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The Moldovan Association for Biosafety and Biosecurity (MDBBA) is a scientific and practical, instructive and educational, non-governmental, apolitical and non-profit professional organization, founded in 2017.

The main objective of the association is the development of good practices and culture in the field of biosafety and biosecurity and the promotion of knowledge within professional and research-innovation groups.

BIOSAFETY

includes security principles, technologies and rules to be followed to prevent unintended exposure to pathogens and toxins or their accidental release/ leakage.

"Protection of personnel, population from unintended exposure to pathogens/ biohazardous material".

BIOSECURITY

includes a wide spectrum of measures (biosecurity policies, regulatory regime, scientific and technical measures) applied in an organized framework, necessary to minimize risks (prevention of actions, terrorist attacks by the intentional release of pathogens or toxins as well as loss, their theft or misuse).

"Protection and prevention of theft, intentional misuse of pathologies/biohazardous material".

RISK MANAGEMENT

is a decision-making process in which the results of risk assessment (the process of estimating workplace hazards) are integrated with economic, technical, social and political principles to generate strategies for risk reduction.

One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems.

It recognizes that the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent.

While health, food, water, energy and environment are all wider topics with sector-specific concerns, the collaboration across sectors and disciplines contributes to protect health, address health challenges such as the emergence of infectious diseases, antimicrobial resistance, and food safety and promote the health and integrity of our ecosystems.

By linking humans, animals and the environment, One Health can help to address the full spectrum of disease control – from prevention to detection, preparedness, response and management – and contribute to global health security.

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Science and the One Health Approach: Advancing Occupational Health and Prevention

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Scientific progress is a key driver of better health, quality of life, and sustainable development. In an era of rapidly evolving health challenges, the generation, dissemination, and application of scientific knowledge are essential for evidencebased decision-making and effective prevention strategies.

Research in the fields of public health and occupational medicine has improved disease prevention, occupational safety, environmental health and the management of health risks present here. These advances show that health protection requires continuous scientific research, interdisciplinary collaboration, and the use of elements of 4P medicine (Predictive, Preventive, Personalized, Participation), and it has opened and can open up new paths in both prevention and treatment, which will fundamentally change the importance of occupational health in the face of emerging threats.

The increasing complexity of global challenges such as emerging infections, antimicrobial resistance, environmental change, and occupational risks, highlights the importance of the One Health concept, which recognizes the interdependence of human, animal, and environmental health and promotes integrated solutions across disciplines.

Scientific journals play a critical role in translating research into practice. By ensuring scientific rigor, transparency, and knowledge exchange, they support lifelong learning, innovation, and the development of policies that improve population health.

The One Health & Risk Management journal serves as a multidisciplinary platform that fosters scientific dialogue and collaboration among experts in medicine, public health, veterinary sciences, environmental sciences, microbiology, epidemiology, and related fields. Through the dissemination of high-quality research, the journal contributes to advancing the One Health agenda and addressing contemporary health challenges.

Professor Sára Felszeghi, PhD
University of Miskolc, Hungary

ORIGINAL RESEARCH ARTICLE

MEDICAL SCIENCES

DEVELOPMENT OF A CLINICAL ALGORITHM FOR MONITORING AND PROGNOSTIC ASSESSMENT IN PATIENTS WITH CKD AFTER COVID-19

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ABSTRACT

Introduction Chronic kidney disease and coronavirus disease 2019 represent a high-risk intersection, yet renal follow-up after coronavirus disease 2019 remains insufficiently standardized. We developed and internally validated a risk-stratified clinical algorithm for monitoring and prognostic assessment of patients with chronic kidney disease after coronavirus disease 2019.

Materials and methods This was a prospective cohort study of 280 non-dialysis patients with chronic kidney disease stages G2-G5: 140 post-coronavirus disease 2019 and 140 controls. At 6 to 12 months, we assessed estimated glomerular filtration rate, proteinuria, and inflammatory, metabolic, and hematologic markers. Coronavirus disease 2019 severity and the occurrence of acute kidney injury during infection were recorded. Predictors of advanced chronic kidney disease stages G4-G5 were identified by multivariate logistic regression; algorithm performance was evaluated by calibration and receiver operating characteristic analysis.

Results The decline in renal function was comparable between groups. In post-coronavirus disease 2019 patients, persistent proteinuria, elevated serum phosphate, and low hemoglobin independently predicted advanced chronic kidney disease (odds ratio 5.0, 1.8, 1.4, respectively ($p<0.005$). The model showed good internal performance (area under the curve approximately 0.88).

Conclusions Coronavirus disease 2019 appears to amplify renal vulnerability. A structured, risk-based algorithm may improve early detection of renal deterioration and support personalized management.

Keywords Chronic kidney disease, COVID-19, monitoring algorithm, risk stratification, proteinuria, prognosis.

DEZVOLTAREA UNUI ALGORITM CLINIC DE MONITORIZARE ȘI DE PROGNOSTIC LA PACIENȚII CU BOALĂ CRONICĂ DE RINICHI ÎN PERIOADA POST-COVID

Introducere Boala cronică de rinichi și infecția COVID-19 reprezintă o situație critică prin suprapunerea factorilor de risc major, cu toate acestea monitorizarea renală post-COVID-19 rămâne insuficient standardizată. În acest context, a fost elaborat și validat intern un algoritm clinic de stratificare a riscului, destinat monitorizării și evaluării prognostice a pacienților cu boală cronică de rinichi în perioada post-COVID-19.

Materiale și metode Studiu prospectiv de cohortă care a inclus 280 de pacienți cu boală cronică de rinichi în stadiile G2-G5, nedializați: 140 pacienți post-COVID-19 și 140 martori. La 6-12 luni s-au evaluat rata estimată de filtrare glomerulară, proteinuria și markerii inflamatori, metabolici și hematologici. Au fost înregistrate severitatea COVID-19 și apariția leziunii renale acute în faza activă a infecției. Predictorii asociați stadiilor avansate de boală cronică de rinichi (G4-G5) au fost identificați prin regresie logistică multivariată; performanța algoritmului a fost evaluată prin calibrare și analiza curbei ROC.

Rezultate Declinul funcției renale a fost comparabil între grupuri. La pacienții post-COVID-19, proteinuria persistentă, nivelul crescut al fosfatului seric și hemoglobina scăzută au reprezentat predictori independenți pentru stadiile avansate de boală cronică de rinichi (OR 5,0; 1,8; 1,4; $p<0,005$). Modelul a demonstrat o bună validitate internă (aria sub curbă de aproximativ 0,88).

Concluzii Infecția cu COVID-19 acționează predominant ca un factor de amplificare a vulnerabilității renale. Un algoritm structurat, bazat pe stratificarea riscului, poate îmbunătăți detectarea precoce a deteriorării și poate susține managementul personalizat.

Cuvinte-cheie Boală cronică de rinichi, COVID-19, algoritm de monitorizare, stratificarea riscului, proteinurie, prognostic.

INTRODUCTION

COVID-19 is a systemic inflammatory disease with frequent renal involvement. High ACE2 expression in renal tissue explains the high incidence of COVID-19-associated acute kidney injury (AKI), reported in up to 30% of hospitalized patients and over 50% of those requiring intensive care. COVID-associated AKI results from combined viral, inflammatory, thrombotic, and hemodynamic mechanisms and is associated with adverse outcomes (1, 2).

Chronic kidney disease (CKD) constitutes a major global public health burden and was a key vulnerability factor during the COVID-19 pandemic (3). CKD patients experienced higher rates of severe infection, hospitalization, and mortality. Moreover, SARS-CoV-2 infection may precipitate incomplete AKI recovery, trigger de novo CKD, or accelerate progression of pre-existing CKD (4,5). Longitudinal studies demonstrate persistent eGFR decline, albuminuria, and increased major adverse kidney events among COVID-19 survivors, particularly following severe disease or ICU admission (4,5).

However, consensus-based and evidence-driven protocols specifying follow-up intervals, risk stratification criteria, and core renal biomarkers after coronavirus disease 2019 remain insufficiently defined (5,6). Current recommendations are heterogeneous, and a substantial proportion of patients with COVID-associated AKI remain without nephrologist follow-up, which delays detection of CKD progression.

Objective: To identify independent predictors of advanced chronic kidney disease after coronavirus disease 2019, to evaluate their prognostic performance using multivariate modeling, and to construct and internally validate a risk-stratified clinical monitoring algorithm based on these predictors.

MATERIALS AND METHODS

Study design and population

We conducted a prospective, analytical observational cohort study including 280 adult patients with CKD, enrolled from nephrology clinics between 2021 and 2022." Patients were aged 18–70 years and were not receiving dialysis and had not undergone kidney transplantation and were divided into two equal groups: 140 CKD patients recovered from confirmed COVID-19 (≥30 days post-recovery) and 140 CKD patients without a history of COVID-19. ***Inclusion criteria*** were: age 18-70 years; established CKD of any etiology defined by eGFR <60 mL/min/1.73 m^2 (CKD stages G3a-G5) and/or persistent proteinuria for >3 months; and, for the post-COVID group, documented SARS-CoV-2 infection confirmed by PCR or antigen testing, or based on clinical diagnosis followed by documented recovery. ***Exclusion criteria*** included end-stage renal disease requiring renal replacement therapy, kidney transplantation, active malignancy or active tuberculosis, and inability to provide informed consent or to complete the follow-up period.

Ethical approval

The study protocol was reviewed and approved by the Research Ethics Committee of "Nicolae Testemițanu" State University of Medicine and Pharmacy, Chișinău, Republic of Moldova (Approval No. 6, 18 June 2023). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and applicable national regulations. Written informed consent was obtained from all participants prior to enrollment.

Clinical and laboratory assessment

Demographic data and comorbidities were recorded. In patients after COVID-19, acute infection characteristics were extracted from medical records, including disease severity (mild, moderate, severe), AKI occurrence (KDIGO criteria), and dialysis requirement. Evaluations were performed 6-12 months after COVID-19 infection (median 9 months) or at a comparable time point in controls. Assessments included renal function (serum creatinine, eGFR by CKD-EPI; cystatin C measured in 60% of patients), urine protein-to-creatinine ratio (persistent proteinuria defined as ≥0.3 g/g), inflammatory markers (CRP, ESR, ferritin), hematologic parameters (hemoglobin), metabolic and mineral markers (albumin, calcium, phosphate, iPTH), and electrolytes.

Cardiac status was systematically evaluated using the New York Heart Association functional classification based on structured clinical interview and resting electrocardiographic assessment. Transthoracic echocardiography was performed according to predefined criteria, including symptoms suggestive of heart failure, abnormal electrocardiographic findings, known structural heart disease, or elevated natriuretic peptides. Quality of life was assessed in all participants using the validated Short Form-36 questionnaire administered by trained personnel at the follow-up visit. All analyses were performed in accredited laboratories using standardized methods, and both groups received standard CKD care.

Statistical analysis and algorithm development

Comparisons between groups were performed using Student's *t*-test or Mann–Whitney *U* test for continuous variables and chi-square test for categorical variables. Adverse kidney prognosis was defined as CKD stage G4-G5 (eGFR <30 mL/min/1.73 m^2) and/or >25% eGFR decline. Independent predictors were identified by multivariable logistic regression with adjusted odds ratios (95% CI). Model calibration and discrimination were assessed using Hosmer-Lemeshow test and ROC-AUC analysis ($p<0.05$). Based on significant predictors, a risk-stratified algoritm for CKD patients after COVID-19 monitoring algorithm was developed and internally validated.

RESULTS

Patient characteristics and comparative outcomes

A total of 280 CKD patients were included: 140 post-COVID (mean age 59.3±10.8 years; 52% male) and 140 non-COVID controls (58.1±11.5 years; 50% male). Baseline demographics, CKD etiologies (chronic glomerulonephritis 32%, diabetic kidney disease 28%, hypertensive nephrosclerosis 22%, polycystic kidney disease 5%, others 13%), and comorbidities (hypertension ~85%, diabetes ~40%, ischemic heart disease ~30%) were comparable between groups. In the post-COVID cohort, disease severity was mild in 20%, moderate in 54%, and severe in 26%; AKI occurred in 27% (5% stage 3), and 7% required acute dialysis. Median time since infection was 9 months (range 1-18 months).

At follow-up, renal function did not differ significantly between post-COVID and control groups (eGFR 37.8±15.6 vs 39.5±14.2 mL/min/1.73 m^2; $p=0.40$), nor did CKD stage distribution or rates of advanced CKD (G4-G5: 55% vs 50%; $p=0.45$). Blood pressure control, glycemic status, and electrolyte levels were similar, indicating no overall acceleration of CKD progression after non-severe COVID-19.

Subgroup analyses demonstrated marked heterogeneity. Post-COVID patients with prior AKI showed a higher prevalence of advanced CKD compared to those without AKI (72% vs 45%; $p<0.01$). Similarly, severe COVID-19 was associated with greater eGFR decline from pre-infection baseline (-5.4 vs -1.8 mL/min), consistent with an accelerated renal trajectory in high-severity cases. In contrast, patients with mild COVID-19 exhibited renal outcomes comparable to those of controls, with predominantly stable kidney function during follow-up.

Laboratory and clinical profile and prognostic factors

Inflammatory markers did not differ significantly between groups (CRP 8.5 vs 7.9 mg/L, p=0.6; ESR 28 vs 26 mm/h, p=0.5). However, post-COVID patients more frequently showed CRP >10 mg/L (24% vs 15%), lower serum albumin (~3 g/dL), and more severe anemia (hemoglobin 10.5 vs 11.2 g/dL, p=0.03). Ferritin levels were higher in post-COVID CKD (380 vs 300 µg/L, p=0.04) and inversely correlated with hemoglobin (r=-0.3, p<0.01), indicating a malnutrition–inflammation profile. Hyperphosphatemia (>4.5 mg/dL) was more prevalent post-COVID (30% vs 20%, p=0.07), while calcium and potassium levels were comparable.

Post-COVID CKD patients more often exhibited advanced heart failure symptoms (NYHA II-III: 40% vs 25%, p=0.02), despite a similar left ventricular ejection fraction. The prevalence of arrhythmias did not differ significantly (14% vs 22%, p=0.1), and hepatic, coagulation, and respiratory parameters were comparable. No late thromboembolic events were observed.

Quality-of-life assessment showed lower Short Form-36 vitality scores in patients after COVID-19 (47 vs 55, p=0.01). After adjustment for chronic kidney disease stage, no significant differences were observed in the physical functioning or emotional role domains between groups. In the post-COVID cohort, univariate analysis identified persistent proteinuria, higher serum phosphate, lower hemoglobin, elevated CRP, and prior AKI as predictors of advanced CKD (G4-G5). Multivariable logistic regression identified three independent predictors (Table 1): persistent proteinuria (OR 5.0, 95% CI 2.0-12.5; p<0.001), serum phosphate (OR 1.8 per +1 mg/dL; p<0.001), and hemoglobin (OR 1.4 per -1 g/dL; p=0.005). Age, sex, diabetes, inflammatory markers, and acute COVID severity were not independently associated. The model demonstrated good calibration (Hosmer–Lemeshow p=0.45) and discrimination (AUC 0.88). Patients with all three risk factors uniformly had advanced CKD, whereas those without them remained largely stable.

Table 1. Independent predictors of advanced CKD (Stage G4-G5) in post-COVID patients (Multivariate Logistic Regression, n=140)

Predictor	Adjusted OR (95% CI)	p-value
Persistent proteinuria (yes vs no)	5.0 (2.0 – 12.5)	<0.001
Serum phosphate (per +1 mg/dL)	1.8 (1.3 – 2.5)	<0.001
Hemoglobin (per –1 g/dL)	1.4 (1.1 – 1.8)	0.005
D-dimer (per +1 µg/mL)	1.2 (0.9 – 1.6)	0.10 (NS)
Age (per +10 years)	1.1 (0.9 – 1.3)	0.18 (NS)
Male sex (vs female)	1.3 (0.5 – 3.1)	0.60 (NS)

Note: OR – odds ratio; CI – confidence interval; NS – not significant. Proteinuria is defined as urine protein-creatinine ratio ≥0.3 g/g.

Development of the monitoring algorithm: Based on study findings, we developed a risk-stratified clinical algorithm for management of CKD after COVID-19. Patients are classified as high risk if they have had severe COVID-19 (ICU admission or major complications) or COVID-associated AKI, and/or present adverse prognostic markers at follow-up (persistent proteinuria, serum phosphate >4.5 mg/dL, hemoglobin <11 g/dL). Patients with mild COVID-19 and no high-risk laboratory abnormalities are classified as Low Risk.

High-Risk patients are scheduled for nephrology follow-up at 1, 3, 6, and 12 months post-recovery, including assessment of serum creatinine and eGFR (± cystatin C), urine protein or albumin and sediment, serum phosphate, potassium, hemoglobin, blood pressure, and glycemic control. Low-Risk patients are monitored at 6 and 12 months, in addition to routine CKD care.

Predefined criteria for clinical deterioration included a decline in estimated glomerular filtration rate ≥10% from baseline, new-onset or doubling of proteinuria, uncontrolled blood pressure despite therapy adjustment, serum phosphate >4.5 mg/dL, or a decrease in hemoglobin ≥1 g/dL. The occurrence of any of these criteria prompted nephrology reassessment according to the study protocol. In the high-risk group, at least one deterioration criterion was documented in 30% of patients during follow-up, most commonly a ≥10% decline in estimated glomerular filtration rate within 3 months or doubling of proteinuria. The algorithm prioritizes early nephroprotective interventions, including optimization of RAAS blockade, initiation of SGLT2 inhibitors when indicated, strict glycemic and blood pressure control, dietary sodium and phosphate restriction, and targeted management of anemia and CKD-mineral bone disorder (e.g., phosphate binders, iron supplementation, erythropoiesis-stimulating agents).

To ensure a multidisciplinary approach, High-risk patients are advised to undergo cardiology evaluation at 3-6 months after COVID-19, with ECG and echocardiography as indicated, due to increased heart failure burden. Patients with persistent fatigue or functional impairment are referred for rehabilitation programs to improve physical capacity and quality of life.

The clinical algorithm is summarized in (Table 2). This structure was retrospectively applied to our cohort of patients with CKD after COVID-19: it correctly identified the 35 high-risk patients who experienced significant renal function decline and would have led them to closer surveillance or early intervention, potentially preventing delay in care. Meanwhile, it would have spared low-risk patients from unnecessary frequent visits. No low-risk patient in our study had an adverse event that would have been missed under the algorithm's follow-up scheme, supporting its safety and efficiency.

Table 2. Post-COVID Monitoring Algorithm for CKD Patients

Risk Category	Criteria	Monitoring Plan	Recommended Interventions
High Risk CKD post-COVID (vulnerable to progression)	• Severe COVID-19 (hospitalized, ICU or COVID-AKI) • Adverse renal markers at follow-up: persistent proteinuria, hyperphosphatemia, and/or anemia	Nephrology follow-up at 1, 3, 6, 12 months in first year post-recovery. Each visit: Check serum creatinine (eGFR) ± cystatin C, urinalysis (proteinuria, hematuria), serum phosphate, potassium, hemoglobin, BP, etc.	If any decline in eGFR or abnormal finding, escalate care promptly: • Optimize BP (<130/80) with RAAS blockade (ACEi/ARB) unless contraindicated. • Start SGLT2 inhibitor (if diabetic CKD or eligible) for renal protection. • Treat proteinuria (maximize ACEi/ARB, add finerenone if indicated). • Manage phosphate (dietary restriction, phosphate binders) and CKD-MBD per guidelines. • Correct anemia (iron, EPO stimulating agents if Hb <10). • Ensure strict glycemic control in diabetes (A1c ~7%). • Cardiology consultation at 3–6 months: ECHO & ECG to evaluate post-COVID cardiac function (especially if heart failure history or symptoms). • Rehabilitation for persistent fatigue: graded exercise program, nutritional counseling, and psychological support as needed.
Low Risk CKD post-COVID (likely stable course)	• Mild COVID-19 (outpatient or brief illness) AND • No significant proteinuria, normal phosphate, no severe anemia at follow-up	Follow-up at ~6 months post-COVID (and again at 12 months if stable). Evaluate the same parameters as above.	Continue routine CKD care with primary care/nephrology as per standard schedule. If new abnormalities emerge (e.g., develops proteinuria or eGFR drop), reclassify as High Risk and intensify monitoring & therapy accordingly.

Note: BP – blood pressure; RAAS – renin-angiotensin-aldosterone system; ACEi – angiotensin-converting enzyme inhibitor; ARB – angiotensin receptor blocker; SGLT2 – sodium-glucose cotransporter-2; CKD-MBD – chronic kidney disease mineral-bone disorder; ECHO – echocardiogram; ECG – electrocardiogram.

DISCUSSION

The present study evaluated renal outcomes in patients with chronic kidney disease after coronavirus disease 2019 and developed an internally validated monitoring algorithm based on identified prognostic factors. The main findings are: (1) renal progression after COVID-19 was heterogeneous; (2) severe infection and acute kidney injury were associated with a greater decline in renal function; and (3) persistent proteinuria, elevated serum phosphate, and low hemoglobin independently predicted advanced chronic kidney disease.

Renal outcomes differed according to infection severity. Patients with mild coronavirus disease 2019 showed kidney function trajectories comparable to controls, consistent with previous longitudinal analyses reporting preserved renal function in most survivors (6, 7). In contrast, individuals with severe disease or COVID-19–associated acute kidney injury experienced a greater estimated glomerular filtration rate decline and higher prevalence of advanced chronic kidney disease. This gradient is in agreement with large cohort studies demonstrating increasing risk of chronic kidney disease progression and end-stage kidney disease proportional to the severity of acute infection (8,9).

A subgroup of post-COVID-19 patients exhibited higher ferritin levels, lower albumin, and more pronounced anemia. These findings suggest persistent inflammatory activity, which is a recognized contributor to chronic kidney disease progression. Similar inflammatory patterns have been described in post-acute coronavirus disease 2019 syndromes (15, 16). However, in the multivariable analysis, inflammatory markers were not independent predictors, indicating that their prognostic impact is likely mediated through renal functional parameters.

Multivariate modeling identified three independent predictors of advanced chronic kidney disease: persistent proteinuria, serum phosphate concentration, and hemoglobin level. These factors are well-established determinants of chronic kidney disease progression irrespective of infection status. Persistent proteinuria reflects ongoing glomerular injury, hyperphosphatemia contributes to vascular and renal structural damage, and anemia promotes tissue hypoxia and fibrosis. The lack of independent associations with age, diabetes, or acute infection severity suggests that current biological status is more relevant than prior infection characteristics in determining medium-term renal prognosis.

Based on these findings, we developed a risk-stratified monitoring algorithm integrating infection severity and laboratory predictors. This strategy is consistent with the Kidney Disease: Improving Global Outcomes recommendations for post–acute kidney injury surveillance (10-12), while extending risk stratification by incorporating proteinuria, phosphate, and hemoglobin. Early identification of high-risk patients may facilitate timely nephrology follow-up and optimization of nephroprotective therapy, which is known to delay progression and reduce mortality (13, 14).

Our results align with population-level analyses showing increased adverse kidney events after coronavirus disease 2019 (17, 18). Unlike machine-learning prediction models requiring complex inputs (19–21), the proposed algorithm relies on routinely available clinical parameters, which enhances feasibility in daily practice.

Overall, progression of chronic kidney disease after coronavirus disease 2019 was not universal but concentrated in identifiable high-risk subgroups. Structured monitoring based on modifiable renal risk factors may support more efficient allocation of healthcare resources.

Limitations

Several limitations should be acknowledged. Follow-up duration was limited (median approximately 9 months), and longer observation is required to determine long-term renal trajectories. The observational design limits causal inference. External validation of the algorithm is necessary, as current performance metrics are based on internal validation. Classification of infection severity relied on medical documentation, which may introduce misclassification bias. Finally, emerging biomarkers and genetic factors were not evaluated.

CONCLUSIONS

1. In patients with chronic kidney disease, renal outcomes after coronavirus disease 2019 were heterogeneous. Mild infection was not associated with significant changes in kidney function compared with controls, whereas severe infection and coronavirus disease 2019-associated acute kidney injury were associated with a greater decline in estimated glomerular filtration rate and higher prevalence of advanced chronic kidney disease.
2. Persistent proteinuria, elevated serum phosphate, and low hemoglobin were independent predictors of advanced chronic kidney disease after COVID-19. These parameters may be used to identify patients at increased risk of progression during follow-up.
3. A structured monitoring strategy based on infection severity and these laboratory predictors may facilitate earlier nephrology reassessment and optimization of nephroprotective therapy, while allowing stable patients to be followed at standard intervals.

CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this study. No financial or personal relationships influenced the conduct or outcomes of this research.

ETHICAL APPROVAL

The research protocol was approved by the Institutional Ethics Committee of “Nicolae Testemițanu” State University of Medicine and Pharmacy (Approval No. 6 of 18/06/2023). All participants provided informed consent prior to enrollment. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and Good Clinical Practice guidelines. Participant confidentiality was strictly maintained throughout the study.

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MEDICAL SCIENCES

PATTERNS OF OCCUPATIONAL INJURIES BY BODY REGION IN INDONESIA'S UPSTREAM OIL AND GAS INDUSTRY

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ABSTRACT

Introduction The oil and gas sectors are inherently high-risk due to complex processes, high-pressure systems, and hazardous physical & chemical exposure. Yet evidence on injury patterns remains limited, hindering effective safety interventions. This study aimed to categorize body part injuries by event type, severity, and work activity to address this gap.

Materials and methods This descriptive cross-sectional study used secondary data from five oil and gas companies in Indonesia (2013–2023), including 948 injury cases, of which 621 were limb injuries, which were analyzed. Data were categorized by injured body part (BPI), event type (TOE), work activity, and severity. The Phi coefficient was used to assess relationships between TOE, work activity, and BPI.

Results This study found that hand, finger, or forearm injuries (BP5) were the most frequent (294 cases; 49.34%) and predominated in all companies, especially Company X1 (>70%). Being caught in, on, between, or under objects was the most common cause, usually involving pinch mechanisms. A strong association was observed between TOE5 and hand/finger injuries (Phi = 0.563), suggesting frequent upper limb pinch and crushing injuries. These incidents, totaling 134 cases, often occurred during nonspecific work activities.

Conclusions This study highlights the high burden of hand and finger injuries in the oil and gas industry, revealing gaps in safety practices. Targeted prevention focusing on pinch hazards and task-specific risks is needed. Future research should assess the effectiveness of interventions and ergonomic improvements to reduce limb injuries.

Keywords Occupational injury, body part injured, oil and gas industry, accident mechanism, prevention, hand injury, Indonesia.

RISCURI DE LEZIUNI ALE DIFERITELOR PĂRȚI ALE CORPULUI ȘI PROVOCĂRILE PRIVIND SIGURANȚA ÎN RÂNDUL LUCRĂTORILOR DIN INDUSTRIA PETROLIERĂ ȘI A GAZELOR DIN INDONEZIA

Introducere Industria petrolieră și a gazelor naturale este considerată una dintre cele mai periculoase ramuri economice, din cauza proceselor tehnologice complexe, a sistemelor care funcționează la presiuni înalte și a expunerii la numeroși factori fizici și chimici periculoși. Cu toate acestea, informațiile privind tipurile leziunilor ocupaționale rămân limitate, ceea ce îngreunează elaborarea unor măsuri eficiente de prevenire. Acest studiu și-a propus să clasifice leziunile în funcție de partea corpului afectată, tipul activității, gravitatea și intensitatea muncii desfășurate.

Materiale și metode Studiul descriptiv transversal a utilizat date secundare provenite de la cinci companii din sectorul petrolier și al gazelor din Indonezia, colectate în perioada 2013–2023. Au fost analizate 948 de cazuri de accidentare, dintre care 621 au reprezentat leziuni ale membrelor. Datele au fost clasificate în funcție de partea corpului lezată, tipul activității, activitatea desfășurată și severitatea leziunii. Relațiile dintre tipul activității, și partea corpului afectată au fost evaluate utilizând coeficientul Phi.

Rezultate Leziunile mâinii, degetelor sau ale antebrațului au fost cele mai frecvente, fiind înregistrate în 294 dintre cazuri (49,34%) și predominând în toate companiile analizate, în special în Compania X1 (peste 70% din cazuri). Cea mai comună cauză a fost prinderea între, sub sau de obiecte, de regulă prin mecanisme de strivire sau ciupire. S-a observat o asociere puternică între TOE5 și leziunile mâinilor/degetelor (Phi = 0,563), sugerând o frecvență ridicată a traumatismelor membrelor superioare cauzate prin strivire și prindere. Aceste incidente, însumând 134 de cazuri, au avut loc, frecvent, în timpul unor activități de muncă nespecificate.

Concluzii Studiul evidențiază povara semnificativă a leziunilor mâinilor și degetelor în industria petrolieră și a gazelor naturale, indicând existența unor lacune în practicile de securitate ocupațională. Sunt necesare măsuri de prevenire, orientate spre reducerea riscurilor de prindere și strivire, precum și spre gestionarea pericolelor specifice anumitor sarcini de lucru. Cercetările viitoare ar trebui să evalueze eficiența intervențiilor preventive și a îmbunătățirilor ergonomice în reducerea leziunilor membrelor.

Cuvinte-cheie Accidentare ocupațională, parte a corpului lezată, industria petrolieră și a gazelor, mecanism de accidentare, prevenire, leziuni ale mâinii, Indonezia.

INTRODUCTION

The oil and gas industry in Indonesia plays a crucial role in supporting national economic growth by supplying a significant portion of the country's energy resources. However, this sector is also characterized by hazardous working environments, including high-pressure systems, toxic chemicals, and extreme field conditions, all of which increase the risk of occupational injuries and illnesses (1,2). In the United States, the rate of non-fatal injuries in the oil and gas sector reached 1.8 per 100 full-time workers by 2022, signaling similar concerns globally (3). Moreover, OSHA data indicate a substantial burden of severe workplace injuries, with upper extremities, particularly fingers, being the most affected body parts. Injuries to the fingers and fingertips consistently rank as the most affected body parts, accounting for approximately 24.7% of all severe injury cases, underscoring that the hands remain the most vulnerable body parts in high-risk occupational settings (4). Arifuddin et al. (2020), in their study, reported data from PT Jamsostek on occupational accidents in Indonesia from 2010 to 2017(5). Subsequently, data from BPJS Ketenagakerjaan (2022), covering the period from 2017 to 2022, indicate a continuous year-on-year increase in the number of occupational accidents (6).

The oil and gas industry is characterized by high-risk environments that expose workers to significant injury hazards (7,8). In this context, analyzing injury patterns linked to specific body parts is crucial for formulating effective safety intervention strategies. Workers often operate under physically and mentally demanding conditions, on rotating shifts, and in various hazardous environments. These conditions increase the risk of musculoskeletal disorders and limb injuries (9–11).

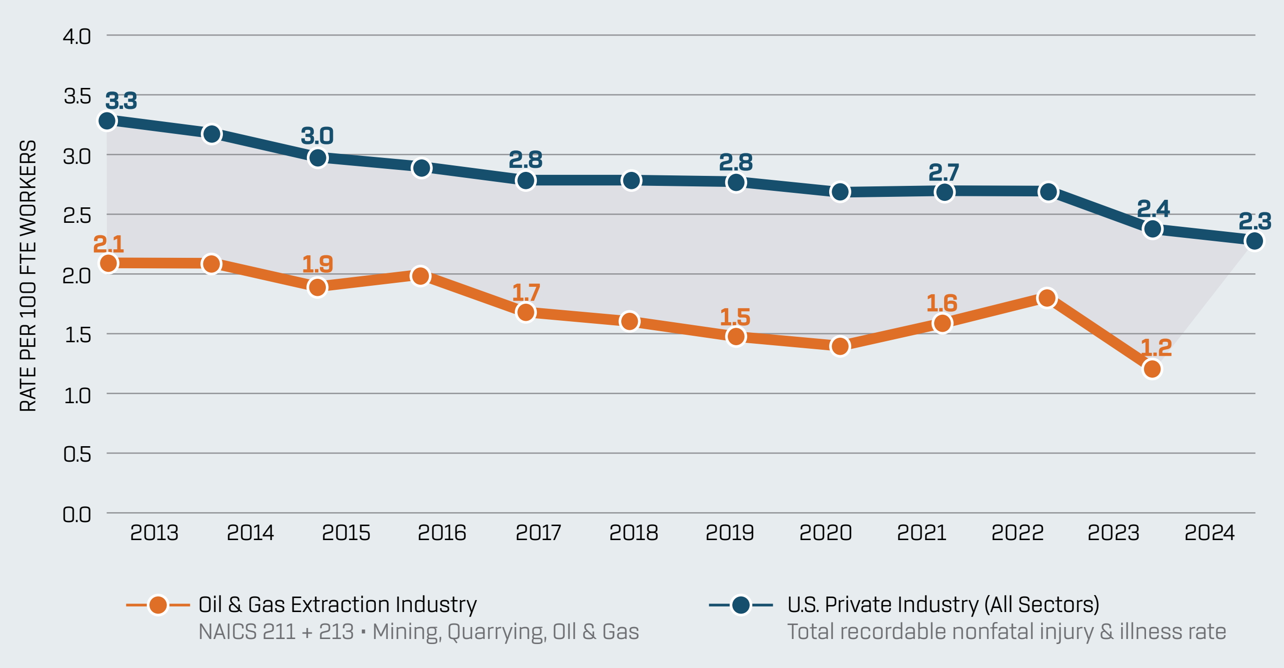


Figure 1. Prevalence of Oil and gas Sector vs Private Sector Non-Fatal Injuries in the United States in 2013-2024 (12)

Despite an overall downward trend in non-fatal injury and illness incidence rates over the past decade, the oil and gas sector continues to present notable occupational safety concerns. As shown in Figure 1, injury rates in the Oil and Gas Extraction Industry decreased substantially, yet remained consistently below the U.S. private industry average. However, the persistence of injuries, particularly those with severe outcomes, highlights ongoing challenges in occupational safety within this high-risk sector.

Recent evidence indicates that upper-extremity injuries are highly prevalent in the oil and gas sectors. A CDC/MMWR study published in 2024 found that 42.6% of severe injuries in the oil and gas industry from January 2015 to July 2022 involved upper extremities, with contract workers in service and drilling subindustries bearing a disproportionately higher burden of these injuries (13). Hand and finger injuries are among the most prevalent types of injuries in the oil and gas sector, often associated with machine tool usage, chemical exposure, unsafe behaviors, inadequate machine maintenance, time pressures, and insufficient training (14,15). Consistent with this, NIOSH data (2015–2022) indicate a substantial burden of injuries to the fingers, hands, and wrists, while national statistics further confirm that upper extremities remain the most commonly affected body region in occupational injuries (16,17).

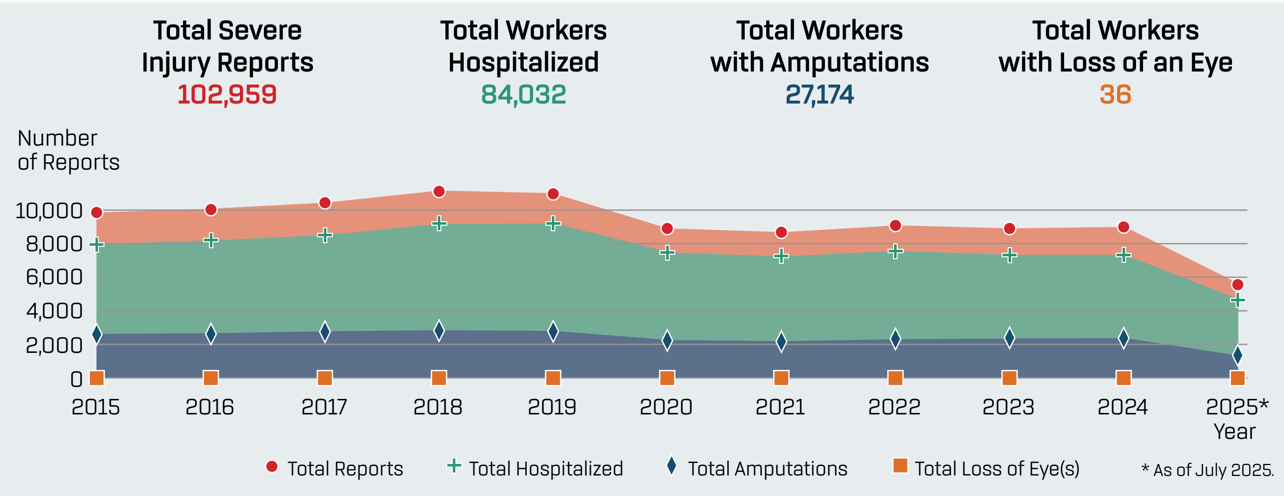


Figure 2. Annual Trends in Severe Workplace Injury Outcomes Reported to OSHA, United States, 2015–2025 (4)

Workplace injuries in the United States continue to pose a significant threat to worker safety (18). OSHA data from 2015 to July 2025 report over 102,000 severe injury cases, with a substantial proportion resulting in hospitalization and a considerable number involving amputations. As shown in Figure 2, although the annual number of reported cases has generally declined since its peak in 2017–2019, the severity of injuries has remained relatively unchanged, as reflected by the persistently high proportion of cases requiring hospitalization. Amputation cases also remained consistently reported over time, indicating ongoing exposure to high-risk hazards. These patterns highlight persistent challenges in workplace safety and underscore the need for more targeted and effective preventive interventions, particularly in high-risk sectors such as oil and gas.

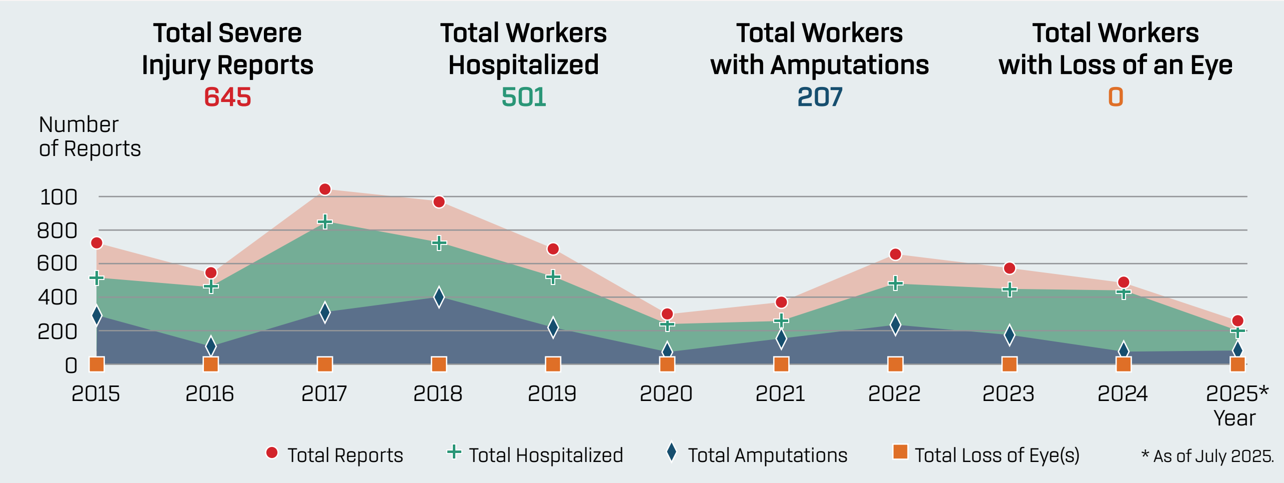


Figure 3. OSHA – 213111: Drilling oil and Gas wells injury reports data (4)

Focusing on the oil and gas sector, OSHA data from 2015 to 2025 recorded 645 severe injury cases, with a substantial proportion resulting in hospitalization and a notable number involving amputations. As shown in Figure 3, injury reports peaked around 2017–2018, declined sharply in 2020, and then fluctuated in subsequent years. Despite the overall decline, the consistently high proportion of hospitalizations indicates that injuries in this sector are often severe. These patterns highlight the persistent risk associated with oil and gas operations and underscore the need for strengthened safety interventions, particularly in settings where safety systems are still developing, such as Indonesia.

Occupational health risks in the oil and gas sector arise from complex operational processes and hazardous workplace exposures, increasing the likelihood of injuries and adverse health outcomes (17,19). Evidence shows that safety management practices—including training, clear procedures, communication, and safety promotion—play a critical role in reducing accident rates, particularly when supported by worker compliance (20–23). In addition, the role of safety culture in preventing injuries cannot be ignored; safety culture is a predictor of safety behavior and safety performance (24). This is especially pertinent in the oil and gas sector, where the inherently high-risk nature of operations requires a robust safety culture characterized by strong safety practices and effective communication to mitigate accident and injury rates (25–27). A study of workers in Nigeria's oil and gas industry found that safety culture significantly influences worker performance (28).

However, challenges remain in ensuring consistent implementation and compliance. Additionally, demographic factors such as age, marital status, and level of experience are associated with injury vulnerability, with newer workers facing higher risks (29,30). Considering these injury patterns and risk factors, stakeholders must implement effective health and safety measures to address both immediate hazards and long-term health impacts. Despite growing research on safety management, evidence on detailed limb injury patterns by event type, severity, and work activity remains limited, particularly in the Indonesian oil and gas context.

Therefore, this study aimed to analyze the incidence and characteristics of body part injuries in Indonesia's oil and gas industry based on type of event, severity, and work activity. It was hypothesized that specific event types are significantly associated with body part injuries in this industry. The findings are expected to inform targeted interventions for improving occupational safety and preventing limb-related injuries in this high-risk sector.

MATERIAL AND METHODS

RESEARCH TYPE

This study employed a quantitative descriptive approach to analyze occupational injury data in the oil and gas industry. The research aimed to provide a comprehensive overview of injury patterns affecting limbs, categorized by the type of incident, severity level, and work activity associated with each case.

POPULATION AND SAMPLE

The study population comprised all reported occupational injury cases from five oil and gas companies in Indonesia, identified by the anonymized codes X1, X2, X3, X4, and X5. Of the 948 total recorded cases, 621 cases of limb injuries reported between 2013 and 2023 were included using total population sampling, ensuring complete representation of injury records across the selected companies.

RESEARCH LOCATION

The study was conducted using occupational injury records obtained from five companies in Indonesia, representing diverse operational environments within the national oil and gas sector.

INSTRUMENTATION OR TOOLS

Secondary data were obtained from official company safety reports, government regulatory records, and industry safety databases. Data variables included the injured body part, type of incident, severity level, and type of work activity involved. To ensure consistency in classification, injury-related variables were standardized using coding systems adapted from industrial safety protocols.

DATA COLLECTION PROCEDURES

Data were extracted retrospectively and compiled into a structured database. Injuries were categorized into five body part groups using a Body Part (BP) code: BP1 – body, back, waist, or shoulders; BP2 – feet, toes, or knees; BP3 – head, face, eyes, neck, or ears; BP4 – internal organs (respiratory, digestive, or other); and BP5 – hands, fingers, or forearms.

The causes of injury were categorized into 31 event types, each assigned a Type of Event (TOE) code, including events such as pinch mechanisms (TOE5), contact with hazardous materials (TOE13), falls (TOE3–TOE4), equipment failure (TOE18), fire and explosion (TOE16–TOE17), and others. Severity was classified into six levels: First Aid (Level 1), Medical Treatment (Level 2), Restricted Workday (Level 3), Day Away from Work (Level 4), and Fatality (Level 5). Work activity types were coded into 12 categories (A1–A12), including construction (A1), maintenance (A5), production operations (A7), land and marine transport (A10–A11), and unspecified activities (A12).

DATA ANALYSIS

Descriptive statistical analysis was conducted to identify the distribution of limb injuries by body part, incident type, severity level, and work activity. Results were tabulated and visualized to determine patterns and high-risk combinations, particularly focusing on the most common injury mechanisms and body regions affected. In addition to descriptive analysis, the strength of association between categorical variables was examined using the Phi coefficient (φ). Phi correlation analysis was applied to assess the relationship between Type of Event (TOE) and Body Part Injury (BP), as well as between work activity categories (A1–A12) and injured body parts.

Given that the Phi coefficient is appropriate for 2×2 contingency tables, categorical variables were dichotomized prior to analysis. Correlation strength was interpreted as weak ($\varphi < 0.20$), moderate ($\varphi = 0.20–0.39$), strong ($\varphi = 0.40–0.59$), and very strong ($\varphi \geq 0.60$). Statistical significance was determined using chi-square p-values, with $p < 0.05$ considered statistically significant. This combined descriptive and associative approach allowed identification not only of the most frequent injury categories but also of the most strongly concentrated body part–event and body part–activity combinations within the oil and gas occupational context.

RESULTS

A total of 621 cases of body-part injury were recorded in five oil and gas companies in Indonesia from 2010 to 2023 in Figure 4. (31)

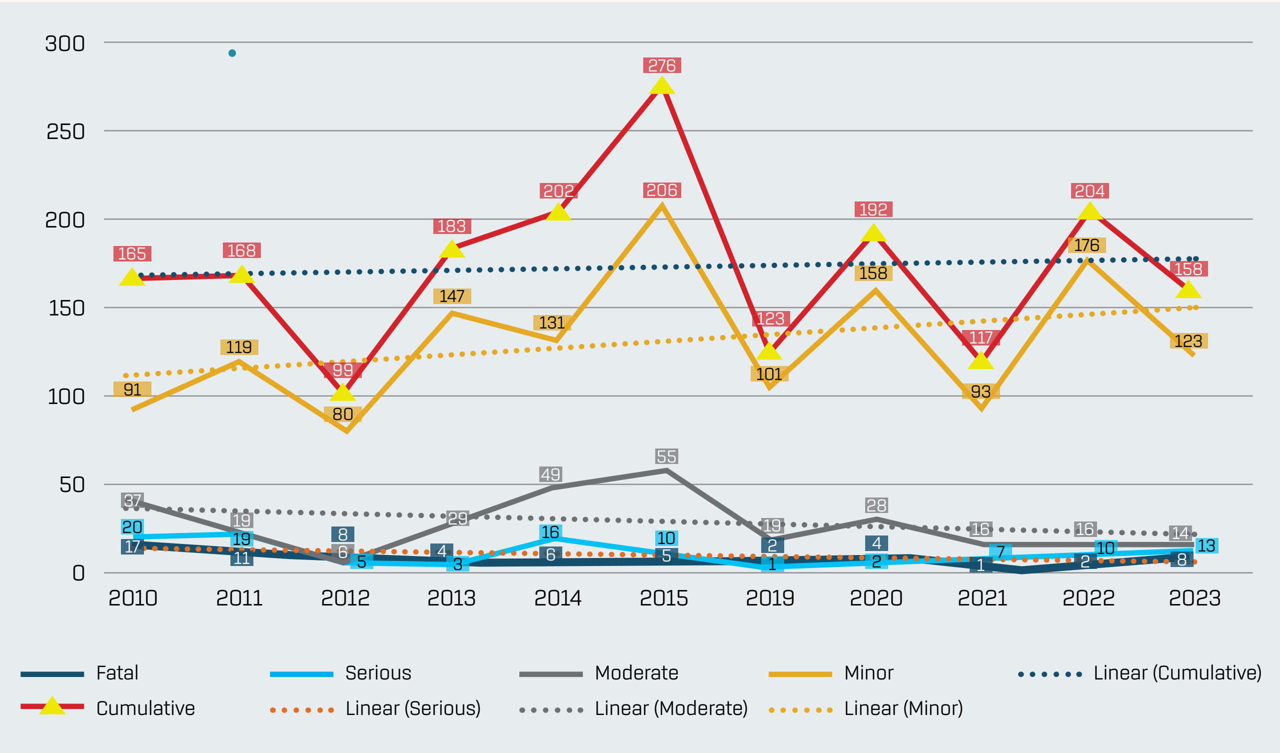


Figure 4. Indonesia's Upstream Oil and gas Work Accident (2010-2023)

The descriptive analysis revealed that the most frequently injured body part was the hands, fingers, or forearms (BP5), accounting for 294 cases (47,34%). This was followed by injuries to the head, face, eyes, neck, or ears (BP3) with 125 cases (20.13%), feet, toes, or knees (BP2) with 119 cases (19.16%), respiratory, digestive, or other internal organs (BP4) with 43 cases (6.92%), and body, back, waist, or shoulders (BP1) with 40 cases (6.44%) in Table 1.

Table 1. Number of Personal Body Injury Incidents among Workers in Oil and gas Companies

No	Body Part Injury (BP)	Frequency	%
1	BP1	40	6,44
2	BP2	119	19,16
3	BP3	125	20,13
4	BP4	43	6,92
5	BP5	294	47,34
	Total	**621**	**100**

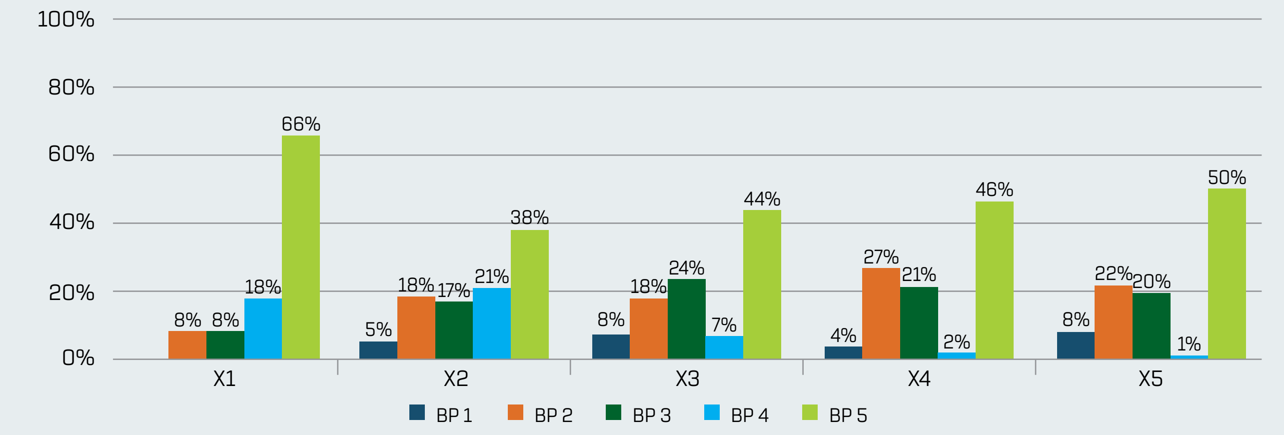
Source: Secondary Data

When examined by company, BP5 remained the most common injury type across all five organizations. In Company X1, about 66% of injuries involved BP5. Company X5 and X3 also reported a high number of BP5 cases (236 and 203 cases, respectively), whereas injuries involving body, back, waist, or shoulders (BP1) were relatively rare but most common in Company X3 (Table 2, Figure 5).

Table 2. Number of Personal Body Injury Incidents among Workers in Each Oil and gas Company

No	Company	BP1	BP2	BP3	BP4	BP5	Total
1	X1	0	4	4	9	33	50
2	X2	4	14	13	16	29	76
3	X3	18	42	56	16	104	236
4	X4	2	15	12	1	26	56
5	X5	16	44	40	1	102	203
	Total	**40**	**119**	**125**	**43**	**294**	**621**

Source: Secondary Data



Source: Secondary Data

Figure 5. Percentage Chart of Personal Body Injury Incidents in Workers in Each Company

A comparison with OSHA data based on NAICS codes 213111 (Drilling Oil and Gas Wells) and 213112 (Support Activities for Oil and Gas Operations) confirmed that hand and finger injuries are consistently the most prevalent type of injury in the oil and gas drilling sector across jurisdictions in Figure 6.

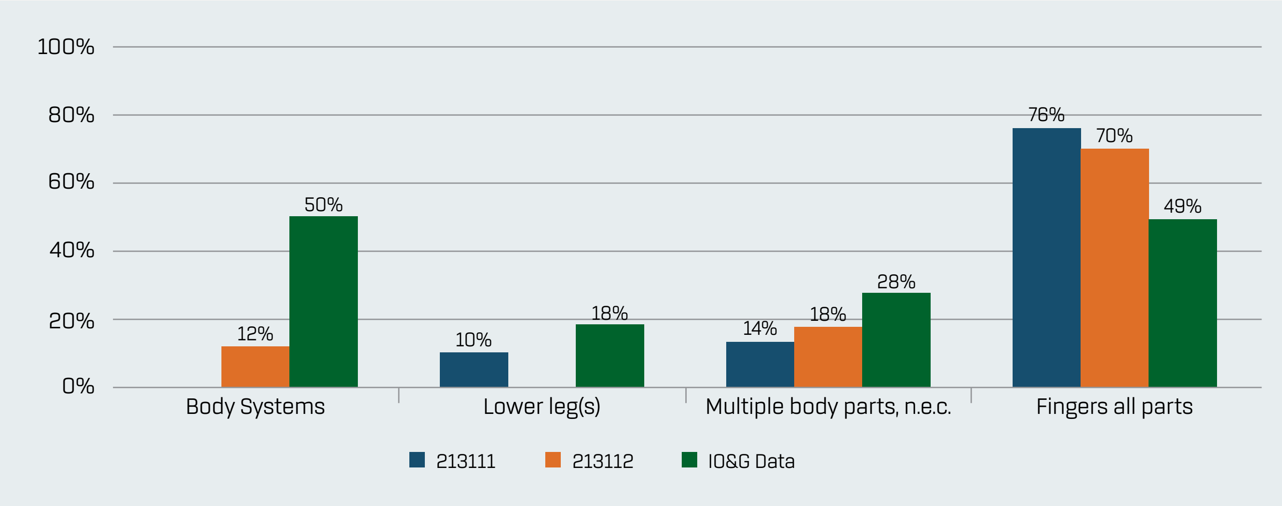


Figure 6. Percentage Chart of Personal Body Injury OI&G Data Compared to NAICS Codes 213111 and 213112

Type of Event (TOE) refers to the classification of incidents involving workers that are formally reported and recorded. This classification is compiled using the PHE SCAT (Systematic Cause Analysis Technique) Table. Analysis of event types in the accident investigation process allows for more effective identification of risk factors and prevention. Table 3 highlights that being struck (TOE2) was the most prevalent type of event, recording 142 cases, with Company X3 accounting for the highest incidence at 60 cases. This was closely followed by being caught in or between objects, or under/being crushed (TOE5), accounting for 140 cases. Other unspecified causes (TOE30) contributed 95 cases, while falling from a height (TOE3) and falling from the same height (TOE4) were less common, with 67 and 56 cases, respectively in Table 3.

Table 3. Number of Type of Event (TOE) among Workers in Oil and gas Companies

Type of Event	Description	X1	X2	X3	X4	X5	Total
TOE2	Being struck (hitting a moving object)	9	15	60	20	38	142
TOE3	Falling from a height (person/equipment/material)	5	9	44	14	12	67
TOE4	Falling from the same height (slipping/tripping)	6	8	17	4	25	56
TOE5	Being trapped in, on, between, or under/being crushed	13	12	55	17	43	140
TOE30	Others	15	6	30	6	50	95

Source: Secondary Data

Activities are characterized as the specific area or tasks in which workers are engaged directly before or at the precise moment an incident takes place. Table 4 illustrates the distribution of various activities among workers across five oil and gas companies. The most frequently observed activity was non-specific activities (A12), accounting for 214 cases, with Company X3 accounting for the highest incidence at 86 cases. This was closely followed by Drilling, Workover, Well Services (A3) with 150 cases, and Maintenance, Inspection, Testing (A5) with 113 cases. Notably, Company X3 consistently exhibited the highest overall activity, particularly dominating in A3 (74 cases) and A5 (49 cases), while Company X5 also showed a high volume of A5 activities (48 cases).

Table 4. Number of Activity among Workers in Oil and gas Companies

Activity	Description	X1	X2	X3	X4	X5	Total
A3	Drilling, Workover, Well Services	11	16	74	16	33	150
A4	Lifting, Crane, Rigging, Deck Operations	1	6	20	12	13	52
A5	Maintenance, Inspection, Testing	4	10	49	2	48	113
A6	Office, Warehouse, Accommodation, Catering	5	9	10	4	22	50
A12	Non-specific activities	19	21	86	47	41	214

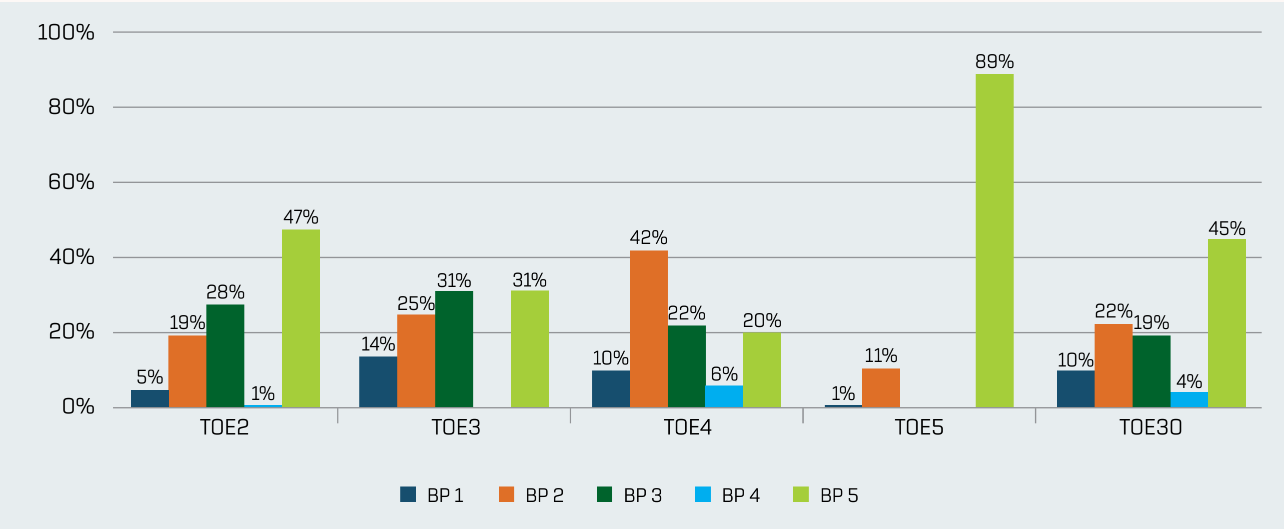
Source: Secondary Data

Injury trends by type of event indicated that BP5 injuries were most frequently caused by being caught in, on, between, or under equipment or objects (TOE5), accounting for 132 cases. This was followed by being struck by moving objects (TOE2) and other unspecified causes (TOE30). Injuries to the head, face, eyes, neck, or ears (BP3) and injuries to the feet, toes, or knees (BP2) were mostly linked to being struck by moving objects (TOE2), while body, back, waist, or shoulders (BP1) were primarily caused by falls from height (TOE3) in Table 5, Figure 7.

Table 5. Body Part Injury by Type of Event

Type of Event	Description	BP1	BP2	BP3	BP4	BP5	Total	Highest BP (φ)
TOE2	Being struck (hitting a moving object)	8	30	43	1	74	156	BP3 = 0.293
TOE3	Falling from a height (person/equipment/ material)	11	20	25	0	25	81	BP1 = 0.232
TOE4	Falling from the same height (slipping/tripping)	5	21	11	3	10	50	BP2 = 0.237
TOE5	Being trapped inside, on, between, or under/ being crushed	1	16	0	0	132	149	BP5 = 0.563
TOE30	Others	10	23	20	4	46	103	BP5 = 0.199

Source: Secondary Data



Source: Secondary Data

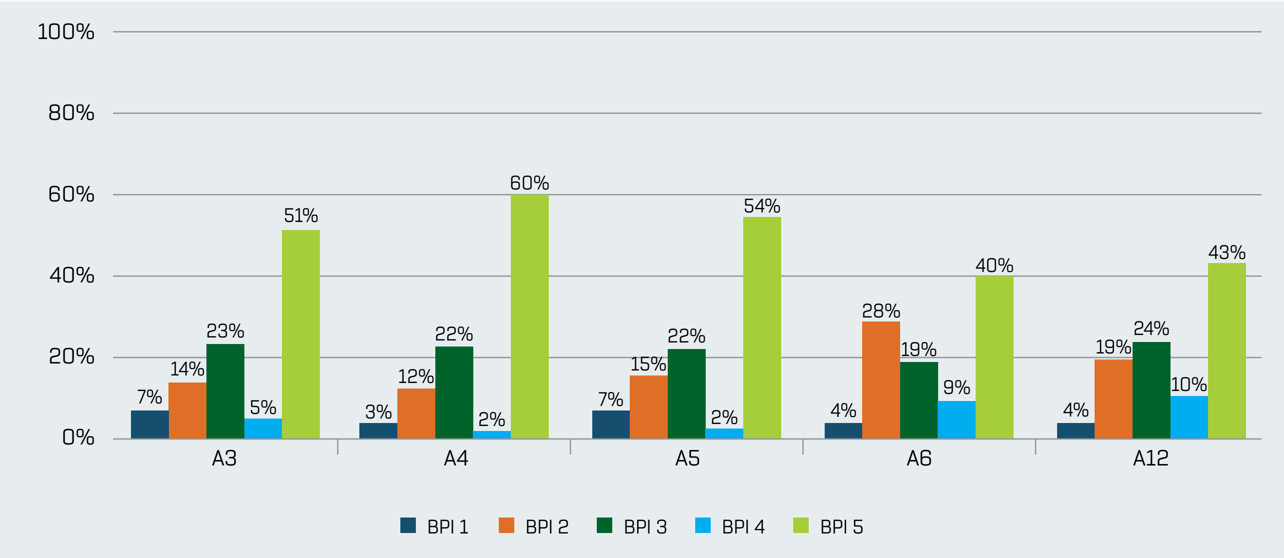
Figure 7. Percentage Chart of Personal Body Injury in Type of Event

In terms of work activity, most BP5 injuries occurred during non-specific activities (A12), with 79 cases, followed by drilling, workover, and well services (A3) with 75 cases, and maintenance, inspection, and testing (A5) with 74 cases. A similar pattern was observed for other body part injuries, with most incidents occurring during A12, A3, and A5 activities in Table 6, Figure 8.

Table 6. Body Part Injury in Each Activity

Activity	Description	BP1	BP2	BP3	BP4	BP5	Total
A3	Drilling, Workover, Well Services	10	20	34	7	75	146
A4	Lifting, Crane, Rigging, Deck Operations	2	7	13	1	35	58
A5	Maintenance, Inspection, Testing	9	21	30	3	74	137
A6	Office, Warehouse, Accommodation, Catering	2	15	10	5	21	53
A12	Non-specific activities	7	36	44	19	79	185

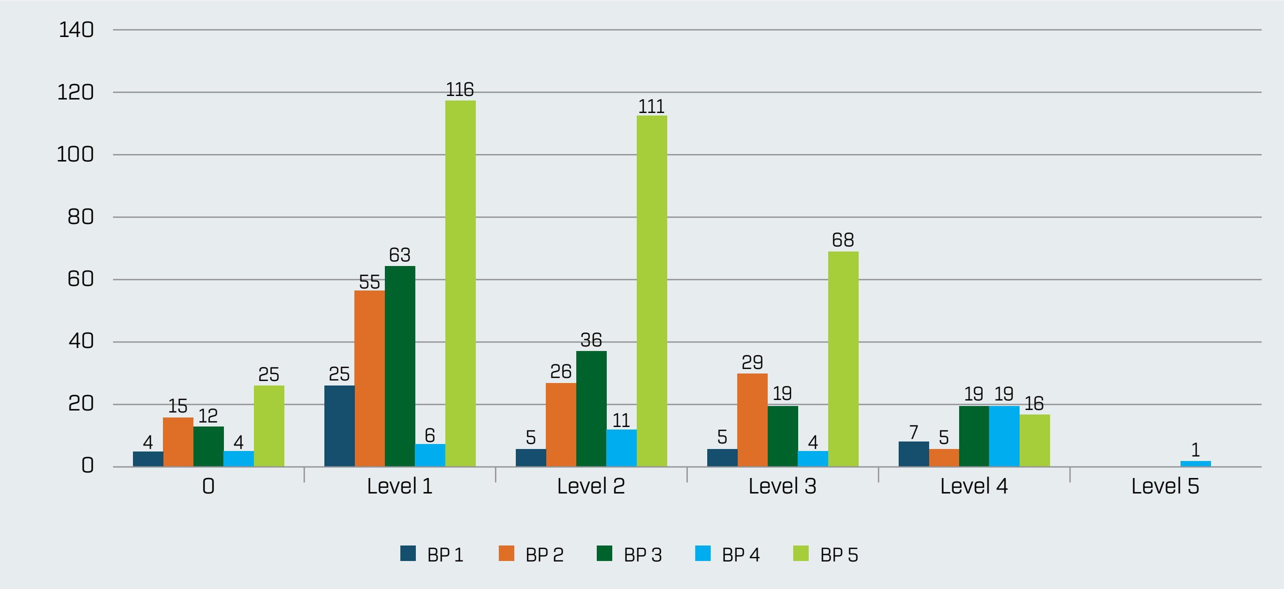
Source: Secondary Data



Source: Secondary Data

Figure 8. Distribution of Occupational Injuries by Body Region in Each Activity

Analysis of injury severity demonstrated that injuries categorized as BP5, BP3, BP2, and BP1 were primarily of Level 1 (First Aid) severity. In contrast, BP4, despite representing the lowest number of cases, exhibited the highest proportion of Level 4 (Day Away from Work) severity ratings in Figure 9.



Source: Secondary Data

Figure 9. Graph of the Number of Personal Body Injury Incidents by Severity Level

These results underscore the high prevalence of upper limb injuries in oil and gas operations, particularly during high-risk and undefined work activities. The findings also highlight key injury mechanisms such as pinch points and contact with moving machinery, providing critical insights for targeted prevention strategies.

Table 7. Correlation between type of event and body part injury

Correlation (Phi Coefficient)	BP0	BP1	BP2	BP3	BP4	BP5
TOE2	-0.026959	0.066379	0.138906	0.293314	-0.028275	0.182433
TOE3	0.232156	0.161474	0.131430	0.163508	0.001415	0.045475
TOE4	0.124480	0.054237	0.237119	0.061236	0.021219	-0.008887
TOE5	-0.007099	-0.024466	0.057367	-0.076820	-0.025792	0.563432
TOE30	0.090708	0.063539	0.093961	0.067391	0.044668	0.198715

The correlation analysis indicates generally weak associations between event types and injured body parts, suggesting that no single event strongly predicts specific injury locations (Table 7). Nevertheless, distinct patterns highlight differentiated risk profiles across activities. Some event types exhibit more specific injury tendencies, reflecting task-related exposure mechanisms, while others show a more distributed pattern, indicating broader hazard exposure. A particularly notable finding is one event type demonstrating a concentrated association with a single body part, suggesting a localized and specific injury mechanism. The presence of both positive and negative correlations further reflects heterogeneity in injury pathways, where risks vary depending on task interactions and work conditions. Overall, these findings suggest that injury risks are shaped by activity-specific processes and exposure dynamics, emphasizing the importance of targeted, rather than generalized, safety interventions.

Table 8. Correlation between work activity and body part injury

Correlation (Phi Coefficient)	BP0	BP1	BP2	BP3	BP4	BP5
A3	0.091129	0.079062	0.090015	0.168713	0.027909	0.248822
A4	0.087951	0.024665	0.062901	0.090782	-0.015194	0.181037
A5	0.025720	0.079504	0.095125	0.162155	0.010411	0.242920
A6	0.034763	0.020480	0.119190	0.058384	0.059017	0.090007
A12	0.226310	0.055004	0.137772	0.164707	0.138715	0.211786

The correlations are generally weak, indicating that no single work activity strongly determines the location of injuries. However, some activities (e.g., A3, A5, and A12) show more specific associations with particular body parts, suggesting focused exposure to hazards. In contrast, other activities display more diffuse patterns, indicating broader exposure (Table 8). Overall, the variation reflects task-specific risk mechanisms, highlighting the need for activity-based targeted safety interventions.

DISCUSSION

Workplace accident data from 2010 to 2023 in Indonesia's oil and gas sector indicate a fluctuating trend across injury-severity categories (31). Despite the growing attention to occupational safety, hand and finger injuries continue to be among the most prevalent, with studies estimating that these account for approximately 15% of all lost-time injuries, often caused by pinch mechanisms, contact with machinery, and insufficient training (14,16). This study found that injuries to the hands, fingers, and forearms (BP5) were the most common among workers in five oil and gas companies in Indonesia between 2013 and 2023. These upper-limb injuries accounted for nearly half of all reported injuries.

This finding is consistent with a report from PT XYZ in 2021–2022, where hand injuries led to medical treatment and work restrictions (32). Similar trends are also seen in the United States, where OSHA records for drilling and well operations (NAICS 213111 and 213112) show upper limb injuries as the most frequently reported. These results suggest that BP5 injuries are a major concern in both national and international oil and gas operations. This pattern is consistent with findings from other industrial sectors, where upper-limb injuries are the most frequent (33). Studies in manufacturing and construction indicate that workers' hands and fingers are particularly vulnerable due to their direct involvement in operating tools and machinery (34). The high prevalence of BP5 injuries observed in this study aligns with previous research, which identifies inadequate training and poor hazard control as key contributing factors (35,36).

Like our findings, Dang et al. (2019) reported that blunt trauma was the primary cause of head and neck injuries in Oil and gas sites in Alberta, Canada, accounting for nearly half of all injuries (37). Head and neck injuries are also common in other industrial sectors, particularly in manufacturing and construction (38). Our data also revealed a notable percentage (28%) of injuries to the head, face, neck, and eyes (BP3), often due to impacts with moving objects (TOE2). This supports earlier studies that found head trauma to be a key cause of workplace deaths (39,40). Likewise, lower limb injuries (BP2) were often associated with slips, trips, and falls, which are common across industrial sectors and often lead to lost workdays (41–44). Injuries to the back, waist, and shoulders (BP1), though less frequent, were tied to high-risk ergonomics and falls from height (45,46). Internal organ injuries (BP4), though rare, often stem from chemical exposure or body function failure, reinforcing previous findings on respiratory and digestive risks from exposure to hydrocarbons and pollutants (47–49).

Analysis of incident data by type of event (TOE), as presented in Table 3, identified TOE2 (being struck) and TOE5 (being trapped inside, on, between, or under/being crushed) as the most dominant causes of incidents. These two types of events contributed 142 and 140 incidents, respectively, collectively accounting for approximately 45% of the total recorded incidents. This significant proportion indicates that workers in oil and gas environments are at high risk of impact and crushing hazards. Further observation revealed variations in the distribution of incidents per TOE across companies. Companies X3 and X5, for example, recorded relatively high numbers of incidents across most TOE categories, which implies the urgency of a comprehensive evaluation of standard operating procedures and hazard controls at these facilities.

As presented in Table 5 and Figure 7, TOE5 within BP5 exhibited the highest event frequency, contributing 132 cases (24%) and representing the largest proportion of the 539 recorded events, indicating a concentration of incidents in this category rather than a correlational relationship. This finding suggests that injuries in BP5 are mostly a direct consequence of being caught or crushed. From an occupational ergonomics perspective, the oil and gas industry involves numerous physical and ergonomic demands, as both upstream and downstream operations rely on complex technologies that require substantial human involvement during operational and maintenance activities (50,51). Ergonomic hazards are recognized as significant contributors to debilitating injuries and long-term disabilities among oil and gas drilling workers (52). Workers in the oil and gas industry frequently perform lifting, operate heavy machinery, perform repetitive tasks, and work in confined spaces, all of which may increase ergonomic strain, particularly during maintenance and operational activities (53).

The predominance of TOE5-related BP5 injuries may also reflect insufficient implementation of engineering and technical risk control measures, particularly during non-routine activities such as startup, shutdown, maintenance, and commissioning processes, which generally require greater levels of human involvement in system operations and are associated with elevated accident risks due to the potential for operator errors and deviations from established procedures (54). In addition, TOE2 showed a substantial contribution to injuries in BP5 and BP3. Meanwhile, TOE3 (falling from a height) was more frequently associated with injuries in BP3 and BP5. In contrast, TOE4 (falling from the same height/slipping/tripping) predominantly caused injuries in BP2.

Analysis of incidents by work activity category reveals distinct patterns in their contribution to total injuries. A12 (non-specific activities) recorded the highest number of incidents, suggesting gaps in task classification or risk identification for non-routine or poorly defined activities. In addition, core operational activities such as A3 (Drilling, Workover, Well Services) and A5 (Maintenance, Inspection, Testing) also contributed substantially to the occurrence of injuries. This indicates that significant risks are not limited to non-specific tasks but are also inherent in essential operational processes. These activities typically involve close interaction with heavy equipment and hazardous energy sources, making them particularly high-risk (55,56). Variations in incident distribution by activity type across companies (e.g., X3 and X4) further suggest differences in work-process characteristics, safety-procedure implementation, or exposure to specific risks (57). The relationship between work activity type and injured body part consistently confirms BP5 (hand, finger, or forearm) as the most frequently injured body part across nearly all activity categories. The consistent presence of BP5 injuries across companies and activities shows a shared vulnerability. These findings support the need for targeted safety programs focusing on hand protection and machine safety.

These findings indicate common, widespread risk factors contributing to hand and forearm injuries across various task types. While BP5's dominance is clear, variations, such as the more even injury distribution between BP2 (foot, toe, or knee) and BP5 in A6 (Office, Warehouse, Accommodation, Catering), suggest differences in injury mechanisms depending on the nature of the work. Pinch-point injuries (TOE5) in which workers' limbs are trapped between, under, or inside objects emerged as the leading mechanism of harm, particularly during nonspecific (A12) and lifting-related activities (A4). These patterns reinforce previous studies indicating that pinch injuries commonly arise from unsafe behaviors, poor hazard recognition, and inadequate safety measures (58).

Detailed incident data show that injuries to BP5 (hands, fingers, forearms) are the most frequent and severe. This was particularly linked to TOE5 (being caught, crushed, or pinched), showing a clear connection between hand use in operations and injury mechanisms. TOE2 (struck by moving objects) was also a major cause of upper-limb injuries, underscoring the dangers of uncontrolled machine movement. These incidents are often associated with insufficient implementation of engineering controls such as machine guarding or lockout/tagout procedures (59). The high frequency of such incidents highlights gaps in mechanical safety systems, supervision, and worker protection measures. Variations across companies further suggest differences in safety culture and the effectiveness of occupational safety and health systems.

The findings underscore the urgent need to strengthen workplace safety in the Indonesian Oil and gas sector. Given the high burden of hand and finger injuries, implementing standardized use of protective gloves and other personal protective equipment (PPE) is critical. Studies show gloves can significantly reduce the severity of impact-related injuries (60). Furthermore, investing in regular training, hazard awareness, and the Permit-to-Work (SIKA) system has been shown to improve safety knowledge and reduce workplace incidents (31,61). Addressing root causes of unsafe behavior, such as lack of competence, poor supervision, and weak enforcement, is essential. Strengthening safety culture through leadership commitment and effective communication can further improve compliance and reduce injury risk. Safety culture plays a pivotal role in driving worker behavior; promoting this through clear communication and leadership accountability can lead to measurable improvements in safety performance (31,61).

This study has several limitations. First, it is based on secondary data collected from company reports and industry databases, which may vary in quality, completeness, and consistency across companies and reporting periods. In addition, the use of company-reported injury records may introduce reporting bias, including underreporting, inconsistent incident classification, or differences in reporting practices across organizations. Second, the available datasets lacked detailed socio-demographic and occupational variables such as age, tenure, gender, job position, employment status, work experience, shift pattern and educational background. The absence of these variables limited the ability to examine individual- and occupational-level risk factors associated with body-part injuries. Moreover, the descriptive design does not allow causal inferences or statistical modeling to control confounding variables. Nevertheless, the study provides an essential overview of injury patterns and mechanisms that can inform safety management practices.

Future research should incorporate qualitative and longitudinal methods to examine root causes, behavioral factors, and organizational safety practices, thereby enhancing our understanding of workplace safety and informing more effective safety management systems and policy frameworks in high-risk industries.

CONCLUSIONS

1. Limb injuries in Indonesia's oil and gas industry are predominantly concentrated in the upper extremities, particularly the hands, fingers, and arms (BP5), making them the most affected body region among reported cases.
2. The most common mechanisms of injury include pinch points, being struck by moving objects, and slips or falls, indicating consistent exposure to mechanical and operational hazards.
3. Injuries occurred most frequently during drilling, lifting, and routine operational tasks.
4. The distribution of injuries across body parts, event types, and work activities highlights specific high-risk combinations that require focused attention.
5. These findings support the need for targeted, activity-based occupational safety strategies, particularly addressing upper limb protection and high-risk operational tasks.

CONFLICT OF INTEREST The authors declare no conflicts of interest.

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ETHICAL APPROVAL This study was approved by the Research and Community Engagement Ethical Committee, Faculty of Public Health, University of Indonesia (Approval Number: Ket-524/UN2.F10.D11/PPM.00.02/2025). The research used secondary data from company safety reports and regulatory records that contained no personally identifiable information. Therefore, informed consent was not required. All data were anonymized prior to analysis, and confidentiality was maintained throughout the research process in accordance with ethical standards.

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MEDICAL SCIENCES

CLINICAL ASSESSMENT OF RISK FACTORS FOR TRAUMATIC BRAIN INJURY OUTCOMES IN PREHOSPITAL AND EMERGENCY DEPARTMENT CARE

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ABSTRACT

Introduction Traumatic brain injury (TBI) remains a major global health burden, associated with high mortality and long-term disability. Secondary brain injury related to hypoxia and hypotension worsens outcomes, particularly in the prehospital stage.

Materials and methods This retrospective observational study included 486 adult patients with acute TBI managed between 2020 and 2024 in the prehospital setting and in the Emergency Department of the Institute of Emergency Medicine, Chisinau, Republic of Moldova. Injury severity was assessed using the Glasgow Coma Scale. Associations between physiological parameters and clinical outcomes were analyzed using Pearson's correlation coefficient.

Results Advanced age, low systolic blood pressure, and prehospital hypoxia were significantly associated with greater TBI severity and increased mortality ($p < 0.0001$). Hypoxia showed a moderate positive correlation with both severity and mortality. Hyperglycemia was not associated with injury severity but correlated significantly with mortality.

Conclusions Early recognition and correction of hypoxia and hypotension during prehospital care are essential to limit secondary brain injury and improve outcomes in patients with TBI.

Keywords Traumatic brain injury, hypoxia, hypotension, mortality, prognosis, risk factors, secondary brain injury.

EVALUAREA CLINICĂ A FACTORILOR DE RISC ÎN TRAUMATISMUL CRANIO-CEREBRAL ÎN STADIUL PRESPITAL ȘI ÎN DEPARTAMENTUL DE MEDICINĂ DE URGENȚĂ

Introducere Traumatismul cranio-cerebral (TCC) reprezintă o problemă majoră de sănătate, asociată cu mortalitate și dizabilitate crescută. Leziunile cerebrale secundare, determinate de hipoxie și hipotensiune, influențează negativ prognosticul, în special în etapa prespitalicească.

Materiale și metode Studiul retrospectiv observațional a fost realizat pe un lot de 486 pacienți adulți cu TCC acut, evaluați în perioada 2020–2024, în etapa prespitalicească și în Departamentul de Medicină de Urgență al Institutului de Medicină Urgentă din Chișinău, Republica Moldova. Severitatea leziunii a fost apreciată prin scala Glasgow. Corelațiile dintre parametrii fiziologici și rezultatele clinice au fost analizate utilizând coeficientul de corelație Pearson.

Rezultate Vârsta înaintată, hipotensiunea și hipoxia prespitalicească au influențat semnificativ severitatea TCC și mortalitatea ($p < 0,0001$). Hipoxia, însă, a prezentat corelații pozitive moderate. Hiperglicemia nu s-a asociat cu severitatea, dar a corelat semnificativ cu mortalitatea.

Concluzii Monitorizarea și ajustarea precoce a hipoxiei și hipotensiunii la etapa prespitalicească au fost esențiale pentru reducerea leziunilor secundare și îmbunătățirea prognosticului.

Cuvinte-cheie Traumatism cranio-cerebral, hipoxie, hipotensiune, mortalitate, prognostic, factori de risc, leziuni cerebrale secundare.

INTRODUCTION

Traumatic brain injury (TBI) remains a major global public health concern, with substantial social and economic consequences. Its incidence varies across regions, ranging from 2.18 to 8.65 cases per 1,000 population, with a markedly higher prevalence among males. In countries such as the United States, the United Kingdom, China, Finland, and Sweden, TBI-related hospitalization rates are approximately 2 per 1,000 population (1).

The leading causes of TBI are road traffic accidents, falls, and interpersonal violence, accounting for 80-90% of all cases (2, 3). Central nervous system injuries represent 30-40% of all trauma cases and are the primary contributors to post-traumatic disability (25-30%) (3, 4). In young adults aged 18–35 years, TBI is the leading cause of trauma-related death (1, 3).

In the Republic of Moldova, recent trends indicate a rise in the number of TBI cases managed during the prehospital care, increasing from 16.443 cases in 2021 to 17.493 in 2022. In the national trauma profile, TBI ranks second after musculoskeletal injuries.

Pathophysiologically, TBI involves both primary brain injuries, either focal or diffuse, and secondary injury developing after the initial insult. Secondary injury may result from systemic factors, including hypoxia, hypotension, and hyperglycemia, as well as intracranial factors such as cerebral edema, raised intracranial pressure, and ischemia. Cerebral ischemia is considered the most critical secondary insult and is reported in approximately 90% of TBI-related deaths (4).

Secondary brain injury contributes to neurological deterioration through complex molecular and cellular mechanisms and may result in irreversible damage. For instance, hypoxia leads to neuronal death and cognitive impairment, while even transient episodes of hypotension may significantly impair cerebral perfusion and worsen neurological outcomes (5).

Effective prehospital management of TBI is therefore essential to limit secondary injury and maintain adequate cerebral perfusion. Early correction of hypoxia and hemodynamic instability directly affects clinical outcomes (6). Prehospital emergency teams play a key role in initial stabilization, with continuous vital-sign monitoring and timely targeted interventions required to prevent further neurological deterioration and improve prognosis (7, 8).

Despite advances in emergency medicine, the early identification and management of secondary brain injury during the prehospital phase remain challenging. Although previous studies have highlighted the importance of hypoxia and hypotension, there is still limited evidence regarding the combined impact of multiple physiological parameters assessed in the prehospital setting, particularly in regional healthcare systems. This represents an important gap in current knowledge.

In this context, the present study aimed to clarify the association between early physiological disturbances and TBI outcomes, with a focus on optimizing prehospital care.

The study evaluated the association of age, systolic blood pressure, mean arterial pressure, hypoxia, and hyperglycemia with TBI severity and mortality. It was hypothesized that early abnormalities in these parameters would be associated with poorer clinical outcomes.

MATERIALS AND METHODS

This study was conducted within the Department of Emergency Medicine of "Nicolae Testemițanu" State University of Medicine and Pharmacy, in collaboration with the Emergency Department of the Institute of Emergency Medicine and the National Center for Prehospital Emergency Medical Assistance, from January 2, 2020 to January 2, 2024.

Study design

This retrospective observational analytical study assessed the association between selected prehospital physiological parameters and TBI severity and mortality.

The study protocol defined the study sample, clinical and paraclinical assessment methods applied during the prehospital and Emergency Department phases, tools for assessing trauma severity and prognosis, and treatment and monitoring procedures. Data were collected using standardized observation and recording forms developed for the study.

Study population and sampling

The study included 486 adult patients aged ≥18 years with acute TBI. Patients were initially assessed by emergency medical services in the prehospital setting and subsequently evaluated in the Emergency Department. A non-probability consecutive sampling method was used, including all eligible patients who met the inclusion criteria during the study period.

Inclusion criteria comprised a confirmed diagnosis of traumatic brain injury, availability of complete prehospital and Emergency Department clinical data, and age ≥18 years. Patients with incomplete key clinical or physiological data were excluded from the analysis.

Outcome measures

TBI severity was assessed at first medical contact using the Glasgow Coma Scale (GCS) and classified as mild (GCS 13–15), moderate (GCS 9–12), or severe (GCS ≤8). Mortality was recorded as a binary outcome, viz. survival or death.

Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of "Nicolae Testemițanu" State University of Medicine and Pharmacy (Decision no. 46, June 17, 2019). Informed consent was obtained where applicable.

Statistical analysis

Descriptive statistics were used to summarize demographic and clinical characteristics. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as absolute frequencies and percentages.

Inferential statistical analysis was performed using Pearson correlation coefficients to evaluate the associations between physiological parameters (age, systolic blood pressure, mean arterial pressure, hypoxia, and hyperglycemia), TBI severity, and mortality. The level of statistical significance was set at $p < 0.05$. Statistical analysis was conducted using standard statistical software.

RESULTS

The study cohort included 486 patients, with a mean age of 51.29 ± 18.34 years, range 18–84 years. Males accounted for 62.9% of cases and females for 37.1%, with a male-to-female ratio of 1.7:1. Most patients were from rural areas, 71.2%.

Mild TBI was recorded in 79.6% of patients, moderate TBI in 12.3%, and severe TBI in 8.0%. The most common mechanisms of injury were falls, 44.65%, followed by physical assault, 25.72%, and road traffic accidents, 18.72%. Demographic and baseline clinical characteristics are shown in Table 1.

Table 1. Demographic and Baseline Clinical Characteristics of the Study Group (n = 486)

Feature	Number of patients	Percentage (%)
Mean age (years)	-	51.29±18.34
Sex		
– Male	306	62.9
– Female	180	37.1
TBI severity (GCS)		
– Mild (GCS 13-15)	387	79.6
– Moderate (GCS 9-12)	60	12.3
– Severe (GCS ≤8)	39	8.0
Residence		
– Urban	140	28.8
– Rural	346	71.2

Isolated TBI without associated injuries was identified in 289 patients, 59.46%. Among these patients, mild TBI predominated, 96.19%, while moderate and severe TBI accounted for 2.42% and 1.39%, respectively. Age showed a weak but statistically significant positive correlation with mortality, r = 0.097, p = 0.033, but was not significantly associated with TBI severity. TBI severity showed a strong positive correlation with mortality, r = 0.594, p < 0.001. Correlations between age, TBI severity, and mortality are presented in Table 2.

Table 2. Correlation Matrix Between Age, TBI Severity, and Mortality Rate (n=486)

Variables	Statistical Indicators	Age	TBI Severity	Mortality Rate
Age	Pearson Correlation	1	0.030	**0.097***
	Sig (2-tailed)		0.513	0.033
	N	486	486	486
TBI Severity	Pearson Correlation	0.030	1	0.594**
	Sig (2-tailed)	0.513		0,000
	N	486	486	486
Mortality Rate	Pearson Correlation	**0.097***	0.030	1
	Sig (2-tailed)	0,033	0.513	
	N	486	486	486

Note: * - Correlation is significant at the 0.05 level (2-tailed)
** - Correlation is significant at the 0.01 level (2-tailed)

Prehospital systolic blood pressure was negatively correlated with both TBI severity, r = –0.254, p < 0.001, and mortality, r = –0.138, p = 0.002. These associations are shown in Table 3.

Table 3. Correlation Between Systolic Blood Pressure and TBI Severity and Mortality in TBI Patients

Variables	SBP	TBI Severity	Mortality Rate
SBP	1	-0,254**	-0,138**
TBI Severity	-0,254**	1	0.594**
Mortality Rate	-0,138**	0.594**	1

Note: *p < 0.05; *p < 0.01. N = 486

Prehospital systolic blood pressure showed a significant negative correlation with TBI severity (r = –0.254, p < 0.001) and mortality (r = –0.138, p = 0.002). The correlation analysis between mean arterial pressure, TBI severity, and mortality is shown in Table 4.

Table 4. Correlation Between Mean Arterial Pressure and TBI Severity and Mortality in TBI Patients

Variables	MAP	TBI Severity	Mortality Rate
MAP	1	-0,195**	-0,213**
TBI Severity	-0,195**	1	0.594**
Mortality Rate	-0,213**	0.594**	1

Note: *p < 0.05; *p < 0.01. N = 486

Mean arterial pressure was significantly negatively correlated with TBI severity (r = –0.195, p < 0.001) and mortality (r = –0.213, p < 0.001).

Table 5. Correlation Between Hypoxia and TBI Severity and Mortality in TBI Patients

Variables	Hypoxia	TBI Severity	Mortality Rate
Hypoxia	1	0,324**	0,264**
TBI Severity	0,324**	1	0.594**
Mortality Rate	0,264**	0.594**	1

Note: *p < 0.05; *p < 0.01. N varies due to missing data (Hypoxia n = 438; total sample n = 486)

Prehospital hypoxia was significantly associated with poorer outcomes. It showed a moderate positive correlation with TBI severity (r = 0.324, p < 0.001) and mortality (r = 0.264, p < 0.001) (Table 5).

Table 6. Correlation Between Hyperglycemia and TBI Severity and Mortality in TBI Patients

Variables	Hyperglycemia	TBI Severity	Mortality Rate
Hyperglycemia	1	-0.088	-0,213**
TBI Severity	-0.088 *	1	0.594**
Mortality Rate	-0,213**	0.594**	1

Note: *p < 0.05; *p < 0.01

Hyperglycemia showed a weak, non-significant negative correlation with TBI severity ($r = -0.088$, $p = 0.060$). In contrast, a significant negative correlation was observed between hyperglycemia and mortality ($r = -0.213$, $p < 0.01$) (Table 6).

DISCUSSION

The present study included 486 patients with TBI managed in the prehospital phase and in the Emergency Department, and examined factors associated with injury severity and mortality. Older age, hypotension, and prehospital hypoxia were significantly associated with greater TBI severity and higher mortality (9–23). These findings are consistent with recent evidence emphasizing the role of early physiological stabilization in improving outcomes after TBI (6, 19). A noteworthy finding is the moderate positive correlation between prehospital hypoxia and both TBI severity and mortality (14–16). This underscores the importance of early oxygen monitoring and timely correction during the prehospital phase, aligning with prior literature emphasizing hypoxia as a major secondary insult in TBI (12). Similarly, lower systolic and mean arterial pressures were associated with more severe injury and increased mortality, confirming the prognostic importance of early hemodynamic stabilization (14 - 16, 21, 22, 24 – 28).

Particular attention should be paid to systemic secondary cerebral insults (ACSOS), which significantly influence TBI progression (4, 7, 9, 12, 13, 25 – 34). These secondary insults, including hypoxia, hypotension, and metabolic disturbances, interact with primary injury mechanisms and exacerbate neurological deterioration.

Early recognition and management of ACSOS are therefore essential during both prehospital care and Emergency Department treatment (23, 24, 26, 28, 29, 31, 32). Structured monitoring of oxygenation and blood pressure may reduce secondary injury and improve survival.

The association between hyperglycemia and mortality was another relevant finding. The moderate negative correlation observed may reflect complex metabolic responses after TBI and warrants further investigation in larger multicenter studies. TBI induces an acute stress response mediated by activation of the sympathoadrenal-medullary axis, leading to increased circulating levels of cortisol, glucagon, insulin, catecholamines, glucose, lactate, and free fatty acids (15, 21, 22, 24, 26, 28). In this context, blood glucose may serve as a marker of post-traumatic metabolic stress.

Hyperglycemia, however, is not only an epiphenomenon. It may aggravate secondary brain injury by increasing oxidative stress through free radical generation, promoting apoptosis, and contributing to tissue lactic acidosis (17, 19). Although treatment often focuses on primary brain injury, secondary insults such as hyperglycemia may be underestimated and may contribute to the "second-hit" phenomenon, adversely affecting outcomes (17, 19).

Regarding injury mechanisms, falls were the most common cause of TBI across all severity categories, followed by assault and road traffic accidents. Moreover, isolated TBI was associated with milder injury and a more favorable prognosis, suggesting that concomitant trauma complicates management and increases the risk of adverse outcomes. These findings support comprehensive assessment in polytrauma patients. The results highlight the clinical relevance of early, structured, and targeted prehospital interventions to reduce secondary brain injury and optimize patient outcomes. These findings are consistent with current evidence supporting prehospital protocols focused on oxygenation, hemodynamic stabilization, and metabolic monitoring (7, 13, 26).

CONCLUSIONS

1. Advanced age, prehospital hypotension, and hypoxia are significant predictors of TBI severity and mortality.
2. Early identification and correction of hypoxia and hemodynamic instability are essential in prehospital care.
3. Hyperglycemia may have a prognostic role in mortality, although it is not associated with injury severity.

CONFLICT OF INTEREST The authors declare no conflicts of interest related to this study.

ETHICS APPROVAL The study was approved by the Research Ethics Committee of the State University of Medicine and Pharmacy "Nicolae Testemițanu" (Decision no. 46 of 17.06.2019).

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MEDICAL SCIENCES

QUALITY OF LIFE IN PRE-DIALYSIS CHRONIC KIDNEY DISEASE: INFLUENCE OF GENDER, STAGE, SYMPTOM BURDEN, AND COMORBIDITIES

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ABSTRACT

Introduction Chronic kidney disease (CKD) negatively affects health-related quality of life (HRQoL) even in the pre-dialysis stages. However, data regarding gender- and stage-related differences in Eastern European CKD populations remain sparse compared to major international cohorts like CRIC and DOPPS. In this study, Low quality of life (low QoL) was defined as a Physical Component Summary (PCS) score below the 25th percentile of the cohort distribution.

Materials and methods This cross-sectional study included 989 adults with CKD stages I–V undergoing conservative management. HRQoL was evaluated using the KDQOL-36™ questionnaire. We performed gender and CKD stage comparisons, Pearson correlations, and multivariate logistic regression to identify predictors of low QoL. Symptom burden was assessed via structured patient interviews, complemented by the KDQOL-36™ symptom domain to ensure standardized reporting.

Results The mean patient age was 58.3 ± 12.5 years, and 52.8% were male. The mean PCS and Mental Component Summary (MCS) scores were 40.2 ± 10.8 and 43.5 ± 11.2, respectively. Women had lower PCS scores than men (38.0 vs. 41.0; $p < 0.05$) and a higher prevalence of fatigue (95.0% vs. 85.0%) and dysuria (70.8% vs. 52.6%; $p < 0.001$). QoL declined progressively with advancing CKD stage (PCS 44.2 in stages I–II vs. 34.5 in stages IV–V; $p < 0.001$), and PCS correlated positively with eGFR ($r \approx 0.45$; $p < 0.001$). Independent predictors of low QoL included advanced CKD stage (OR 2.72), diabetes (OR 1.94), anemia (OR 1.80), hypoalbuminemia (OR 1.70), a disease duration of >5 years (OR 1.50), and female sex (OR 1.38).

Conclusions HRQoL is substantially impaired in pre-dialysis CKD, particularly among women and patients with advanced disease, highlighting the need for targeted, patient-centered interventions.

Keywords Chronic kidney disease, quality of life, KDQOL-36, gender, CKD stages, symptom burden, comorbidities.

CALITATEA VIEȚII ÎN BOALA CRONICĂ DE RINICHI ÎN STADIILE PRE-DIALITICE: INFLUENȚA GENULUI, A STADIULUI, A POVERII SIMPTOMELOR ȘI A COMORBIDITĂȚILOR

Introducere Boala cronică de rinichi (BCR) afectează negativ calitatea vieții, (HRQoL) chiar și în stadiile pre-dializă. Datele privind diferențele legate de gen și de stadiu, în populațiile cu BCR din Europa de Est, sunt limitate. Acest studiu abordează o lacună importantă în cunoaștere, deoarece datele privind determinanții HRQoL în populațiile cu BCR pre-dializă, din Europa de Est rămân limitate, în comparație cu cohortele internaționale majore, precum CRIC și DOPPS. Calitatea scăzută a vieții (QoL scăzută) în acest studiu a fost definită ca un scor al Sumarului Componentei Fizice (PCS) sub 25% de distribuție a cohortei.

Materiale și metode Un studiu transversal a inclus 989 de adulți cu boală cronică de rinichi (BCR) în stadiile I–V, aflați sub tratament conservator. Calitatea vieții legată de sănătate (HRQoL) a fost evaluată utilizând chestionarul KDQOL-36™. Au fost realizate comparații în funcție de gen și de stadiul BCR, corelații Pearson și regresie logistică multivariată pentru a identifica predictorii unei calități scăzute a vieții. Simptomele au fost evaluate prin interviuri structurate cu pacienții, completate cu itemi din domeniul simptomelor al chestionarului KDQOL-36™, pentru a asigura o raportare standardizată.

Rezultate Vârsta medie a fost de 58,3±12,5 ani, iar 52,8% dintre participanți au fost bărbați. Scorurile medii PCS și MCS au fost 40,2±10,8, respectiv 43,5±11,2. Femeile au avut scoruri PCS mai mici decât bărbații (38,0 vs. 41,0; $p<0{,}05$) și o prevalență mai mare a oboselii (95,0% vs. 85,0%) și a disuriei (70,8% vs. 52,6%; $p<0{,}001$). Calitatea vieții a scăzut odată cu progresia stadiului BCR, scorul PCS fiind 44,2 în stadiile I–II comparativ cu 34,5 în stadiile IV–V ($p<0{,}001$). Scorul PCS s-a corelat cu rata de filtrare glomerulară estimată (eGFR) ($r\approx0{,}45$; $p<0{,}001$). Predictorii independenți ai unei calități scăzute a vieții au fost: stadiul avansat al BCR (OR 2,72), anemia (OR 1,80), diabetul (OR 1,94), hipoalbuminemia (OR 1,70), durata bolii >5 ani (OR 1,50), sexul feminin (OR 1,38).

Concluzii HRQoL este substanțial afectată în BCR pre-dializă, în special în rândul femeilor și al pacienților cu boală avansată, evidențiind necesitatea unor intervenții direcționate, centrate pe pacient.

Cuvinte-cheie Boală cronică de rinichi, calitatea vieții, KDQOL-36, gen, stadii BCR, povara simptomelor, comorbidități.

INTRODUCTION

Chronic kidney disease (CKD) is a major global public health concern. It is estimated to affect approximately 10–13% of the adult population worldwide, corresponding to more than 800 million individuals (1). Its prevalence continues to increase, largely because of population aging and the growing burden of major risk factors such as diabetes and hypertension. CKD is also an increasingly important cause of mortality and disability: in 2017, it ranked as the 12th leading cause of death worldwide, and projections suggest that by 2040 it may become the 5th leading cause of years of life lost (2). Beyond its effect on survival, CKD has a substantial impact on patients' daily functioning and overall well-being. Across all stages, it is associated with increased cardiovascular morbidity, fatigue, and reduced quality of life (3). Health-related quality of life (HRQoL) has therefore become an important outcome in CKD care, as it reflects the physical, psychological, and social consequences of the disease (4). In patients with advanced CKD and in those receiving dialysis, HRQoL is often severely impaired– comparable to or worse than many other chronic illnesses. However, relatively fewer studies have focused on HRQoL in earlier, pre-dialysis stages of CKD (5). The period preceding dialysis is particularly important, as patients with advanced CKD often experience increasing symptom burden, uncertainty about disease progression, and growing lifestyle restrictions, all of which may adversely affect QoL. Identifying the determinants of QoL in pre-dialysis CKD is therefore essential for timely intervention (6).

Gender-related differences in CKD progression and outcomes are well documented. Although CKD is more prevalent in women, men are more likely to progress to end-stage kidney disease (7). Yet, women with CKD often report worse subjective health status and a greater symptom burden than men. Prior studies have shown that female patients more frequently experience fatigue, pain, and depressive symptoms, which may contribute to lower quality-of-life scores (8). On the other hand, male patients may under-report symptoms or face different psychosocial stressors. Further clarification is needed regarding the effect of sex on quality of life in CKD, particularly in the pre-dialysis setting, to support a more tailored, patient-centred care. Comorbidities and CKD-related complications are also important determinants of quality of life (6). Diabetes mellitus and cardiovascular disease are common in this population and contribute not only to faster disease progression, but also to poorer functional status and reduced QoL (9). CKD-related anemia, which is common in stages IV and V, is associated with fatigue, weakness, and cognitive impairment, all of which can markedly affect vitality and day-to-day functioning. Likewise, chronic inflammation and poor nutritional status, reflected in part by hypoalbuminaemia, are associated with worse physical and mental well-being (10). Previous studies have shown that greater symptom burden is associated with QoL in CKD, and that correction of potentially treatable factors, such as anaemia, may improve patient-reported outcomes (11). However, the relationship between CKD stage, symptom burden, and quality of life remains incompletely understood, particularly whether quality-of-life impairment in pre-dialysis CKD is driven mainly by disease severity, symptom burden, comorbid conditions, or broader psychosocial factors.

This study evaluated quality of life in a large cohort of pre-dialysis CKD patients across all disease stages (I–V) before the initiation of hemodialysis. The primary objective was to determine whether clinical severity and sex independently predict low HRQoL in pre-dialysis CKD. Secondary objectives were to assess differences in QoL between female and male CKD patients and to examine the relationship of QoL with clinical factors, including symptoms and common comorbidities. The study further aimed to identify the principal predictors of poor QoL in this population. It was hypothesized that

HRQoL in pre-dialysis CKD is significantly influenced by CKD stage, female sex, symptom burden, and major comorbidities (anemia, diabetes, and hypoalbuminemia), with advanced disease stages and female sex independently associated with low PCS scores.

MATERIAL AND METHODS

Patients were recruited consecutively during routine nephrology visits to minimize selection bias and to ensure adequate representation of the outpatient CKD population.

Study Design and Setting

This cross-sectional observational study included adult patients with CKD stages I–V who were receiving nephrology care at a tertiary referral center. Recruitment took place between 2022 and 2023 in the Nephrology Department of the Republican Clinical Hospital "Timofei Moșneaga" in Chișinău, Moldova. At the time of evaluation, all patients were managed conservatively and were not receiving dialysis. The study protocol, entitled *Quality of Life in Chronic Kidney Disease up to Hemodialysis*, was approved by the Research Ethics Committee of Nicolae Testemițanu University (approval No. 35, 2023). Written informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki and national guidelines for research involving human subjects.

Inclusion and Exclusion Criteria

Adult patients (aged ≥18 years) with CKD of any etiology in stages I through V (pre-dialysis) were included. CKD was defined and staged according to KDIGO criteria as persistent GFR <60 mL/min/1.73 m^2 or markers of kidney damage present for ≥3 months, with stages I–V determined by estimated GFR. Exclusion criteria were maintenance dialysis, a functioning kidney transplant, and any other end-stage non-renal illness expected to have a dominant effect on QoL (e.g. metastatic cancer, class IV heart failure, or advanced neurodegenerative disease). Patients with acute kidney injury and those unable to complete the QoL questionnaire because of cognitive or language barriers were also excluded. On the basis of prevalence data and the anticipated subgroup analyses, the target sample size was at least 450 patients to provide adequate statistical power. In total, 989 eligible patients were enrolled, reflecting a broad spectrum of CKD severity.

Data Collection

Clinical data were obtained from medical records and structured interviews. The following data were recorded: demographic characteristics (age, sex, education, employment, and residence), CKD etiology and duration, comorbidities (e.g., hypertension, diabetes, and cardiovascular disease), and recent laboratory parameters, including creatinine, urea, eGFR calculated using the 2021 CKD-EPI equation, hemoglobin, albumin, and proteinuria. CKD stages were classified according to eGFR, with stage 3 further subdivided into 3a and 3b. Treatment-related information and enrollment in pre-dialysis programs were also documented.

Quality of Life Assessment

QoL was assessed using the Romanian-validated KDQOL-36™, which comprises the SF-12 components (PCS and MCS) and three kidney-specific scales: Symptoms/Problems, Effects of Kidney Disease, and Burden of Kidney Disease.

Scores range from 0 to 100, with higher scores indicating better QoL. The questionnaire was self-administered or interviewer-administered, as appropriate. Standard scoring algorithms were used to derive PCS, MCS, subscale scores, and the Kidney Disease Summary Score (KSS).

Symptom and Clinical Assessment

Beyond KDQOL items, patients were screened for common CKD symptoms (fatigue, back pain, dysuria, sleep disturbances, pruritus, edema) via interview and exam. Edema was graded as absent, peripheral, or anasarca. Anemia (Hb <12 g/dL in women and <13 g/dL in men), erythropoietin use, and hyperkalemia (serum potassium >5.0 mmol/L) were also recorded. These variables were analyzed in relation to QoL. When abnormal values were detected, laboratory measurements were verified according to routine clinical practice.

Patient Characteristics

The study included 989 pre-dialysis CKD patients across stages I–V. The mean age of the overall cohort was 58.3 ± 12.5 years. When stratified by sex, the mean age was 58.7 ± 12.2 years in women and 56.1 ± 14.2 years in men. The median age was 62.0 years (IQR 14.0) in women and 60.0 years (IQR 20.3) in men. Age distribution differed significantly between the sexes ($p = 0.014$). The distribution by CKD stage was as follows: stage I, 18.2%; stage II, 25.3%; stage IIIa, 22.0%; stage IIIb, 15.5%; stage IV, 11.6%; and stage V, 7.4%. Sex distribution was similar across stages ($p = 0.18$), although men were slightly overrepresented in stage V (57%).

The primary CKD etiologies were chronic interstitial nephropathies (~60%), glomerulonephritis (~36%), and diabetic kidney disease (28.9%), often in association with other causes. Comorbidities were common: hypertension was present in 92.5% of patients, with no significant difference between the sexes; diabetes in 29.4%; ischemic heart disease in 9.0% (10.1% in men vs 7.6% in women, $p = 0.2$); obesity in 19.5%; and dyslipidemia in 41.2%, with a significantly higher prevalence in women than in men (48.8% vs 33.3%, $p < 0.001$). Mean eGFR was 60.1 ± 35 mL/min/1.73 m² and was slightly lower in men than in women (57.5 vs 66.1), consistent with the stage distribution. Median CKD duration was 4.8 years (IQR 2–8). Renal anemia was present in 54.0% of patients and was more common in women than in men (57.7% vs 48.9%, $p = 0.011$). Median hemoglobin was 123 g/L in women and 131 g/L in men. Serum albumin <35 g/L was observed in 46.8% of patients, with no significant sex difference, suggesting inflammation or malnutrition. Hyperkalemia (K^+ >5.0 mmol/L) was present in 61.9% and was more frequent in men than in women (67.3% vs 57.3%, $p = 0.003$). Overall, 86.5% of patients had at least one CKD-related complication upon evaluation.

Statistical Analysis

Statistical analyses were performed using SPSS version 23.0 and R. Continuous variables were assessed for normality using the Shapiro-Wilk test. Normally distributed variables are presented as mean ± standard deviation and were compared using Student's t-test or one-way analysis of variance (ANOVA), as appropriate. Non-normally distributed variables are presented as median and interquartile range (IQR) and were compared using the Mann-Whitney U test or the Kruskal-Wallis test. To capture clinically meaningful impairment, Low QoL was defined as a PCS score below the 25th percentile of the cohort. This data-driven, quartile-based threshold is consistent with established approaches in HRQoL research to identify patients at the highest risk of functional limitation.

Categorical variables are presented as absolute numbers and percentages and were compared using the chi-square test or Fisher's exact test, as appropriate. Associations between continuous clinical variables and quality-of-life scores were assessed using Pearson's or Spearman's correlation coefficients, depending on data distribution. Multivariate logistic regression analysis was used to identify independent predictors of low quality of life, defined as a Physical Component Summary (PCS) score below the 25th percentile. Variables with $p < 0.10$ in univariate analysis, together with clinically relevant covariates (age, sex, CKD stage, anemia, diabetes mellitus, hypoalbuminemia, and CKD duration), were entered into the multivariate model. Results are reported as odds ratios (ORs) with 95% confidence intervals (CIs). Across all analyses, a two-sided p-value < 0.05 was considered statistically significant. In addition to logistic regression, a multivariable linear regression model with PCS as a continuous dependent variable was also examined to assess the robustness of the observed associations.

RESULTS

Group comparisons and associations are presented according to variable distribution and predefined statistical models, as detailed in the Statistical Analysis section.

Symptom Burden

Most patients with CKD reported multiple symptoms. Chronic fatigue and low back pain were each present in 91.5% of patients, increasing alongside advancing disease stage and the presence of anemia. Dysuria was reported by 64.8% of patients, indicating that urinary symptoms were common in this cohort. Sleep disturbances, pruritus, and appetite loss were also frequently reported, particularly in advanced CKD.

Women had a significantly greater symptom burden than men. Specifically, fatigue and back pain were present in approximately 95% of women versus 85% of men ($p < 0.001$), while dysuria affected 70.8% of women compared to 52.6% of men ($p < 0.001$) (Figure 1). In contrast, the prevalence of edema was comparable between sexes (approximately 52% in both groups; $p = 0.90$), suggesting that fluid retention correlates more closely with overall disease severity than with patient sex (Table 1).

This difference is consistent with previous reports showing that women with CKD report symptoms more frequently and with greater intensity than men. Higher symptom burden was also associated with significantly lower QoL: patients reporting three or more moderate-to-severe symptoms had markedly lower physical function and vitality scores ($p<0.001$). These outcomes are consistent with international data, which demonstrate that a high symptom load in non-dialysis CKD reduces PCS and MCS scores by approximately 13 and 8 points, respectively. Consequently, these results highlight that the targeted management of fatigue, pain, and other predominant symptoms is essential to improving quality of life.

Table 1. Prevalence of self-reported symptoms among women and men

Symptom	Women (n=662) N (%)	Men (n=327) N (%)	p-value
Low back pain			<0.001
Yes	628 (94.9%)	277 (84.7%)	
No	34 (5.1%)	50 (15.3%)	
Dysuria			<0.001
Yes	469 (70.8%)	172 (52.6%)	
No	193 (29.2%)	155 (47.4%)	
Fatigue			<0.001
Yes	629 (95.0%)	278 (85.0%)	
No	33 (5.0%)	49 (15.0%)	
Edema			0.9
Yes	345 (52.1%)	168 (51.4%)	
No	317 (47.9%)	159 (48.6%)	

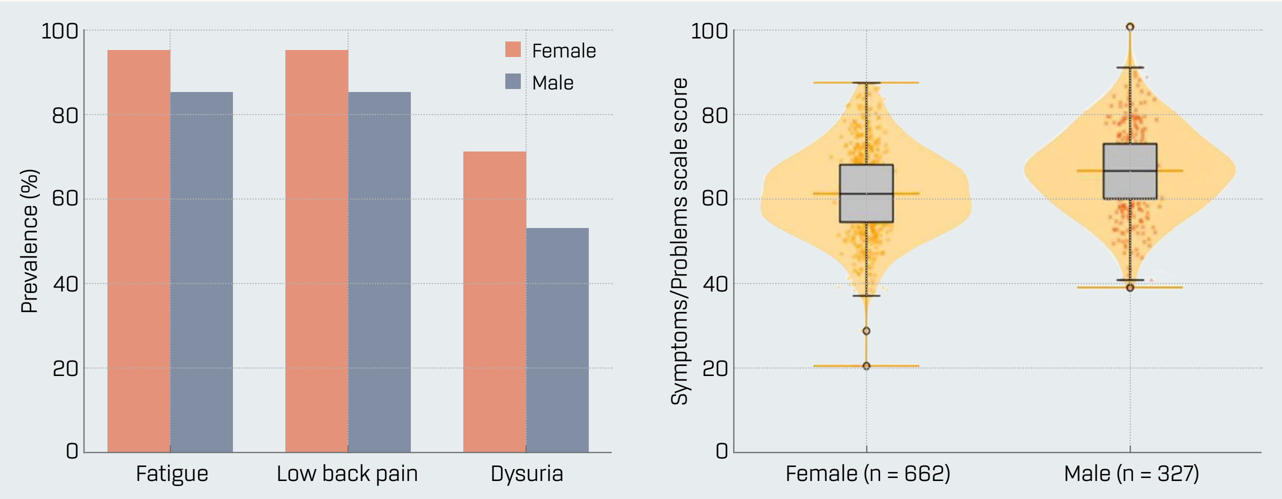

Figure 1. Prevalence of key chronic symptoms in CKD patients by gender.

Quality of Life Scores

Quality of life (QoL) was significantly impaired across the pre-dialysis CKD cohort. The mean SF-12 Physical Component Summary (PCS) and Mental Component Summary (MCS) scores were 40.2 ± 10.8 and 43.5 ± 11.2, respectively, both below the population norm of 50, indicating substantial physical and emotional impairment. Women had lower scores across all KDQOL-36 domains, including PCS (38.0 vs 41.0) and MCS (approximately 42.0 vs 45.0) (p<0.05). A similar pattern was observed for the kidney-specific subscales, with lower scores in women for Symptoms, Effects, and, most notably, Burden (mean 34.7 ± 21 in women vs 41.5 ± 23 in men, p<0.01) (Figure 2). This difference remained significant after adjustment for CKD stage, hemoglobin, and other covariates, with female sex independently associated with 3-5 point lower QoL scores.

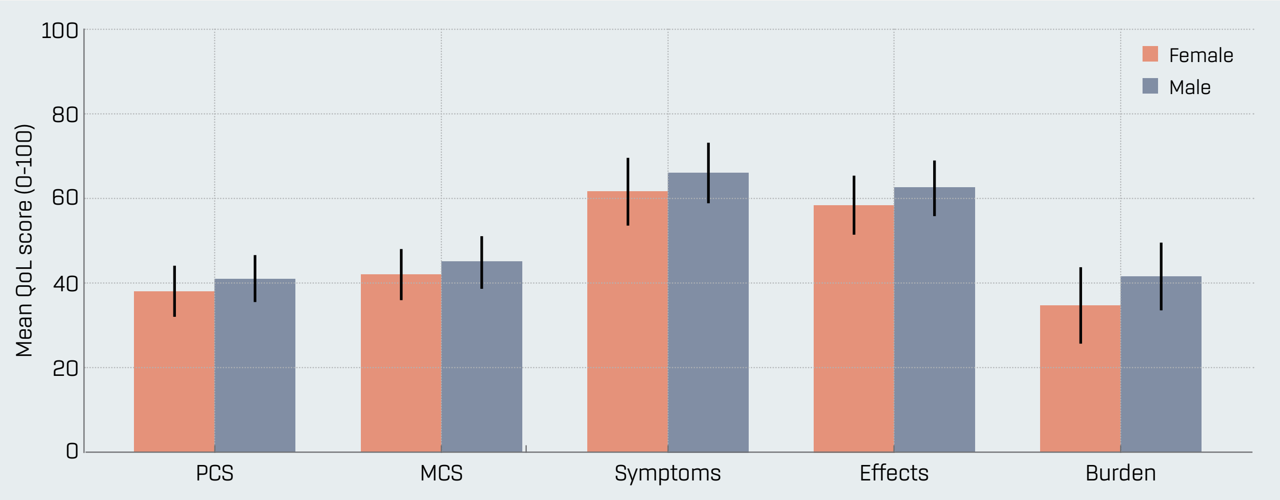

Figure 2. Health-related quality of life (HRQoL) scores in pre-dialysis CKD by gender (KDQOL-36 domains). This chart compares female (red) and male (blue) patients' mean scores (0–100 scale) on the SF-12 Physical Component (PCS) and Mental Component (MCS), and the kidney-disease-specific subscales: Symptoms/Problems, Effects of kidney disease, and Burden of kidney disease. Female patients scored lower in all domains. All gender differences were statistically significant ($p<0.05$). Error bars show standard deviations.

Quality of Life by CKD Stage

As expected, QoL deteriorated progressively with advancing CKD stage. There was a clear gradient: patients in early CKD (stages I-II) had the highest QoL scores, those in intermediate stage III had mid-range scores, and advanced CKD (stages IV-V) patients had the poorest QoL. For instance, mean PCS in stage I-II patients was 44.2, compared to 39.0 in stage III and only 34.5 in stage IV-V ($p<0.001$ across groups). A similar pattern was observed for MCS, although the decline was less pronounced, with mean values of approximately 46.7 in the early stages, 42.0 in stage III, and 39.0 in stages IV–V ($p<0.001$). The differences between early (I-II) and advanced (IV-V) groups were highly significant for both physical and mental components (Figure 3). When dichotomized, advanced-stage CKD (G4-G5) patients had an average PCS about 8 points lower and MCS ~7 points lower than those in mild CKD (G1-G2). In fact, stage IV-V patients' mean PCS of ~36 indicates severe functional impairment comparable to patients on dialysis or those with congestive heart failure. The stage-related trend was evident as well in the kidney-specific subscales: for example, the Symptoms/Problems score worsened from a mean ~75 in early CKD to ~60 in advanced CKD, and the Burden score dropped from ~45 in early stages to ~30 in stage V ($p<0.01$ for trend). The physical function and role limitations aspects of SF-36 showed the sharpest declines at advanced stages, reflecting accumulated disability. Interestingly, general mental health and emotional well-being scores, while lower in advanced CKD, did not drop as precipitously; some patients maintained stable mental QoL despite progression, possibly due to coping mechanisms or support systems. Nonetheless, overall HRQoL was significantly compromised by late-stage CKD, corroborating prior reports that each stepwise decline in GFR is associated with worse patient-reported outcomes.

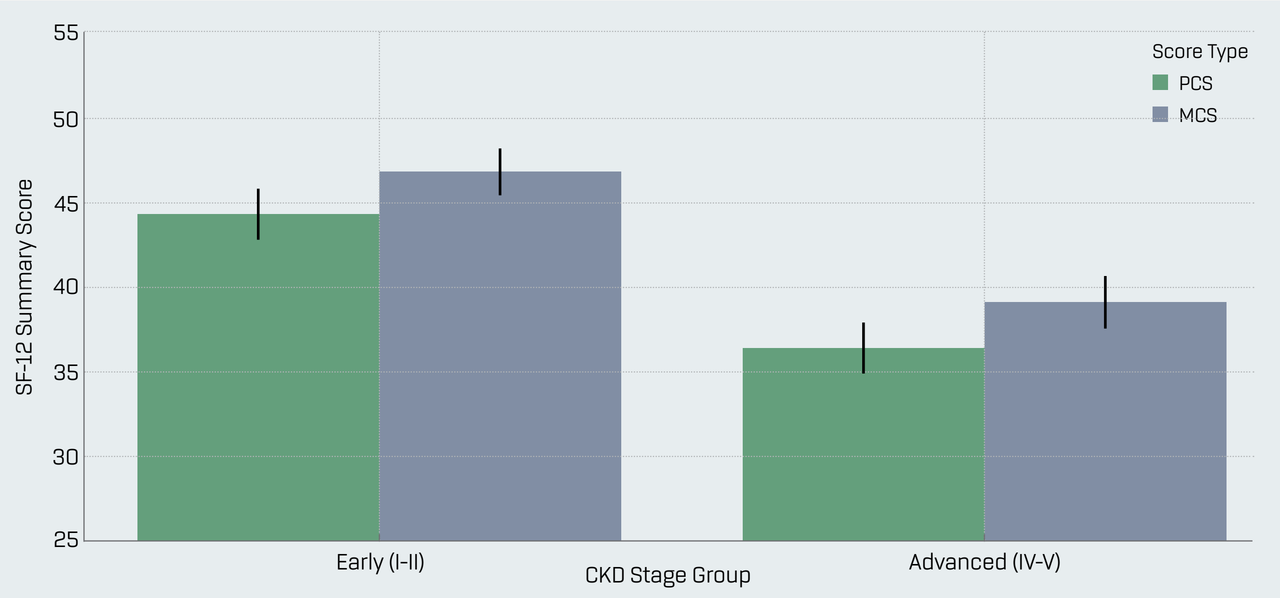

Figure 3. Physical and mental component summary scores in early vs advanced CKD stages.

Further analysis examined whether specific stage transitions were associated with the greatest impact on QoL. The largest reduction in PCS was observed between stage III and stage IV, corresponding to a decline in eGFR below ~30 ml/min; This transition is often accompanied by a substantial increase in symptom burden, including fatigue and anorexia, together with more marked lifestyle limitations. Stage V (pre-dialysis) patients had the lowest scores of all, on par with patients just starting dialysis reported in literature. Notably, there was a moderate positive correlation between eGFR and PCS ($r \approx 0.45$, $p<0.001$), indicating that better kidney function was associated with better perceived physical health. In contrast, the correlation between eGFR and MCS was weak ($r \approx 0.10$, $p=0.09$), suggesting that mental health in CKD may depend less on renal function per se than on other factors, including psychosocial support, coping mechanisms, and comorbid depression.

Factors Associated with Low QoL

Several clinical variables were strongly associated with poorer QoL. Diabetic patients had lower PCS scores by ~3.5 points and reduced kidney-specific QoL ($p<0.01$), likely due to added burdens such as neuropathy and cardiovascular disease. Similarly, patients with cardiac disease had PCS scores ~4 points lower ($p=0.02$). Anemia (Hb <11 g/dL) was linked to ~5-point lower PCS and reduced vitality ($p<0.001$), with hemoglobin moderately correlating with the Vitality subscale ($r \approx 0.5$). Hypoalbuminemia (<35 g/L) was associated with more severe symptoms ($r \approx -0.4$) and lower MCS ($r \approx -0.25$). Longer CKD duration (>5 years) was also linked to diminished social and mental functioning ($p<0.05$), possibly due to cumulative disease burden. Multivariate regression identified independent predictors of low QoL (PCS <33): advanced CKD stage (OR 2.72, 95% CI 1.9-3.9, $p<0.001$), diabetes (OR 1.94), anemia (OR 1.8), hypoalbuminemia (OR 1.7), disease duration >5 years (OR 1.5), and female sex (OR 1.38). Age >60 was not independently predictive.

DISCUSSION

This study assessed health-related quality of life in a large cohort of pre-dialysis CKD patients and examined the associations of sex, CKD stage, symptoms, and comorbidities with QoL outcomes. To current knowledge, it represents one of the most comprehensive evaluations of QoL across all stages of CKD in an Eastern European population. The present findings highlight important determinants of patient well-being in CKD and have relevant implications for nephrology practice. Given the cross-sectional design, the observed relationships should be interpreted as associative rather than causal.

Quality of Life in CKD – Overall Impact

The present findings confirm that CKD has a substantial adverse effect on quality of life even before the onset of dialysis. Mean PCS and MCS scores in this pre-dialysis cohort were markedly lower than population norms, indicating significant impairment in both physical and mental health. The reduction in physical QoL, with a mean PCS of approximately 40, is comparable to that reported in patients with advanced heart failure or COPD, highlighting the considerable burden of CKD. This observation is consistent with previous studies showing that HRQoL is significantly reduced in CKD and declines further as kidney function worsens (6). Even in stage III CKD, often considered mild to moderate, patients showed meaningful limitations in energy and physical functioning, indicating that CKD may affect daily life well before the onset of kidney failure (12). The progressive decline in QoL with advancing CKD stage is also consistent with previous cross-sectional studies (13). In particular, patients in stages IV–V had PCS and MCS scores approximately 7–8 points lower than those in stages I–II, confirming a statistically and clinically significant decline. Each 10 mL/min drop in eGFR roughly corresponded to a few-point drop in PCS in our cohort. Importantly, mental QoL did not decline as steeply as physical QoL, as reported in other studies (14). This pattern may reflect a degree of psychological adaptation or resilience; however, by stage V, even mental health scores were quite low (~39). These findings further indicate that QoL impairment in CKD is multidimensional. In addition to the generic SF-12 components, the kidney-specific domains of the KDQOL-36—Symptoms, Effects, and Burden—captured important aspects of symptom distress and illness intrusiveness. The Burden of Kidney Disease domain, in particular, showed very low mean scores, reflecting the extent to which CKD affects daily life through dietary restrictions, medication burden, and concern about future disease progression. Taken together, these findings highlight the importance of addressing not only biomedical targets, but also the functional and psychological burden of CKD in routine clinical care (15).

Gender Disparities

A notable finding of this study was the clear difference in QoL between female and male patients with CKD. Female patients consistently reported poorer QoL than male patients across all five KDQOL-36 subscales, despite having, on average, slightly less advanced disease according to some clinical measures, including eGFR. After adjustment for CKD stage and comorbidities, female sex remained an independent predictor of low QoL (OR ~1.4). This finding is consistent with reports from other CKD cohorts and chronic disease populations. Fletcher et al. (6), for example, showed that women with CKD often experience a greater symptom burden and poorer HRQoL, a pattern observed across different settings. In the present cohort, women reported significantly higher rates of fatigue, pain, and urinary symptoms than men, which may partly explain their lower QoL scores. The literature suggests several reasons for this gender gap: biologically, women might experience certain symptoms more intensely (e.g. higher prevalence of anemia-related fatigue, as we saw, and greater likelihood of UTI-related discomfort) (16). Psychosocial factors may also contribute, as women may be more likely to report symptoms and emotional distress, whereas men may underreport symptoms or use different coping strategies. In addition, women with chronic illness often face distinct social roles and responsibilities, including caregiving demands, which may increase the perceived burden of disease. The present data showed women had especially low scores on the Burden scale, indicating they felt more encumbered by the illness in daily life (17). This could be due to role expectations; for instance, dietary restrictions and functional limitations related to CKD may interfere more substantially with family and daily responsibilities or coincide with lower levels of social support.

Interestingly, despite poorer QoL among women, epidemiological data indicate that men are more likely to progress to ESRD more rapidly (7). This paradox has been described previously: although CKD progression tends to be slower in women, this may coexist with poorer perceived health, possibly because of a greater symptom burden or disparities in access to care (18). In an international CKD outcomes study (CKDopps), women with non-dialysis CKD were more likely than men to report a high symptom burden (adjusted OR ~1.5), which was associated with lower physical QoL. Similar findings have been reported in dialysis populations, where women have also been shown to have poorer QoL and higher rates of depression than men (19).

These findings support the need for a gender-sensitive approach to CKD management. Symptoms and QoL should be assessed routinely, particularly in female patients, in whom symptom burden may be greater. Targeted treatment of anemia, appropriate pain management, and psychosocial support may be especially important for improving QoL in this group. Multidisciplinary care involving dietitians, social workers, and psychologists may also help address the broader challenges associated with living with CKD (20). Although interventional outcomes were not examined directly in this study, female sex emerged as a marker of greater symptom burden and poorer QoL, supporting the need for proactive supportive care.

Symptom burden and comorbidities

Beyond gender and CKD stage, symptom burden and comorbidities appeared to be major determinants of QoL in this present study. Fatigue, pain, and related symptoms are not merely consequences of CKD, but important contributors to impaired functioning and reduced well-being (6). Fatigue, reported by 91% of patients, was strongly associated with lower vitality and poorer physical QoL scores. This is consistent with the findings of Farag et al. (2023), who showed that anemia-related fatigue in CKD significantly impairs physical activity (21). Treatment of anemia remains one of the few interventions shown to improve QoL in CKD, in line with trial data indicating that modest increases in hemoglobin may lead to better energy levels and physical functioning. In this cohort, each 1 g/dL decrease in hemoglobin was associated with a meaningful decline in PCS and vitality scores, supporting the importance of appropriate anemia management as a QoL-oriented strategy (21).

Pain also appears to be an under-recognized determinant of reduced QoL in CKD. Nearly 92% of patients reported chronic back pain, and pain is known to adversely affect sleep and mental health. Adequate analgesia, with careful attention to renal dosing, together with treatment of renal bone disease or neuropathy when present, may help improve patients' daily comfort and QoL (22). Comorbidities such as diabetes were identified as independent predictors of poor QoL. Diabetic CKD patients are likely to experience multiple contributors to symptom burden, including neuropathy, vascular complications, and dietary restrictions, which may further worsen quality of life. Previous studies have likewise shown that diabetes is associated with poorer physical QoL and higher rates of hospitalization. These findings are consistent with other reports (23), which have shown that comorbid chronic conditions, particularly depression and diabetes, synergistically lower QoL in older adults. Ischemic heart disease and heart failure were also more common in the studied men and were associated with lower QoL, though the effect size was smaller after controlling for stage and anemia. Given that cardiovascular disease remains a leading cause of death in CKD, its presence may also signal a reduced exercise capacity and more hospital visits, affecting QoL (24).). Together, these findings underscore the importance of optimal management of comorbid conditions in CKD. Cardiovascular risk reduction, glycemic control, and appropriate treatment of complications may help preserve or improve QoL, in addition to improving survival.

Another notable finding was that hypoalbuminemia was associated with lower QoL, particularly with greater symptom burden and poorer mental health. Serum albumin is a marker of nutritional and inflammatory status, and reduced albumin levels in CKD often accompanies anorexia, inflammation, and muscle wasting – all factors that can make patients feel unwell (25). We found patients with albumin <35 g/L had more severe symptom scores ($r = -0.4$). This observation is consistent with the malnutrition-inflammation complex described in CKD, which has been linked to fatigue, frailty, and depression. Nutritional support and anti-inflammatory strategies may therefore contribute indirectly to improved QoL by raising albumin or reducing inflammation, although this remains challenging in clinical practice. Nonetheless, recognizing a low albumin as a red flag for poor QoL could prompt clinicians to involve dietitians or start an early oral nutrition support.

Limitations

Several limitations should be considered when interpreting these findings. The cross-sectional design did not allow assessment of changes in QoL over time and precluded any inference of causality. Data were based on patient self-report and medical records and were therefore subject to potential reporting bias, although validated tools were used. The inclusion of a single-country, ethnically homogeneous cohort may also limit the generalizability of the results. In addition, depression and anxiety were not evaluated using standardized psychometric instruments, such as the PHQ-9 or HADS, and their contribution to impaired mental QoL may therefore have been underestimated. Other potentially relevant clinical variables, including comorbidity severity and treatment adherence, were not fully detailed. Despite these limitations, the large sample size and robust methodology of the study support the overall reliability of the findings.

CONCLUSIONS

1. This study demonstrates that quality of life (QoL) was substantially impaired in patients with CKD prior to dialysis, particularly among women and those with advanced stages (G4-G5). These groups reported lower physical and mental health scores and a greater symptom burden.
2. Diabetes, anemia, hypoalbuminemia, and longer disease duration were independently associated with poorer QoL, indicating that these factors represent important targets for clinical intervention.
3. Routine assessment of QoL should be incorporated into the care of patients with CKD, together with a multidisciplinary approach focused on medical management, symptom control, and psychosocial support.

4. Tailored interventions, especially for high-risk patients (e.g., female sex, CKD stages IV–V, presence of diabetes or anemia), may improve daily functioning and overall well-being.

5. From a public health perspective, both slowing CKD progression and addressing the patient experience should be considered core priorities, as QoL emerges as a critical patient-reported outcome for clinical decision-making and the development of more holistic care models for individuals with CKD.

CONFLICT OF INTEREST

The author declares no conflicts of interest related to this work. The research was conducted independently and received no industry funding.

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ETHICAL APPROVAL

The study protocol was approved by the Ethics Committee of the Nicolae Testemițanu State University of Medicine and Pharmacy, Chișinău (Approval No. 35, issued April 2023). All participants provided written informed consent. The study was conducted in accordance with the Helsinki Declaration and applicable national regulations for research in human subjects, with particular care to protect patient confidentiality and well-being. No experimental interventions were performed; only questionnaire and observational data were collected. Participants identified with severe depressive symptoms or distress during interviews were offered referral to counseling services as an ethical measure to ensure their well-being.

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MEDICAL SCIENCES

WASH-BIOSECURITY INTERVENTION STRATEGIES TO REDUCE *E. COLI* AND ESBL *E. COLI* EXPOSURE IN FARMWORKERS

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ABSTRACT

Introduction *E. coli* and extended-spectrum β-lactamase-producing *E. coli* in livestock farming represent a significant occupational health risk to farmworkers. To evaluate potential mitigation strategies within a *One Health* framework, this study applied a Quantitative Microbial Risk Assessment at a teaching farm in Indonesia.

Materials and methods The assessment examined the effects of various *WASH-biosecurity* interventions, including feed silo installation, the use of semi-automatic manure scrapers and conveyors, and modifications to composting practices, by using a Monte Carlo simulation to estimate the potential exposure reduction.

Results The interventions showed variable effectiveness. Modifying the ruminant composting house with porous concrete was the most effective approach, reducing *E. coli* exposure by approximately 99%. The installation of semi-automatic scrapers for ruminant manure and feed silos also proved highly effective, resulting in reductions of 88.3% and 87.6%, respectively.

Conclusions The study concluded that targeted source-specific WASH-biosecurity strategies, particularly improvements to ruminant composting infrastructure, are crucial for significantly reducing microbial exposure and protecting the health of farmworkers from antimicrobial resistance-related risks.

Keywords *E. coli*, Indonesia, intervention scenario, livestock, occupational health.

STRATEGII DE INTERVENȚIE WASH PENTRU A REDUCE EXPUNEREA LA *E. COLI* ȘI *E. COLI* PRODUCĂTOARE DE ESBL LA LUCRĂTORII DIN FERME

Introducere *E. coli* și *E. coli* producătoare de β-lactamaze cu spectru extins (ESBL) reprezintă agenți patogeni relevanți în fermele zootehnice, constituind un risc major pentru sănătatea lucrătorilor agricoli. Pentru a evalua strategiile de reducere a riscului în cadrul conceptului *One Health*, prezentul studiu a apelat la o estimare cantitativă a riscului microbian într-o fermă didactică din Indonezia.

Materiale și metode Evaluarea a modelat impactul diferitelor intervenții *WASH-biosecuritate*, inclusiv instalarea de silozuri pentru furaje, utilizarea de raclete semiautomate pentru gunoiul de grajd și benzi transportoare, precum și modificări ale procesului de compostare, folosind o simulare Monte Carlo pentru a analiza potențialele reduceri ale expunerii.

Rezultate Studiul a demonstrat eficiențe variate între intervențiile evaluate. Modificarea adăpostului de compostare pentru rumegătoare cu beton poros a reprezentat cea mai eficientă strategie, reducând expunerea la E. coli cu aproximativ 99%. Instalarea de raclete semiautomate pentru gunoiul de grajd de la rumegătoare și silozurile pentru furaje au fost, de asemenea, foarte eficiente, contribuind la reduceri de 88,3% și 87,6%, respectiv.

Concluzii Studiul a relevat că strategiile *WASH-biosecuritate*, direcționate și specifice sursei, în special îmbunătățirile infrastructurii de compostare pentru rumegătoare, sunt esențiale pentru reducerea semnificativă a expunerii microbiene și protejarea sănătății lucrătorilor din ferme împotriva amenințării rezistenței antimicrobiene.

Cuvinte-cheie *E. coli*, Indonezia, scenariu de intervenție, animale de fermă, sănătatea ocupațională.

INTRODUCTION

ESBL *E. coli* refers to strains of *E. coli* that produce an enzyme called β-lactamase, making it resistant to various β-lactam antibiotics, including penicillins and cephalosporins (1). As antimicrobial-resistant strains, these organisms can thrive in a variety of environmental reservoirs. Their presence complicates the treatment of infection and has been detected in soil, water, and ambient air within farm environments. Such resistance is a potential threat to animal health and increases the risk of occupational exposure among farmworkers who are in daily contact with livestock and contaminated surroundings. Consequently, this may contribute to development of urinary tract infections, respiratory tract infections, and sepsis (2).

Direct contact with animal feces is a key transmission route for both *E. coli* and ESBL-producing *E. coli*, with beef cattle stool posing the highest modelled infection risk (9.8×10^{-3} pppy) due to concentrations of up to 2.49 $\log_{10}$ CFU/gram and seasonal ingestion rates of 6.84–8.64 mg/day (3). ESBL *E. coli* exposure affected 12% of livestock workers and up to 43% of farming communities, with ingestion responsible for 90% of colonization, which highlights the urgent need for targeted interventions (4–6).

The One Health approach integrates human, animal, and environmental health to address issues such as exposure to *E. coli* and ESBL *E. coli*. Within this framework, the WASH-biosecurity intervention model is particularly relevant to occupational health, as it combines water, sanitation, and hygiene (WASH) measures with biosecurity practices. The WASH-biosecurity strategy in livestock settings was initially introduced by Jimenez *et al.* and later developed into a comprehensive framework (7,8).

The WASH program focuses on providing clean water, adequate sanitation facilities, and promoting hygiene practices to reduce the spread of *E. coli* and ESBL *E. coli* (9). Biosecurity measures, including restricted access to livestock areas, routine disinfection procedures, and livestock vaccination, further contribute to reducing transmission of *E. coli* and ESBL *E. coli* (10). By combining these strategies, the One Health approach is expected to reduce *E. coli* and ESBL *E. coli* exposure in farming communities and protect both human and animal health from its adverse effects.

This study employed a Quantitative Microbial Risk Assessment (QMRA) framework to analyze the exposure of *E. coli* and ESBL *E. coli* in ruminant and poultry areas at the Teaching Factory (TEFA). ESBL *E. coli* concentrations were determined through systematic sampling and laboratory analysis conducted between November 2023 and July 2024 in livestock areas within the TEFA facility in Sukabumi City, West Java Province, Indonesia. *E. coli* was used as a fecal indicator organism to assess environmental contamination, while ESBL-producing *E. coli* was treated as an antimicrobial resistance (AMR) outcome with direct implications for occupational health. Additionally, fecal ingestion rates were estimated by analyzing incidental fecal-oral exposure pathways among farmworkers (3). The QMRA results and fecal ingestion rates were used to assess infection risks and guide targeted interventions for farmworker safety.

This study aimed to assess exposure using a One Health approach and a WASH-biosecurity strategy. The proposed interventions were tailored to priority groups, including poultry and ruminant farmworkers. The intervention scenarios were designed to reduce levels of *E. coli* and ESBL *E. coli* in livestock environments compared to baseline concentrations. This decrease in microbial levels, along with reduced ingestion rates, was expected to decrease overall exposure among farmworkers. Identification of the most promising WASH-biosecurity strategies, based on their effectiveness in reducing exposure to *E. coli* and ESBL *E. coli*, was considered a key outcome of the study.

MATERIALS AND METHODS

This study addressed not only ESBL *E. coli* but also *E. coli* more broadly. This approach is supported by previous research on WASH and biosecurity interventions, which has predominantly targeted the reduction or elimination of *E. coli* in the environment. In the present study, *E. coli* was considered a fecal indicator bacterium and a proxy for potential exposure to enteric pathogens.

Exposure of *E. coli* and ESBL *E. coli*

Data on the occurrence of *E. coli* and ESBL *E. coli* were obtained from previous analyses conducted at TEFA in Sukabumi. The study site includes various livestock facilities, such as broiler chicken farms, poultry farms (including ducks, quails, and layer chickens), cattle farms, and small ruminant farms. Only sampling points with high concentrations of *E. coli* and ESBL *E. coli* (Table 1), namely: (1) broiler and duck stools; (2) poultry- and cattle-derived fertilizers; and (3) concentrated feed for broilers, ducks, and cattle were selected for intervention-based exposure reduction analysis. Subsequently, the fecal ingestion rates, together with other relevant variables (Table 1) and the concentrations of E. coli and ESBL E. coli, were used to estimate exposure at each sampling point using the following QMRA equations:

Exposure due to farmworker contact with livestock stools (11),

$$C_{stool} = IR_{fecal} \times Conc_{Ec\_stool/ESBL\ Ec\_stool} \tag{1}$$

where C_{stool} represents the exposure resulting from worker contact with feces ($\log_{10}$ CFU/day), IR_{fecal} denotes the fecal ingestion rate (mg/day), and $Conc_{Ec\_stool}$/$ConcESBL_{Ec\_stool}$ refers to the concentrations of *E. coli* and ESBL *E. coli* derived from fecal samples ($\log_{10}$ CFU). The IR_{fecal} value was further adjusted based on location, specifically whether the exposure occurred at a ruminant or poultry farm and was derived from previous studies conducted at the same sites.

Exposure due to worker contact with livestock feed (12),

$$C_{feed} = IR_{feed} \times Conc_{Ec\_feed} \tag{2}$$

where C_{feed} is the exposure due to worker contact with livestock feed ($\log_{10}$CFU/day), IR_{fecal} is the ingestion rate (mg/day), and $Conc_{Ec\_feed}$ is the concentration of *E. coli* in livestock feed samples ($\log_{10}$ CFU).

Exposure due to worker contact during the application of fertilizer to soil (13),

$$C_{fertilizer} = IR_{fertilizer} \times Conc_{Ec\_fertilizer} \times 10^{-(k.t)} \tag{3}$$

where $C_{fertilizer}$ is the exposure due to worker contact with fertilizer ($\log_{10}$ CFU/day), $IR_{fertilizer}$ is the ingestion rate (mg/day), $Conc_{Ec\_fertilizer/ESBL\ Ec\_fertilizer}$ is the concentration of *E. coli* in fertilizer samples ($\log_{10}$ CFU), k is the decay kinetics of *E. coli* per day ($\log_{10}$/day), and t is the time between fertilizer application to the field and exposure, ranging from 0 to 30 days. Exposure was assumed to occur 30 days after fertilizer application.

The magnitude of exposure to *E. coli* and ESBL *E. coli* depended on the independent and dependent variables presented in Table 1. Concentration data for livestock stools, feed, and livestock fertilizer were derived from previously conducted unpublished primary research.

Table 1. The variables used to calculate exposure to *E. coli* and ESBL *E. coli* in this study.

Mathematical Formula / Variable	Description	Distribution & Parameters	Source
Ingestion Rate (IR) of Non-fecal Source			
Feed source (IR_{feed}) (mg/day)	Analogous to soil volume accidentally ingested during transport of soil-filled sacks	Uniform: Min = 32, Max = 42.5	(14,15)
Fertilizer source ($IR_{fertilizer}$) (mg/day)	-	Uniform: Max. = 480, Min. = 50	(13)
Ingestion Rate (IR) of Fecal Source			
Ruminant stools (IR_{fecal}) (mg/day)	-	Log normal: Average = 6.84, Min. = 1.26, Std. dev.= 6.22	(3)
Poultry stools (IR_{fecal}) (mg/day)	-	Weibull: Scale = 0.45, Shape = 0.8, Location = 0	(3)
Concentrations			
$Conc_{Ec\_stool}$ ($\log_{10}$ CFU)	Concentration of *E. coli* in cattle and small ruminant stool	Log-normal: *E. coli* in cattle Mean = 3.79, SD = 0.44, Min = 2.95; *E. coli* in small ruminant Mean = 3.15, SD = 0.26, Min = 2.95	Primary data
$Conc_{Ec\_feed}$ ($\log_{10}$ CFU)	Concentration of *E. coli* in feed	Log-normal: Mean = 7.40, SD = 0.04, Min = 7.37	Primary data
$Conc_{Ec\_fertilizer}$ ($\log_{10}$ CFU)	Concentration of *E. coli* in fertilizer	Log-normal: Mean = 5.3, SD = 1.2, Min = 3.0	Primary data
$Conc_{Ec\_stool/ESBL\ Ec\_stool}$ ($\log_{10}$ CFU)	Concentration of *E. coli* and ESBL *E. coli* in broiler and duck stool	Log-normal: *E.coli* in broiler Mean = 7.82, SD = 0.60, Min = 6.60; *E. coli* in duck Mean = 6.25, SD = 1.77, Min = 2.95; ESBL *E. coli* in broiler Mean = 7.48, SD = 7.80, Min = 4.23; ESBL *E. coli* in duck Mean = 4.95, SD = 5.09, Min = 3.13	Primary data
$Conc_{Ec\_feed}$ ($\log_{10}$ CFU)	Concentration of *E. coli* in feed	Log-normal: *E. coli* in broiler Mean = 6.95, SD = 1.88, Min = 4.78; *E. coli* in duck Mean = 6.99, SD = 0.46, Min = 6.30	Primary data
$Conc_{Ec\_fertilizer}$ ($\log_{10}$ CFU)	Concentration of *E. coli* in fertilizer	Log-normal: Mean = 6.3, SD = 1.6, Min = 3.3	Primary data
The Other Parameters and Distributions			
Decay kinetics of *E. coli* (k) ($\log_{10}$/day)	Die-off rate of *E. coli*	PERT: Min = 0.041, Most likely = 0.05, Max = 0.0625	(13)
Recovery factor (RF) of *E. coli*	Recovery efficiency of *E. coli*	Uniform: Min = 50%, Max = 90%	(16)
Time interval after fertilizer application (t) (day)	After fertilizer application	Uniform: Min = 0, Max = 30	(17)

Exposure Reduction and Sensitivity Analysis

Efforts to reduce exposure to *E. coli* and ESBL *E. coli* were focused on WASH-biosecurity intervention scenarios directed at critical exposure sources posing a high risk to livestock workers. Once the intervention-modified variables had been identified, exposure was recalculated to estimate the percentage reduction. A Monte Carlo simulation (10,000 iterations, Oracle Crystal Ball v.11) was used to quantify the contribution of each input parameter to output variance. One source of uncertainty was the use of literature-based fertilizer ingestion rates.

RESULTS

Magnitude of *E. coli* and ESBL *E. coli* Exposure and Intervention Scenario

Exposure to *E. coli* and ESBL *E. coli* varied widely across sources. For *E. coli*, the highest median was from poultry fertilizer (6,139 $\log_{10}$ CFU/day), followed by cattle fertilizer (2,474 $\log_{10}$ CFU/day). Ruminant feed (median: 275 $\log_{10}$ CFU/day) exceeded poultry feed (median: 240 $\log_{10}$ CFU/day). Cattle and small ruminant stools (median: 17 $\log_{10}$ CFU/day) surpassed poultry stools (median: 2 $\log_{10}$ CFU/day). For ESBL *E. coli*, poultry fertilizer showed the highest exposure (median: 5,290 $\log_{10}$ CFU/day), followed by cattle fertilizer (median: 304 $\log_{10}$ CFU/day). Broiler feed (median: 220 $\log_{10}$ CFU/day) exceeded other feed types (median: 129 $\log_{10}$ CFU/day). Cattle and small ruminant stools (median: 11 $\log_{10}$ CFU/day) had higher exposure than poultry stools (median: 1 $\log_{10}$ CFU/day). Overall, fertilizers contributed the greatest exposure, followed by feed and stools.

The intervention scenario aimed at reducing exposure to *E. coli* and ESBL *E. coli* was divided into two categories based on the receptor: workers on ruminant and poultry farms. One study found that optimizing C:N ratio and moisture during poultry manure composting reduced ESBL *E. coli* by up to 2 $\log_{10}$ CFU (18). Details of these scenarios, together with the magnitude of reduction achieved through approaches targeting either *E. coli* concentration, ESBL *E. coli* concentration, or the ingestion rate, are presented in Table 2. The ingestion-rate reduction scenario was based on the installation of semi-automatic scrapers and conveyors, which may reduce both the duration of work and the amount of fertilizer material inadvertently ingested by farmworkers by approximately 50% (19).

Table 2. Intervention scenarios for reducing exposure to *E. coli* or ESBL *E. coli* among workers in TEFA.

Target Group	Exposure Source	Intervention	Modified Variable	Modified Variable	Source
Farmworkers on Ruminant Farms	Livestock Feed	Installation of feed storage silos	*E. coli* concentration	Reduction of 5 – 7 $\log_{10}$ CFU	(20)
	Ruminant Stools	Modification of ruminant composting house	*E. coli* concentration	~99% reduction	(21)
	Ruminant Fertilizer	Installation of semi-automatic scrapers	Ingestion rate	50% reduction	(19)
Farmworker in Poultry Farms	Livestock Feed	Installation of feed storage silos	*E. coli* concentration	Reduction of 5 – 7 $\log_{10}$ CFU	(20)
	Poultry Stools	Optimization of poultry composting process	ESBL *E. coli* concentration	Reduction of ~2$\log_{10}$ CFU	(18)
	Poultry Fertilizer	Installation of semi-automatic conveyor	Ingestion rate	50% reduction	(19)

The highest exposure levels of *E. coli* were observed in poultry fertilizer and broiler feed. ESBL *E. coli* followed similar exposure pathways in poultry fertilizer and the handling of poultry stools. While exposure via livestock feed and fertilizers can be mitigated through the implementation of storage silos and semi-automatic transport systems, the reduction of fecal exposure requires highly specific, source-oriented interventions. Within the integrated WASH-biosecurity framework, the use of feed silos aligns with hygiene-biosecurity protocols, semi-automatic transport systems under sanitation measures and fecal exposure mitigation represents a combined sanitation-biosecurity approach.

Mitigating *E. coli* Exposure from Livestock Feed and Fertilizer

Feed Storage Silo Installation

Under baseline conditions, without intervention (Figure 1), *E. coli* exposure from livestock feed varied by feed type. Broiler feed showed the highest exposure levels, reaching up to 500 $\log_{10}$ CFU/day. In contrast, non-broiler poultry feed exposure ranged from 0 to 400 $\log_{10}$ CFU/day, with peak probabilities concentrated between 100 and 300 $\log_{10}$ CFU/day. Ruminant feed exhibited a lower exposure profile, ranging from 0 to 250 $\log_{10}$ CFU/day and peaking between 150 and 200 $\log_{10}$ CFU/day. According to this study, installing feed storage silos reduced worker exposure during daily feed handling. The highest efficiency was observed for broiler feed, with an exposure reduction of 87.6% (95% CI: 85.6–89.6%), followed by non-broiler poultry feed at 85.8% (95% CI: 83.6–88.0%) and ruminant feed at 81.1% (95% CI: 78.7–83.5%).

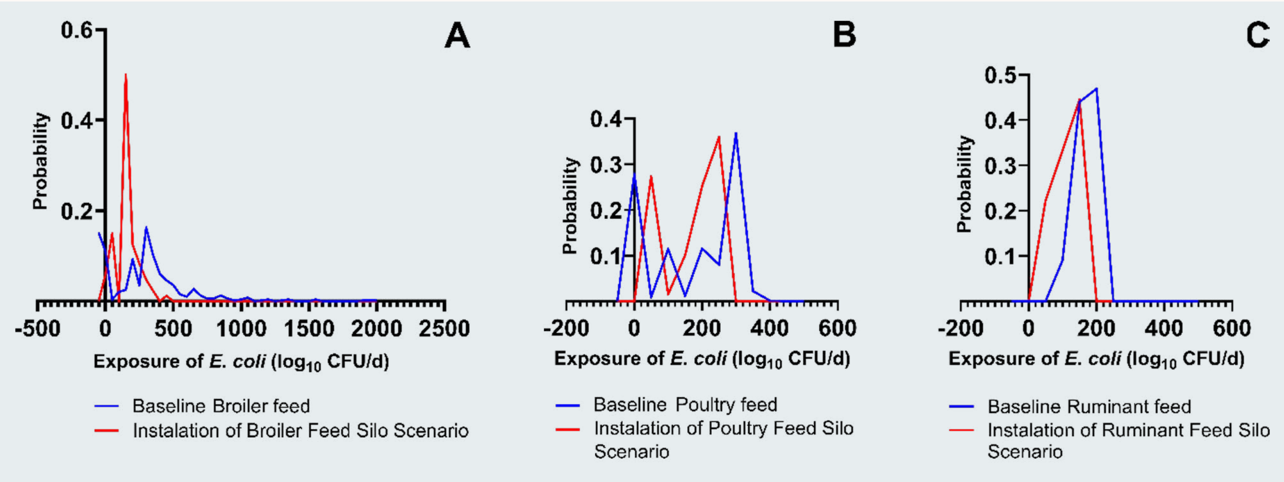

Figure 1. Comparison of *E. coli* exposure in livestock feed stored in silos.
The feed sources included broilers (A), non-broiler poultry (B), and ruminants (C).
The comparison included the baseline conditions (blue) and feed silo installation scenario (red). (A) Broiler feed: The baseline showed a broad distribution exceeding 500 $\log_{10}$ CFU/day, with a peak probability of 0.17. After the silo installation, the exposure was markedly reduced, with the peak probability rising to 0.50 (at 100 $\log_{10}$ CFU/day).
(B) Non-broiler poultry feed: Baseline ranges 0–400 $\log_{10}$ CFU/day with peak 0.37 (at 300 $\log_{10}$ CFU/day); post-silo, the peak shifts to 0.36 (at 250 $\log_{10}$ CFU/day). (C) Ruminant feed: Baseline ranges 0–250 $\log_{10}$ CFU/day with peak 0.47 (at 200 $\log_{10}$ CFU/day); after silo, the peak shifts to 0.44 (at 150 $\log_{10}$ CFU/day).
The x-axis depicted the *E. coli* exposure levels, and the y-axis indicated the probability of exposure. The x-axis is represented in $\log_{10}$ CFU/d (d = day), while the y-axis illustrated the probability (0-1).

Installation of Semi-automatic Scrapers and Conveyors

The installation of scrapers for ruminant manure and conveyors for poultry manure significantly reduced the risk of *E. coli* exposure relative to baseline conditions (Figure 2). Under baseline scenarios, exposure to ruminant fertilizer showed a broader distribution, with daily estimates ranging from 10^3 to 10^4 $\log_{10}$ CFU/day. The 50% scraper scenario reduced *E. coli* exposure to undetectable logarithmic levels, corresponding to a reduction efficiency of 88.3% (95% CI: 86.3–90.3%). In contrast, poultry fertilizer showed higher baseline exposure, reaching up to 1.5×10^4 $\log_{10}$ CFU/day. The 50% conveyor scenario achieved a 56.1% reduction (95% CI: 53.0–59.2%), with the highest probability observed at the lowest exposure level of approximately 10^3 $\log_{10}$ CFU/day.

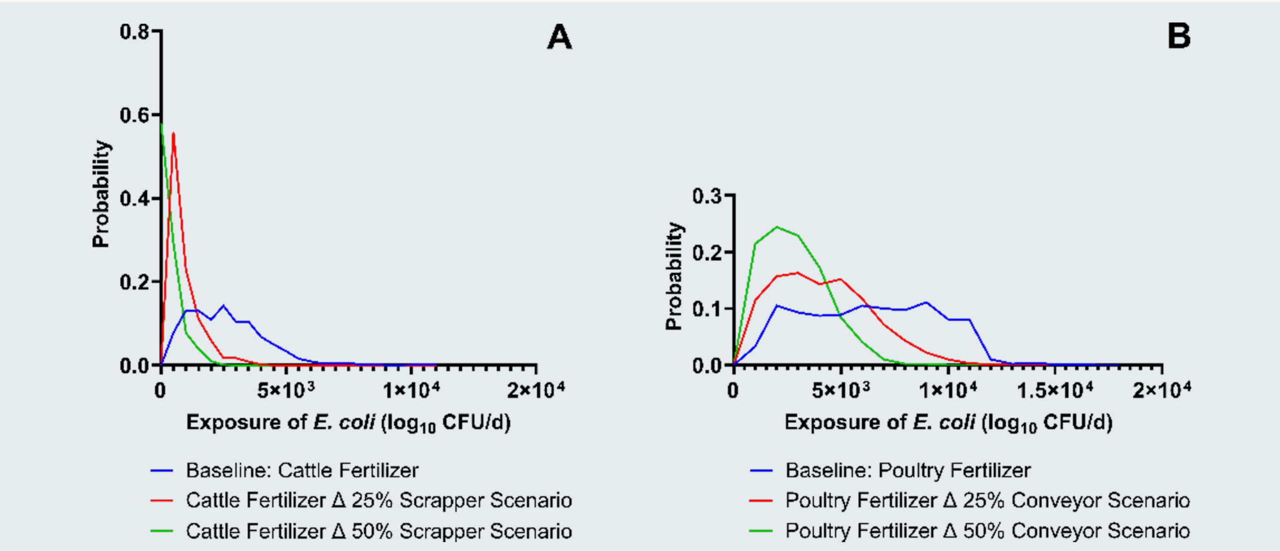

Figure 2. Comparison graph of *E. coli* exposure following the installation of scrapers and conveyors for manure handling. The manure sources included ruminants (A) and poultry (B). The comparison included baseline conditions (blue), a 25% ingestion reduction scenario (red), and a 50% ingestion reduction scenario (green).

(A) Ruminant fertilizer (cattle): The baseline exposure was broadly distributed between 10^3 and 10^4 $\log_{10}$ CFU/day. The 25% scraper narrowed the distribution and shifted the peak probability to 0.55 at much lower exposures (< 10^3 $\log_{10}$ CFU/day). The 50% scraper further reduced exposure to undetectable logarithmic levels, and the peak probability moved close to zero exposure.

(B) Poultry fertilizer: Baseline exposure reached up to 1.5×10^4 $\log_{10}$ CFU/day. The 25% conveyor reduced the maximum exposure and increased the peak probability to 0.16 at lower exposure levels. The 50% conveyor shifted the distribution further left, increasing the peak probability to 0.24 at much lower exposures. The x-axis depicted the *E. coli* exposure level, and the y-axis indicated the probability of exposure. The x-axis is represented in $\log_{10}$ CFU/d (d = day), while the y-axis illustrated the probability (0-1).

Mitigation of *E. coli* and ESBL *E. coli* Exposure from Ruminant and Poultry Fecal Sources

Optimization of the Poultry Composting Process

For broiler stools, the highest probability of exposure to ESBL *E. coli* was 0.3 at 2 $\log_{10}$ CFU/day, decreasing sharply as exposure levels increased to 40 $\log_{10}$ CFU/day (Figure 3). Composting reduced this probability to 0.2 at the same exposure level, with further reductions observed up to 30 $\log_{10}$ CFU/day. For non-broiler stools, the highest probability was 0.2 at 2 $\log_{10}$ CFU/day and decreased to zero at 30 $\log_{10}$ CFU/day. Under the composting mitigation scenario, non-broiler stools showed a peak probability of 0.3 between 2 and 4 $\log_{10}$ CFU/day, with the exposure range decreasing to 28 $\log_{10}$ CFU/day. Optimization of the composting process was more effective for non-broiler stools (63%; 95% CI: 60–66%) than for broiler stools (40.2%; 95% CI: 37.2–43.2%).

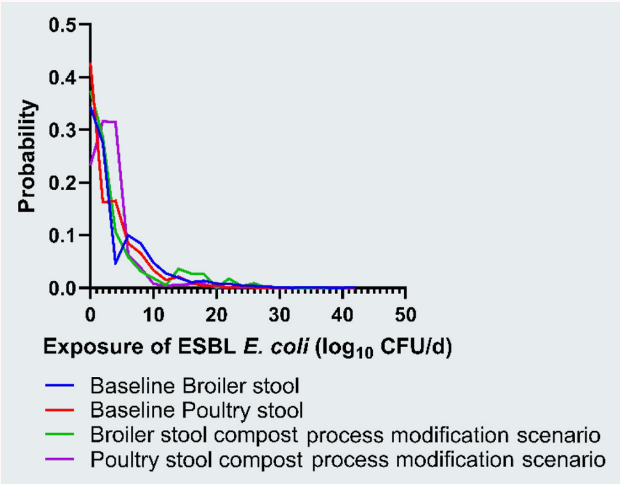

Figure 3. Comparison graph of ESBL *E. coli* exposure following composting process modifications in poultry farming areas. Baseline broiler stools are represented in blue, baseline non-broiler poultry stools in red, modified composting scenario for broiler stools in green, and modified composting scenario for non-broiler poultry stools in purple. For broiler stools (blue), the highest exposure probability is 0.3 at 2 $\log_{10}$ CFU/day, then falls sharply as the exposure increases to 40 $\log_{10}$ CFU/day. The composting scenario (green) reduced the peak probability to 0.2 at the same exposure level and contracted the maximum exposure range to 30 $\log_{10}$ CFU/day. For non-broiler poultry stools, the baseline (red) peak probability was 0.2 at 2 $\log_{10}$ CFU/day, reaching zero at 30 $\log_{10}$ CFU/day. After composting mitigation (purple), the peak rose to 0.3 across 2–4 $\log_{10}$ CFU/day, whereas the maximum exposure range decreased to 28 $\log_{10}$ CFU/day. The x-axis is represented in $\log_{10}$ CFU/d (d = day), while the y-axis is illustrated the probability of exposure (0-1).

Modification of Ruminant Composting House

Baseline *E. coli* exposure from cattle stools showed a probability of 0.3 at an exposure level of 1 $\log_{10}$ CFU/day, which decreased to approximately 7×10^{-2} at 4 $\log_{10}$ CFU/day and approached zero at higher exposure levels (Figure 4). Modification of the composting facility with porous concrete resulted in a reduction efficiency of up to 99% (95% CI: 98.4–99.6%). In small ruminant stools, the baseline scenario showed the highest exposure probability of 0.5 at 1 $\log_{10}$ CFU/day, which dropped sharply to approximately 5×10^{-2} at exposure levels above 4 $\log_{10}$ CFU/day. The porous concrete intervention in small ruminant composting facilities also showed the same reduction efficiency of 99% (95% CI: 98.4–99.6%).

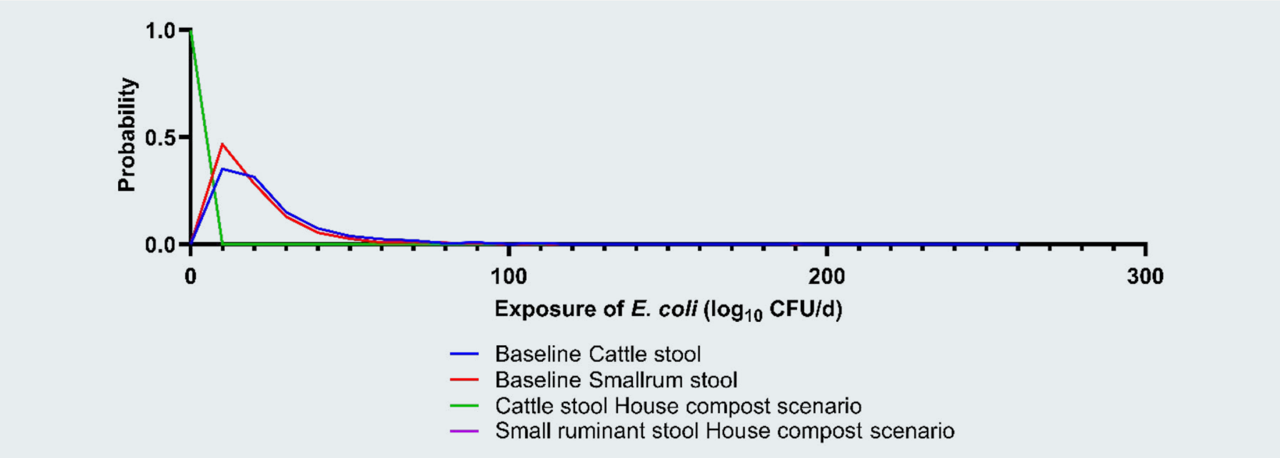

Figure 4. Comparison of *E. coli* exposure following the construction of composting facilities using porous concrete in ruminant farming areas. Baseline cattle stools are represented in blue, baseline small ruminant stools in red, the intervention scenario for cattle composting facilities in green, and the intervention scenario for small ruminant composting facilities in purple. For cattle stool (blue), the baseline exposure probability was 0.3 at 1 $\log_{10}$ CFU/day, falling to 7×10^{-2} at 4 $\log_{10}$ CFU/day, and approaching zero at higher exposures. For small ruminant stool (red), the peak probability was 0.5 at 1 $\log_{10}$ CFU/day, dropping to 5×10^{-2} above 4 $\log_{10}$ CFU/day. The porous concrete modification (green and purple curves) showed probabilities rising to 1.0 near zero exposure. The x-axis represented the *E. coli* exposure levels in $\log_{10}$ CFU/d (d = day), while the y-axis indicated the probability of exposure.

DISCUSSION

Sources of Exposure

This study elucidated two distinct yet complementary dimensions of microbial exposure within livestock environments. The study found that exposure to *E. coli* was consistently higher in fertilizers and livestock feed than in stools, challenging the conventional assumption that animal feces are the primary source of microbial risk. As a fecal indicator organism, *E. coli* reflects general hygiene and sanitation conditions, and its elevated levels in fertilizers and feed suggest that suboptimal composting practices and nutrient-rich substrates can amplify microbial concentrations. Furthermore, cross-contamination during feed storage further elevates exposure, underscoring vulnerabilities in current farm hygiene management (22). In contrast, ESBL-*E. coli* served as an antimicrobial resistance (AMR) endpoint. Its presence in fertilizers resulted in significantly lower peak exposure levels compared to general *E. coli*, with more pronounced reduction efficacy observed in non-broiler manure than in broiler-derived samples. These findings highlight occupational health risks that extend beyond environmental contamination. The risk of ingestion is further heightened by frequent and prolonged worker contact during routine cleaning and animal handling, emphasizing the necessity of stringent occupational hygiene protocols (3,23).

Effectiveness of Intervention Scenarios

A simplified intervention scenario involving the installation of scrapers and conveyor systems may provide an effective strategy for mitigating future *E. coli* exposure risks. This approach is based on the physical characteristics of the fertilizer, the concentration of *E. coli* present, and the ingestion rates. Poultry fertilizer, characterized by its high moisture content, low density, and minimal fibre content, is more compatible with conveyor belt systems (24). Conversely, ruminant manure—which tends to be denser and possesses a higher fiber content—is more effectively managed through the use of mechanical scrapers (25). Although poultry manure exhibits higher exposure levels, its response to mitigation using conveyor systems is limited. This may be attributed to the fact that conveyor installations often involve open-system transport, which maintains the potential for worker contact with contaminated surfaces. In contrast, mechanical scrapers demonstrate superior efficacy by providing direct, systemic removal of manure from floor surfaces, thereby minimizing the duration and surface area of environmental exposure that serves as a potential source of contamination.

The reduction of *ESBL E. coli* exposure was greater in non-broiler fertilizer (63%) than in broiler fertilizer (40%) owing to its lower nutrient content, which led to more controlled microbial activity and faster temperature increase during composting, thereby accelerating the degradation of *ESBL E. coli* (18). Consequently, characterizing the physicochemical composition of poultry feces prior to composting is essential for optimizing interventions and understanding differential exposure risks across different poultry types.

Furthermore, the installation of porous concrete as a composting house material significantly reduced *E. coli* exposure. High concrete porosity increases fluid permeability, allowing better airflow and water movement, which supports the organic matter (26). The size and distribution of pores also influence microbial interactions with concrete, and larger and interconnected pores provide better habitats for microbes. However, high porosity can reduce the resistance of concrete to acidic environments, accelerating material degradation and potentially compromising long-term structural durability (27). The use of acid-resistant protective layers may therefore help preserve composting performance while maintaining structural stability.

Field testing is necessary to confirm the effectiveness of livestock feed silos, scrapers, conveyor installations, optimized manure composting, and the use of porous concrete under various geographic and climatic conditions. Environmental variability, such as temperature, humidity, rainfall, and soil conditions, can influence the effectiveness of these interventions in reducing *E. coli* exposure, particularly that of ESBL *E. coli*.

Future Directions

Efforts to reduce exposure to *E. coli* and *ESBL E. coli* have produced mixed outcomes across different farm types. Interventions on ruminant farms have shown promising results, indicating a strong potential to improve health indicators in these settings. However, poultry farms present distinct operational and microbial challenges, such as higher microbial loads and more intensive management practices, which may limit the effectiveness of standard approaches. Future research should investigate the integration of various sanitation technologies to improve the efficiency of ESBL *E. coli* exposure reduction.

CONCLUSIONS

1. Targeted WASH-biosecurity actions have been highly effective in reducing *E. coli* and ESBL *E. coli* among farmworkers. Their success depends on the method used and the type of livestock.
2. The most effective method was changing the ruminant composting area to porous concrete, which reduced *E. coli* exposure by approximately 99%.
3. Other effective methods for ruminant farms included:
   a. Semi-automatic manure scrapers (88.3% reduction)
   b. Feed silos (87.6% reduction)
4. In poultry farms, the interventions were also helpful but showed weaker results compared to ruminant farms.
5. This study provides clear guidance on prioritizing interventions within a One Health framework.

CONFLICT OF INTEREST Nothing to declare.

CONTRIBUTIONS Y. V. Paramitadevi conducted the data analysis, drafted the manuscript, and managed the study. F. Marcelita handled data simulations. I. Rahmatika designed the methodology. C. R. Priadi verified the simulation data, reviewed the manuscript, and supervised the research. A. Ristianingrum and A. Rukmana contributed to the investigation and provided subject-specific insights. N. Suwartha reviewed and supervised the study. S. K. Saptomo supported simulations and secured funding.

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ETHICAL APPROVAL This study did not involve human participants or livestock. Ethical approval was not required according to the current institutional and national guidelines.

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All manuscripts submitted for publication should be accompanied by two abstracts: in English and Romanian.

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The manuscript should comprise the following sub- headings (capitalized):

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- **RESULTS**
- **DISCUSSION**
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Case Report

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The **summary** should contain 1,600 signs with spaces:

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The *One Health* concept

Globally, the One Health concept is a worldwide strategy to expand interdisciplinary collaborations and communications in all aspects related to the health care of humans, domestic animals or wildlife, which can no longer be approached separately, but only jointly.

One Health addresses not only human and animal disease concerns, but also issues related to lifestyle, diet, exercise, the impact of different types of human-animal relationships, and environmental exposures that can affect both populations. In order to achieve the expected effects, it is also necessary to educate the population to make them aware of the risk factors and benefits of prevention, as well as communication and understanding between patients and healthcare providers.

HUMAN HEALTH

The WHO defined health in 1946 as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”, with the later addition of “the capacity to lead a socially and economically productive life”.

ANIMAL HEALTH

The OIE defines animal welfare in 2008: an animal is in good condition if it is healthy, enjoys comfort, is well fed, is safe, is able to display its innate (natural) behavior and does not suffer from unpleasant conditions such as pain, fear and stress.

PLANT AND ENVIROMENTAL HEALTH

Environmental health refers to those aspects of human health that include the quality of life determined by physical, biological, socio-economic and psycho-social factors in the environment. The interrelationships of people with the environment concern medicine, when an ecological system is in a state of equilibrium, the health of the population prevails.