risk-based interventions to reduce AKI burden.
Facilitators	Multidisciplinary Collaboration & Nephrologist Early Engagement	Involvement of nephrologists, pharmacists, radiologist, nurses, and other specialists to ensure timely interventions.
Facilitators	Institutional Endorsement for Nephrology Care	Hospital-based monitoring systems, intake/output charting, and daily creatinine tracking for high-risk patients.
Facilitators	Advancing Technological Innovation	Implementation of AI-driven diagnostics, novel biomarkers (e.g., Cystatin C, NGAL), and electronic alert systems for early AKI detection.
Barriers	Systemic Governance and Policy Barriers	Lack of nephrology-specific policies, fragmented health governance, and insufficient regulatory frameworks.
Barriers	Financial and Operational Constraints	Limited funding, outdated dialysis machines, and poor infrastructure for nephrology services.
Barriers	Human Resource Insufficiency	Shortage of nephrologists, lack of residency programs, and migration of specialists due to low salaries.
Barriers	Prevention Strategies and Awareness Challenges	Poor health literacy, delayed nephrology consultations, and inadequate prevention efforts in primary care.
Barriers	Collaborations and Surveillance System Challenges	Lack of coordination among healthcare providers, absence of a national renal disease registry, and inconsistent patient tracking.
Recommendations	Policy and Governance Reforms	Strengthen nephrology policies, increase funding, implement national strategies, and establish a renal disease registry.
Recommendations	Capacity Building and Education	Expand residency programs, provide structured training for healthcare professionals, and enhance nephrology education.
Recommendations	Public Awareness and Prevention Strategies	Integrate prevention programs in primary care, establish nephrology-specific clinics, and enhance public education on kidney disease management.

corresponding key themes and descriptive insights. The table outlines five enabler themes that support the NRRT implementation, five barrier themes that hinder its adoption, and three strategic recommendation themes aimed at enhancing nephrology care and addressing AKI management in the Palestinian context.

Facilitators for NRRT implementation

Successful implementation of the NRRT model in Palestinian hospitals depends on several key enablers. Five facilitating themes were identified: MOH Strategic Policies, Prevention-Driven Health System, Multidisciplinary Collaboration and Nephrologist Early Engagement, Institutional Endorsement for Nephrology Care, and Advancing Technological Innovation (see Fig. 3). These themes reflect the structural, professional, and technological foundations essential for sustaining NRRT interventions and improving nephrology care.

MOH strategic policies

A strong policy framework and effective leadership from the Ministry of Health (MOH) were consistently recognized as essential drivers for NRRT implementation. Nephrologists emphasized the pivotal role of the MOH in spearheading systemic reforms, ensuring sustainability, and fostering a coordinated approach to nephrology care. Leadership commitment was seen as a prerequisite for overcoming implementation barriers. One nephrologist highlighted this, stating:

"The Ministry of Health alone can establish this system." (Participant no. 8: 35)

In addition, centralized training workshops under MOH supervision were identified as a critical strategy for equipping healthcare providers with the necessary skills. Standardized training ensures uniform nephrology management practices across hospitals. Another participant elaborated:

"If you want to implement it, you need to coordinate and establish a center at the Ministry of Health where workshops are held in all hospitals for nurses and doctors." (Participant no. 4: 29)

Prevention-driven health system

Nephrologists advocated for integrating nephrology into a broader preventive health model, highlighting the importance of early detection, risk assessment, and proactive management of AKI. Shifting toward proactive policies is essential in reducing AKI incidence and its associated burdens. As one participant highlighted,



Fig. 3 Key facilitators to NRRT implementation in the Palestinian health system. This diagram illustrates five core enablers supporting the successful adoption of the nephrology rapid response team (NRRT) model

"If this system is implemented, it will have a great impact, and we will quickly see its benefits, particularly how effective AKI management reduces the duration of hospitalization, improves survival rates for many patients..." (Participant no. 13: 27)

Primary healthcare was seen as a cornerstone of this strategy, particularly in facilitating early-stage CKD identification and long-term monitoring. Participants stressed the need for strengthened infrastructure, such as consistent follow-up protocols and regulated medication dispensing, to operationalize prevention. As one nephrologist explained, effective integration requires:

"They want to activate a preventive health system ... patients with chronic kidney disease should have regular follow-ups and undergo basic tests consistently. Pharmacies should be prohibited from selling medications arbitrarily without a prescription". (Participant no.11: 55)

Multidisciplinary collaboration & nephrologist early engagement

The role of multidisciplinary collaboration was another fundamental facilitator. Early involvement of nephrologists and interdisciplinary teamwork was considered essential for managing AKI. However, in the Palestinian healthcare context, early nephrologist consultations are often unavailable due to a shortage of nephrology specialists, a lack of structured referral systems, and an overburdened healthcare workforce.

Nephrology consultations are delayed or even overlooked due to the absence of nephrologists in certain regions. The heavy workload of the few available specialists limits their ability to provide timely consultations, often leading to late-stage referrals when patients require dialysis or critical care interventions. As one nephrologist remarked,

"Providing nephrology specialists is essential to manage AKI effectively, increasing recovery chances and preserving patients' health. Residency programs are crucial" (Participant no. 4: 29).

Strengthening early multidisciplinary consultation was viewed as a low-cost, high-impact reform to improve AKI prognosis and reduce late-stage interventions.

Institutional endorsement for nephrology care

Institutional endorsement emerged as a significant enabler for implementing the NRRT model, particularly through the standardization of basic monitoring practices. Nephrologists consistently emphasized that simple, low-cost measures such as intake and output charting, regular patient weighing, and daily creatinine testing could serve as foundational tools for early detection and timely AKI management. One nephrologist illustrated this point:

"It is not difficult to take an intake and output chart for any patient. For high-risk patients or those on nephrotoxic medications, conducting daily creatinine lab tests is also simple. These practices do not require high costs, creativity, or significant effort." (Participant no. 3: 51)

These basic monitoring practices, though simple and low-cost, were viewed as foundational enablers of the NRRT implementation. When supported by institutional commitment and embedded into routine workflows, they offer a practical path toward early AKI detection and consistent, preventive nephrology care.

Innovation and technology integration: enabling early detection

Participants emphasized the need to integrate innovative, technology-driven tools to improve the early detection and management of kidney diseases. Two key innovations emerged: the use of novel biomarkers, particularly cystatin C, and the implementation of electronic alert systems. Cystatin C was recognized as a more sensitive indicator than creatinine, capable of detecting renal dysfunctions that traditional tests may miss. Likewise, electronic alert systems were identified as pivotal for the early identification and management of AKI.

As one nephrologist succinctly explained across different points in the interview:-

One of the most important biomarkers is cystatin C. It sometimes detects issues that creatinine cannot reveal ... An automated alert system could ensure timely detection, prompting action before progression becomes irreversible, if integrated effectively with regulations. (Participant no. 1: 56)

In resource-constrained settings like Palestine, participants stressed that the successful implementation of these tools depends on a broader hospital strategy,

including staff training, clearly defined clinical pathways, and strong regulatory oversight to ensure sustainability and impact. To avoid the risk of alarm fatigue, which can occur when alerts are excessive or poorly integrated, participants emphasized the importance of designing systems that prioritize clinical relevance and prompt appropriate action.

Barriers to NRRT implementation

The implementation of the NRRT model in Palestinian hospitals could face several systemic and operational barriers. These obstacles span across governance (e.g., lack of policy coherence and weak leadership), financial constraints (e.g., insufficient funding for nephrology services), resource limitations (e.g., shortage of nephrologists and inadequate diagnostic tools), and awareness deficiencies (e.g., limited knowledge among healthcare providers and patients about AKI management). Five key themes summarizing these barriers are presented in Fig. 4, reflecting the complex interplay of structural and intermediary determinants within the healthcare system.

Weak systemic governance and policy gaps

Structural weaknesses in health governance emerged as a central barrier to NRRT implementation. Nephrology care was described as fragmented, shaped by short-lived initiatives, reactive planning, and limited long-term investment. Participants repeatedly emphasized that Ministry of Health (MOH) programs often lacked continuity, leaving services exposed to shifting political agendas and financial shortfalls. One participant remarked,

"The Ministry of Health initiates programs, but unfortunately, they rarely complete them 100%." (Participant no. 9:65)

This lack of sustainability reflects a broader governance dilemma in which nephrology remains marginalized, with no structured policies guiding decision-making or ensuring equitable service distribution.

Financial and operational constraints

Chronic underfunding and misallocated health budgets were cited as direct impediments to nephrology development. The frustration among participants was palpable, as they linked the dominance of reactive care (dialysis) to a lack of strategic investment in prevention, diagnostics, and early-stage interventions.

One nephrologist sharply criticized the Government of Palestine (GoP) for failing to allocate sufficient funds to the Ministry of Health (MOH), stating:

"They don't allocate a proper budget for the Ministry of Health ... With an adequate budget, we could



Fig. 4 Key barriers to NRRT implementation in the Palestinian health system

conduct proper testing and avoid unnecessary dialysis procedures” (Participant no. 11: 74–75)

Beyond infrastructure limitations, low salaries and overwhelming workloads are driving a wave of physician migration, further weakening the already fragile nephrology workforce. One nephrologist described the reality of Palestinian specialists leaving the country in search of better financial and professional stability:

“Some doctors go abroad and don’t return because the salary is 7,000 NIS (~\$2,000), and they are overburdened with patients.” (Participant no. 13: 45–46)

The brain drain forms a real barrier to implementing structured, team-based models like our proposed NRRT. It deprives the system of the specialized workforce essential for coordinated and preventive nephrology care.

Nephrology workforce shortage

The implementation NRRT model in Palestinian hospitals is hindered by an acute shortage of nephrologists, an issue that has reached an unacceptable level. Dialysis centers often operate without specialist oversight, creating unsafe care environments and violating basic clinical standards. Participants highlighted a systemic failure to scale training programs alongside service expansion.

One participant vividly described this systemic gap:

“Dialysis centers opened ... but where are the nephrology specialists? Ideally, there should be a plan to ensure every center has a specialist, but unfortunately, that’s not the case.” (Participant no. 9: 24)

The absence of nephrologists in dialysis units is an abnormal and unacceptable condition, highlighting a dangerous disconnect between nephrology service expansion and workforce planning. Participants further noted that this workforce gap is compounded by the absence of a formal nephrology residency program and training opportunities in Palestine. Without addressing this imbalance, participants questioned how consistent and timely nephrology care could be delivered.

Weak prevention and public awareness

Participants criticized the underutilization of primary care centers for the early detection of kidney disease. Nephrology is typically addressed at advanced stages, with limited public education and provider training on the early detection of AKI risk. One nephrologist critically observed:

“In our context, ... Patients are only referred to a nephrologist when they reach the stage of needing dialysis.” (Participant no. 3: 29)

Beyond healthcare provider practices, misconceptions about kidney health among patients were also identified as barriers. Many individuals held simplistic or incorrect beliefs about kidney disease prevention, assuming that drinking more or less water alone could maintain kidney health. As one nephrologist noted:

“Some people think drinking too much or too little water affects kidney health, but that’s not true if the kidneys are functioning normally.” (Participant no. 4: 29)

Recommendations

- Expand nephrology residency programs
- Strengthen primary care nephrology training
- Implement the Nephrology Rapid Response Team (NRRT)
- Improve financial investments in preventive care
- Establish a national kidney disease registry

Fig. 5 Key policy and system-level recommendations to strengthen nephrology care delivery in Palestine

These gaps in awareness, limited emphasis on preventive care, and delays in nephrology referrals reflect ongoing challenges in integrating nephrology services within the broader healthcare system.

Collaborations and surveillance system challenges

A fundamental flaw in the current healthcare system, as revealed by participants, is the lack of coordination between primary and secondary healthcare services, fragmenting patient management and leading to disjointed care pathways. Patients often navigate a maze of healthcare providers—the Ministry of Health (MOH), military medical services, relief agencies, and UNRWA—each operating independently, without a centralized treatment plan or communication channel. One nephrologist reflected on this uncoordinated system:

“Healthcare services are being provided in multiple places, but there is no harmony or coordination between the primary healthcare centers.” (Participant no. 10: 28)

This healthcare fragmentation creates delays in patient management, duplication of efforts, and inconsistent medication regimens. Patients receive conflicting prescriptions and undergo unnecessary duplicate tests due to the absence of a shared clinical record system.

Closely tied to this fragmentation is the absence of a national renal disease registry, which significantly limits strategic planning for kidney care. Without a centralized data repository, nephrologists lack critical tools for monitoring patient trajectories, assessing population-level burden, and informing clinical decision-making. One participant underscored this challenge:

... A proper registry system would help us follow patients better, especially as their numbers grow. Unfortunately, we don't have any statistics at all. (Participant no. 7:40–41)

This data vacuum hinders evidence-based decision-making, making it impossible to allocate resources efficiently

or develop national strategies for kidney disease management. The failure to establish a real-time surveillance system for CKD and AKI cases reflects a systemic oversight that continues to undermine nephrology services at every level.

Nephrologists' insights: strategic recommendations for NRRT implementation

Grounded in their lived experiences and professional realities, nephrologists provided strategic recommendations to overcome the systemic barriers hindering the effective implementation of the NRRT model. Figure 5 illustrates and synthesizes the recommendations, which emerged organically from nephrologists' daily experiences and direct engagement with the systemic challenges of the Palestinian healthcare system.

Within the complex and resource-limited healthcare landscape, nephrologists articulated pragmatic solutions, highlighting the need for systemic transformation in nephrology care. Their recommendations consolidate into three interdependent themes, each addressing a critical aspect of health system reform.

The following section provides an in-depth exploration of these recommendations, capturing the nuanced perspectives and frontline realities of nephrologists as they reimagine nephrology care within a constrained yet resilient healthcare system.

Policy and governance reforms: a call for systemic change

Nephrologists consistently emphasized the need for comprehensive reforms in health governance to strengthen nephrology care. Their narratives revealed a fragmented system lacking strategic direction, sustainable funding, and cohesive referral mechanisms, factors that collectively undermine patient outcomes and limit the feasibility of NRRT implementation.

A central recommendation was the expansion of structured primary care services through the family medicine program. This was viewed as essential for shifting from dialysis-centered care toward early detection and prevention-based strategies. One participant articulated this vision through a more structured and patient-centered model:

“The Family Medicine program in Palestine needs to expand significantly and should serve as the first line of defense in managing such cases. These physicians are the ones who see patients first, refer them when necessary, and follow up on their conditions. This ensures a structured and coordinated approach to patient care.” (Participant P. no. 9: 36)

Strengthening frontline care and referral coordination, alongside implementing a national nephrology strategy,

was seen as foundational for enhancing system responsiveness and ensuring the long-term viability of nephrology reforms.

Capacity building and education: strengthening the foundations of nephrology care

A foundational recommendation was to strengthen the nephrology workforce through structured residency programs, continuous medical education, and general physician upskilling. Participants highlighted the need for both specialist and generalist training to improve early detection and AKI management. A nephrologist highlighted the dual necessity of medical training and a structured tracking system:

"General physicians must be trained on how to act as the first line of defense in managing kidney diseases. Additionally, there should be a kidney disease registry to ensure proper tracking and management of these cases." (Participant no. 9: 69)

This emphasis on education and capacity building reflects a deep awareness among nephrologists that closing the knowledge gap is pivotal to improving patient outcomes. Without a skilled and well-trained workforce, nephrology services will continue to struggle, leaving AKI and CKD patients vulnerable to mismanagement and late-stage referrals.

Participants envisioned a future where continuous medical education, structured residency programs, and a well-established nephrology registry would not just enhance individual skills but fortify the entire healthcare system, ensuring better patient care despite resource limitations.

Public awareness and prevention strategies: a shift toward proactive nephrology care

Nephrologists called for wide-scale public education and early intervention campaigns to reduce the rising burden of kidney disease. These would target both community misconceptions and systemic neglect in the early stages of care. A notable proposal was the creation of nephrology-specific outpatient clinics segmented by condition: CKD, AKI, and transplant to provide tailored treatment and improve follow-up. One participant articulated the necessity of this structured approach:

"Another important point is to have specialized clinics within government institutions: separate clinics for CKD and AKI. Managing chronic kidney disease is different from managing acute kidney injury because AKI patients have a good chance of kidney recovery. Therefore, in my opinion, nephrology services should be divided into three distinct clinics for

optimal effectiveness—for kidney transplants, AKI, and CKD. (Participant no. 13: 17)

Integrating preventive nephrology into primary care and restructuring service models to reflect disease progression were seen as transformative strategies to improve long-term care and reduce dialysis dependency.

Discussion

This novel qualitative research provides a deeply contextualized epistemological lens, offering perspectives that quantitative metrics often fail to capture. Through the opinions of Palestinian nephrologists working within a resource-limited healthcare landscape, this study explores the complex interplay between systemic defects, technical barriers, and the potential for transformative nephrology care reforms in Palestine.

By exploring facilitators, barriers, and strategic recommendations, this qualitative analytical research goes beyond identifying challenges; it maps pathways for health reform, providing a locally grounded yet globally informed perspective on improving AKI management. The findings are consistent with international guidelines, such as KDIGO (Kidney Disease: Improving Global Outcomes). Rather than imposing a global standard, this research contextualizes these recommendations within the constraints, realities, and opportunities unique to the Palestinian healthcare system.

Nephrologists consistently asserted the MOH central role in leading systemic reforms to improve nephrology services. As the principal provider of nephrology care under the national health insurance framework, the MOH ensures free coverage for patients diagnosed with End-Stage Kidney Disease (ESKD). While this reflects commendable political will, participants highlight powerfully that embedding preventive strategies aimed at reducing the prevalence of CKD and AKI could significantly enhance the sustainability of health services and cost-effectiveness. The participants also recognize gaps in governance and policy implementation, noting that fragmented policies and the deprioritization of nephrology services undermine systemic efficiency. These observations align with previous research [7, 8], which confirms the need for cohesive national nephrology strategies to ensure long-term service stability.

From the nephrologists' perspective, addressing these governance barriers requires a concerted effort by the MoH to institutionalize nephrology services within the broader public health framework. Strengthening governance structures through policy coherence, regulatory enforcement, and strategic resource allocation was seen as fundamental in fostering a more sustainable, prevention-driven nephrology model. Participants advocated for embedding standardized nephrology protocols within

primary care, ensuring that early detection, risk assessment, and early referrals become vital components of the healthcare system rather than reactive responses.

A severe shortage of nephrology specialists in the West Bank and Gaza Strip presents a critical barrier to AKI and CKD management, significantly limiting timely intervention efforts. Alarming, only 13 board-certified nephrologists are responsible for overseeing nephrology care across the 16 cities in the West Bank, a figure grossly insufficient to meet the escalating burden of ESKD. This shortage is exacerbated by the reality that several hospitals operate hemodialysis units without a nephrologist, leaving general practitioners to manage complex renal cases without specialist oversight. The MOH Annual Health Report [3] underscores the need for workforce expansion and strategic intervention, as dialysis patient numbers have doubled from 1,014 in 2015 to 2,300 patients in 2025. Establishing nephrology residency programs, incentivizing specialization, and integrating structured nephrology training into general medical education were identified as critical facilitators to bridge the gap in nephrology expertise.

From a public health and policy view, addressing these workforce challenges demands systemic reforms that extend beyond hospital settings into primary healthcare facilities. These findings align with those Tam-Tham et al. [9], who similarly reported workforce shortages and collaboration gaps in CKD management within primary care. The NRRT model presents a viable mechanism for enhancing early multidisciplinary collaboration, ensuring that nephrologists are strategically allocated to high-risk cases while primary care physicians receive the necessary training to manage early-stage kidney disease. By prioritizing preventive nephrology services, strengthening early detection policies, and implementing structured workforce policies, the Palestinian healthcare system can antidote the painful maximization in dialysis dependency while improving overall renal health outcomes.

Participants highlighted that inadequate MOH budgets and high out-of-pocket patient costs limit investments in critical infrastructure, workforce development, and diagnostic technologies. These financial barriers frequently slow down patients' access to essential care, perpetuating inequities. Consistent with findings by Abdel-Kader et al. [10], tackling these financial barriers through strategic resource reallocation and health reforms is essential to ensuring sustainability and equity in nephrology care.

Beyond cost containment, which counts \$ 50 million annually, a strong recommendation emerged for enhancing financial investments in preventive nephrology services. Addressing modifiable ESKD risk factors, such as diabetes and hypertension, through early screening, structured patient follow-up, and nephrology integration into primary care, could stop disease progression

and reduce long-term dialysis demand. This prevention-based approach, such as the NRRT, is critical in ensuring a more cost-effective, sustainable, and equitable nephrology care.

The Palestinian health system remains heavily skewed towards curative care, consuming 75.5% of the total health budget, while preventive services receive a mere 1.5%. This disproportionate focus not only rising healthcare costs but also limits the sustainability of essential operational services. By reallocating resources and prioritizing preventive care initiatives, the Palestinian MOH can align its nephrology practices with global benchmarks, reinforcing its leadership in proactive healthcare delivery [11].

The investment in enhancing awareness among both healthcare providers and patients, alongside developing a countable responsiveness primary healthcare system, emerged as a milestone for addressing kidney health challenges. Participants highlighted significant deficits in knowledge and understanding of AKI and CKD. Many primary care providers lacked adequate training, leading to delays in diagnosis and treatment. Moreover, misconceptions about kidney health, such as reliance on hydration as a preventive measure, were common among patients, compounding these challenges. These findings align with Nash et al. [12] and Williams et al. [13], who emphasized the importance of educational programs to improve awareness and adherence to guidelines.

Further insights from Carpenter-Song et al. [14] offer a nuanced perspective on implementing AKI prevention strategies within interdisciplinary frameworks. They identified several systemic barriers to successful implementation, such as workflow disruptions, staff turnover, and limited leadership buy-in.

The NRRT model, if effectively implemented, presents a viable pathway for transforming AKI management, ensuring timely nephrology consultations, structured patient monitoring, and improved care coordination. However, its success depends on strong policy frameworks, financial restructuring, and the integration of multidisciplinary collaboration within the broader healthcare system.

By redirecting financial resources toward preventive nephrology services and enhancing primary care engagement, the Palestinian healthcare system can achieve greater sustainability, improved patient outcomes, and a more equitable distribution of nephrology resources. The findings of this study call for a strategic realignment of health policies that balances immediate patient needs with long-term nephrology care sustainability, ultimately fostering a resilient and prevention-driven healthcare model.

Transferability and relevance to global contexts

The findings of this study, while contextually grounded in Palestine, resonate with global nephrology care priorities, particularly in LMICs facing similar systemic challenges. As documented in the ISN–Global Kidney Health Atlas [15], global inequities in nephrology care persist, with severe shortages in nephrology specialists, limited funding, and inconsistent access to high-quality kidney replacement therapy (KRT). The Atlas emphasizes context-sensitive, preventive models—such as telemedicine, task-shifting, and team-based care—as essential for equitable nephrology advancement [15].

Kalysesubula et al. [16] similarly advocate for the integration of kidney care into broader health systems, emphasizing political will and scalable interventions. Mehta et al. [2], in the ISNs 0by25 Initiative, reinforce this by proposing health system integration, enhanced tracking, and point-of-care diagnostics to reduce preventable AKI deaths. The feasibility of such models is exemplified by Evans et al. [17], whose multicountry evaluation proved that low-cost AKI management using symptom-based risk scores and on-site diagnostics significantly improved early detection and outcomes.

Furthermore, Ravyn et al. [18] highlight facilitators such as institutional support and clinician education that directly strengthen NRRT viability, while Luyckx et al. [19] call for system-level reforms to close persistent knowledge-to-practice gaps. Together, these findings confirm the global relevance of locally generated strategies like NRRT, particularly for LMICs lacking robust infrastructure or universal coverage.

Collectively, these international perspectives enhance the contextual relevance and potential transferability of this study's findings to other low-resource settings. Rather than endorsing a one-size-fits-all solution, they underscore the growing momentum in LMICs toward preventive nephrology strategies that emphasize early AKI detection and system integration. As reflected in participant narratives, timely intervention was viewed not simply as a clinical preference but as a practical and resource-sensitive response in environments where long-term dialysis remains financially and logistically constrained.

Conclusion

This study delves into the perspectives of nephrologists on the feasibility and implementation of the NRRT model in Palestinian governmental hospitals. Insights gathered align with the WHO Social Determinants of Health framework, emphasizing how structural determinants such as governance and resource allocation impact healthcare delivery. By incorporating the perspectives of practicing nephrologists, this research sheds light on systemic, operational, and resource-related challenges

that hinder the optimization of health care services. The findings underscore the central role of the MOH in spearheading systemic reforms, with a focus on policy coherence, resource allocation, and fostering a preventive care paradigm. Proactive measures such as nephrologist-led interventions, primary care integration, and technology adoption emerged as key enablers for enhancing nephrology care, aligning with global guidelines like KDIGO.

Limitations

Despite the richness of insights, several limitations should be acknowledged. The qualitative nature of the research prioritizes depth over generalizability. Although the sample includes all board-certified nephrologists in the West Bank, it does not capture perspectives from the Gaza Strip, nor does it reflect the views of other stakeholders such as nurses, patients, policymakers, general practitioners, medical specialists, pharmacists, and other frontline healthcare providers.

Implications for future research

Future research should aim to triangulate findings through mixed-method approaches, incorporating quantitative data to strengthen the evidence base. Expanding the study scope to include multi-stakeholder perspectives and cross-regional comparisons can provide a more holistic understanding of nephrology care challenges and inform the design of comprehensive interventions. Addressing these limitations will not only enhance the robustness of future studies but also ensure that the insights generated effectively translate into actionable health policy reforms.

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Author contributions

The authors conceptualized and designed the study, conducted interviews, analyzed the data, drafted the manuscript, and approved the final submission.

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Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality agreements with participants, but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This qualitative study is part of a broader doctoral research thesis titled "Enhancing Acute Kidney Injury Management in Southern Palestinian Governmental Hospitals: Impact of Risk Triage, Novel Biomarkers, and Electronic Health Alerts," which comprises three components: a quantitative study, a

qualitative study, and a published systematic review (WCN25–3547, DOI: [10.1016/j.ekir.2024.11.184](https://doi.org/10.1016/j.ekir.2024.11.184)). Ethical approval for this specific qualitative component was obtained from the Institutional Review Board (IRB) at the School of Public Health, Al-Quds University (Approval No: 5/24, dated 13 February 2024), and from the Scientific Research Unit at the Palestinian Ministry of Health (Approval dated 28 February 2024). All participants were nephrology specialists who voluntarily agreed to participate. Informed consent was obtained before conducting any interviews. Participants were informed of the study's objectives, procedures, and their right to withdraw at any point without penalty. Interviews were only conducted after verbal and written consent was secured. This study was conducted in accordance with the Declaration of Helsinki and adheres to the ethical principles of confidentiality, respect for persons, voluntary participation, and protection of participants' rights, under national and institutional guidelines.

Consent for publication

Not applicable. This study does not include any identifiable personal data, images, or other information requiring individual consent for publication.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author details

¹Faculty of Public Health, Al-Quds University, Jerusalem, Palestine

²Faculty of Health Professions, Al-Quds University, Jerusalem, Palestine

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Bilal Jawabreh is a doctoral researcher at the Faculty of Public Health, Al-Quds University, Jerusalem, Palestine, and a fellow with the Robert Koch Institute (RKI), GOARN, and the WHO Hub for Epidemic and Pandemic Intelligence in Berlin. With over 20 years of experience in public health, surveillance, and capacity building, his research focuses on nephrology, acute kidney injury management in low-resource settings, epidemic intelligence, and health system reforms. He is the corresponding author of this manuscript.

Appendix (6): Facilitating A Search Task

28-FEB-2024 14:24 From: To:022742434 Page:1/1

State of Palestine
Ministry of Health
Education in Health and Scientific
Research Unit

دولة فلسطين
وزارة الصحة
وحدة التعليم الصحي
والبحث العلمي

Ref:
Date:.....

الرقم: ٢٠٢٤ / ٤٨٧ / ١٦٢
التاريخ: ٢٠٢٤ / ٢ / ٢٨

عطوفة الوكيل المساعد لشؤون المستشفيات والطوارئ المحترم،،
الاخت ق. أ. مدير عام الادارة العامة لتكنولوجيا المعلومات المحترمة،،

تمية واحترام...

الموضوع: تسهيل مهمة بحث

٢٠٢٤ / ٢ / ٢٨
٢٨ / ٢ / ٢٠٢٤

يرجى تسهيل مهمة الطالب: بلال جوايرة - برنامج دكتوراه الصحة العامة / جامعة القدس،
وبإشراف د. معتصم حمدان في عمل بحث بعنوان:

Enhancing Acute Kidney Injury Management in southern
Palestinian governmental Hospitals: impact of risk Triage, Novel
Biomarkers, and Electronic Health Alerts

من خلال السماح للطلاب بجمع معلومات عن طريق مراجعة ملفات المرضى، وذلك في
مستشفى بيت جالا الحكومي

الرقم:
التاريخ: ٢٨ / ٢ / ٢٠٢٤

مستشفى بيت جالا - مستشفى عاليه

على ان يتم الالتزام باساليب واخلاقيات البحث العلمي، وعدم التعرض للمعلومات التعريفية الموثقة.
على ان يتم تزويد الوزارة بنسخة PDF من نتائج البحث، التعهد بعدم النشر لحين الحصول على موافقة
الوزارة على نتائج البحث.

مع الاحترام...

رئيس وحدة التعليم الصحي والبحث العلمي

نسخة: عميد كلية الصحة العامة المحترم / جامعة القدس

Telfax.:09-2333901 scientificresearch.dep@gmail.com 09-2333901 تلفاكس:

تعزيز إدارة إصابة الكلى الحادة في المستشفيات الحكومية بجنوب الضفة الغربية: تقييم وتصنيف
المخاطر، المؤشرات الحيوية المخبرية المستجدة، والتنبيهات الصحية الإلكترونية - دراسة بالمنهج
المختلط

إعداد : بلال عبد الرحمن نمر جوابرة

إشراف: أ.د. معصم حمدان

الملخص

الخلفية : تُعد إصابة الكلى الحادة (Acute Kidney Injury – AKI) من أبرز أسباب المراضة والوفيات داخل المستشفيات، ويتضاعف عبؤها في الدول ذات الموارد المحدودة. في فلسطين، تسهم محدودية الاكتشاف المبكر، ونقص اختصاصيي أمراض الكلى، وغياب البروتوكولات الوطنية الموحدة في تشتت الرعاية وتأخر التدخل، ما يستدعي تطوير نماذج تدخل عملية وقابلة للتوسع.

الهدف : هدفت هذه الدراسة إلى تقييم فاعلية وقابلية تطبيق نموذج متكامل للكشف المبكر وتدبير إصابة الكلى الحادة في مستشفيات جنوب الضفة الغربية، وقياس أثره السريري والتنظيمي.

المنهجية : استُخدم تصميم منهجية مختلطة. شمل الشق النوعي مقابلات معمقة مع جميع اختصاصيي أمراض الكلى المعتمدين في الضفة الغربية ($n=13$) لاستكشاف الجاهزية والتحديات النظامية. أما الشق الكمي فكان دراسة مستقبلية شبه تجريبية في مستشفين حكوميين (مستشفى تدخل وآخر ضابط)، وضمت 469 مريضاً مصاباً بـ AKI تضمن التدخل نظام تنبيهات إلكترونية، وفرزاً مبكراً للخطورة، واستخدام مؤشرات حيوية حديثة، أبرزها NGAL.

النتائج : أظهرت مجموعة التدخل تحسناً ذا دلالة إحصائية في التعرف المبكر على إصابة الكلى الحادة مقارنة بالمجموعة الضابطة (68.4% مقابل 37.8%، $p<0.001$)، مع زيادة اكتشاف الحالات في المرحلة الأولى وتسريع الاستشارات الكلوية. كما ارتفعت معدلات تعافي الكلى (33% مقابل 20.5%، $p=0.001$) وانخفضت الحاجة إلى غسيل الكلى (7.9% مقابل 16.5%، $p=0.005$). برز المؤشر الحيوي NGAL كأداة تشخيصية وتنبؤية واعدة بدقة تشخيصية متوسطة ($AUC=0.736$)، وارتبطت المستويات المرتفعة (>300 نانوغرام/مل) بإنذارات سريرية أسوأ. كما ساهم نظام فرز الخطورة في التنبؤ بشدة الإصابة وتوجيه التدخل المبكر. وأظهرت مؤشرات جودة الرعاية تحسناً ملحوظاً في التوثيق، وسلامة الأدوية، وضبط السوائل، والمتابعة المخبرية. وكشفت المقابلات النوعية دعماً واسعاً للنموذج

المقترح، مع الإشارة إلى أن التحديات الرئيسية تتمثل في ضعف الحوكمة، ونقص الكوادر، وغياب السجلات الوطنية.

الاستنتاج: أدى دمج أنظمة التنبيه الإلكتروني، وفرز الخطورة، والمؤشرات الحيوية المبكرة إلى تحسين ملموس في نتائج إصابة الكلى الحادة وجودة الرعاية المقدمة. وتوفر هذه الدراسة نموذجًا عمليًا وقابلًا للتوسع لتحسين رعاية مرضى الكلى في البيئات محدودة الموارد، مع التأكيد على أهمية التكامل بين الابتكار التقني، والممارسة السريرية، والإصلاحات الصحية على مستوى السياسات.

الكلمات المفتاحية: إصابة الكلى الحادة، المؤشرات الحيوية، NGAL، نظام التنبيه الرقمي، التنبيه الإلكتروني.