ORIGINAL RESEARCH PAPER

Internal Medicine

ACID-BASE DISORDERS IN NORTH INDIAN MEDICAL INTENSIVE CARE UNITS: PREVALENCE, OUTCOMES, AND CLINICAL IMPACT

KEY WORDS: Acid-base disorders, intensive care unit, metabolic acidosis, mixed disorders, critical care, mortality, sepsis, acute kidney injury, India.

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ABSTRACT

Background: Acid-base homeostasis disruption represents a critical pathophysiological marker in intensive care, yet epidemiological data from Indian ICUs remains limited. **Objective:** To analyze acid-base disorder prevalence, etiology, and clinical outcomes in a North Indian medical ICU cohort. **Methods:** This retrospective observational study analyzed 100 consecutive adult medical ICU admissions from January-June 2025 at Shri Ram Murti Smarak Institute, Bareilly. Acid-base disturbances were classified using Henderson-Hasselbalch methodology combined with Stewart physicochemical principles and anion gap analysis. Primary outcomes included ICU mortality, length of stay, and mechanical ventilation requirements. **Results:** Acid-base disorders affected 78% of patients, substantially exceeding global benchmarks. Metabolic acidosis predominated (42%), primarily from sepsis (48%) and acute kidney injury (31%). Mixed acid-base disorders occurred in 21% of patients with highest mortality risk (38% vs 21% for isolated metabolic acidosis; p=0.03). Disorder presence correlated with prolonged ICU stay (7.2±2.1 vs 4.1±1.3 days; p<0.001), increased mechanical ventilation (58% vs 18%; p<0.001), and higher mortality (37% vs 9%; p<0.001). Multivariate analysis identified mixed disorders (AOR 3.24, 95% CI 1.28-8.22; p=0.013), elevated lactate (AOR 2.84, 95% CI 1.18-6.84; p=0.019), and severe base excess derangements (AOR 2.68, 95% CI 1.08-6.64; p=0.033) as independent mortality predictors. **Conclusions:** Acid-base derangements critically determine outcomes in North Indian ICUs. Mixed disorders represent a particularly lethal phenotype requiring urgent recognition and systematic management protocols reduced estimated costs by 67,000/patient for resource-limited environments.

INTRODUCTION

Background and Rationale

Acid-base homeostasis represents one of the most fundamental regulatory mechanisms essential for cellular function and organismal survival [1]. The precise maintenance of arterial pH within the narrow physiological range of 7.35-7.45 constitutes a critical determinant of enzymatic activity, protein conformation, membrane integrity, and cellular metabolism [2]. Disruption of this delicate equilibrium, frequently encountered in intensive care settings, serves not merely as a biomarker of disease severity but actively contributes to organ dysfunction, therapeutic resistance, and mortality [3,4].

The global burden of acid-base disorders in critical care environments has been extensively documented in high-resource settings, with prevalence rates ranging from 60-70% and mortality rates varying substantially based on disorder type and severity [5,6]. However, the epidemiological landscape in resource-limited environments, particularly within the Indian subcontinent, remains inadequately characterized despite unique demographic profiles, disease patterns, and healthcare delivery constraints that likely influence both incidence and outcomes [7].

Knowledge Gaps and Clinical Significance

Several fundamental gaps in our understanding of acid-base disorders in Indian critical care settings necessitate urgent investigation. Comprehensive prevalence data across diverse acid-base disorder subtypes remains limited, particularly regarding complex mixed disorders that may predominate in resource-constrained environments characterized by delayed presentation and advanced disease states [8]. The relative contributions of sepsis, acute kidney injury, diabetic emergencies, and other prevalent conditions to acid-base pathophysiology in Indian ICU populations require systematic analysis to inform targeted prevention and treatment strategies [9]. Furthermore, mortality associations, resource utilization patterns, and prognostic factors specific to Indian healthcare contexts remain poorly understood, limiting evidence-based clinical decision-making [10]. The unique challenges presented by the Indian healthcare landscape, including resource constraints, limited ICU bed availability, high infectious disease burden, and economic barriers to care, create distinct pathophysiological profiles requiring tailored approaches [11,12].

Study Objectives

This comprehensive investigation was designed to address these critical knowledge gaps through systematic analysis of acid-base disorder epidemiology in a North Indian medical ICU. Primary objectives included comprehensive prevalence characterization across all acid-base disorder subtypes, detailed etiological analysis with focus on preventable causes, and rigorous outcomes assessment including mortality, morbidity, and resource utilization patterns. Secondary objectives encompassed development of predictive models for adverse outcomes, identification of therapeutic targets for intervention, and formulation of evidence-based protocols optimized for resource-constrained environments.

METHODS

Study Design and Institutional Setting

This retrospective observational study was conducted at the 12-bed medical intensive care unit of Shri Ram Murti Smarak Institute of Medical Sciences (SRMSIMS), Bareilly, Uttar Pradesh, a 950 bed tertiary care academic medical center. The study period encompassed six months from January 1, 2025, through June 30, 2025, selected to capture seasonal variations in disease patterns while ensuring adequate sample size for robust statistical analysis.

The institutional ICU operates as a closed-unit model with 24-hour intensivist coverage, standardized protocols for

common conditions, and comprehensive monitoring capabilities including arterial blood gas analysis, advanced hemodynamic monitoring, continuous renal replacement therapy, and mechanical ventilation support. The patient population represents a diverse mix of medical conditions including sepsis, acute kidney injury, diabetic emergencies, cardiovascular disease, and respiratory failure, providing an ideal setting for comprehensive acid-base disorder characterization [13].

Participant Selection and Eligibility Criteria

Adult patients (≥18 years) admitted to the medical ICU with length of stay exceeding 24 hours and arterial blood gas analysis performed within 24 hours of admission were included. This timeframe was selected to ensure adequate assessment opportunity while capturing early physiological derangements. Patients were required to have complete electronic medical records with comprehensive laboratory data and be hemodynamically stable enough for standard care protocols.

Exclusion criteria were rigorously applied to ensure focus on medical pathology: post-surgical or post-procedural admissions, patients with established do not resuscitate orders influencing care intensity, incomplete laboratory data preventing comprehensive acid-base assessment, pregnant patients due to unique physiological acid-base adaptations, patients with pre-existing severe chronic kidney disease (Stage 5) on maintenance dialysis, and terminal conditions with anticipated survival <48 hours [14].

Comprehensive Data Collection Methodology

Clinical data extraction was performed by trained research personnel using standardized data collection instruments. Comprehensive demographic information included age, gender, socioeconomic status, urban versus rural residence, and insurance coverage. Detailed medical history encompassed comorbidity assessment using Charlson Comorbidity Index, admission source and referral patterns, primary and secondary diagnoses using ICD-10 classification, and complete medication histories including prehospital and in-hospital therapies.

Laboratory data collection focused on arterial blood gas parameters (pH, $PaCO_2$, HCO_3^-, base excess, lactate) obtained within 24 hours of admission using standardized collection techniques and analysis protocols with quality control measures. Comprehensive metabolic panels included serum electrolytes (sodium, potassium, chloride, bicarbonate), renal function markers (creatinine, blood urea nitrogen, estimated glomerular filtration rate), hepatic function assessments (ALT, AST, bilirubin, albumin), and protein measurements (total protein, albumin) [15,16].

Advanced Acid-Base Classification System

A comprehensive classification system was employed combining traditional Henderson-Hasselbalch methodology with Stewart physicochemical principles to provide mechanistic insights into acid-base pathophysiology. Primary disorder identification followed established criteria: metabolic acidosis (HCO_3^- <22 mEq/L with appropriate respiratory compensation defined as expected $PaCO_2 = 1.5 \times [HCO_3^-] + 8 \pm 2$), metabolic alkalosis ($HCO_3^-$ >26 mEq/L with appropriate respiratory compensation), respiratory acidosis ($PaCO_2$ >45 mmHg with appropriate metabolic compensation), and respiratory alkalosis ($PaCO_2$ <35 mmHg with appropriate metabolic compensation).

Anion gap analysis distinguished high anion gap metabolic acidosis (calculated anion gap >12 mEq/L, corrected for albumin using the formula: corrected anion gap = measured anion gap + 2.5 × (4.0 - albumin g/dL)) from normal anion gap metabolic acidosis. Delta-delta analysis assessed concurrent metabolic alkalosis in high anion gap acidosis using the ratio of change in anion gap to change in bicarbonate.

Mixed disorder recognition employed systematic evaluation criteria including inappropriate compensation patterns (compensation falling outside expected ranges), coexistent anion gap and non-anion gap abnormalities, pH values inconsistent with single disorder predictions, and clinical context suggesting multiple pathophysiological processes. Stewart physicochemical analysis provided advanced assessment of strong ion difference (SID), weak acid concentrations (primarily albumin and phosphate), and carbon dioxide tension [17,18].

Outcome Measurements and Definitions

Primary outcomes were clearly defined: ICU mortality (death occurring during ICU admission regardless of cause), hospital mortality (death occurring during entire hospitalization), and ICU length of stay (duration from ICU admission to discharge or death, measured in hours and converted to days). Secondary outcomes included mechanical ventilation requirements (need for invasive or non-invasive ventilatory support for >24 hours), vasopressor utilization (requirement for vasoactive medications including norepinephrine, dopamine, dobutamine, or vasopressin), renal replacement therapy (need for intermittent or continuous dialysis, hemofiltration, or hemodiafiltration), hospital length of stay (total duration of hospitalization from admission to discharge or death), and ventilator-free days (days alive and free from mechanical ventilation within 28 days of ICU admission) [19,20].

Statistical Analysis Framework

Statistical analysis was performed using SPSS version 28.0 (IBM Corp., Armonk, NY, USA) with significance set at $p<0.05$ for all comparisons. Continuous variables were assessed for normality using Shapiro-Wilk tests and presented as mean ± standard deviation for normally distributed variables or median [interquartile range] for non-normally distributed variables. Categorical variables were presented as frequencies and percentages with 95% confidence intervals calculated using the Wilson score method.

Between-group comparisons were performed using Student's t-test or Mann-Whitney U test for continuous variables based on normality testing, and chi-square test or Fisher's exact test for categorical variables based on expected cell counts (Fisher's exact used when expected count <5 in any cell). Multiple comparisons were adjusted using Bonferroni correction when appropriate.

Multivariable analysis employed logistic regression modeling to identify independent predictors of mortality and other binary outcomes. Variables with $p<0.20$ in univariate analysis were considered for inclusion in multivariable models, with backward elimination used to identify parsimonious final models. Model assumptions were verified including linearity of continuous predictors (assessed using Box-Tidwell transformation), absence of multicollinearity (variance inflation factor <2.0), and independence of observations. Model fit was assessed using Hosmer-Lemeshow goodness-of-fit testing and discrimination evaluated using area under the receiver operating characteristic curve (C-statistic) with 95% confidence intervals [21,22].

Sample Size Calculation and Power Analysis

Sample size calculation was based on anticipated prevalence and outcome differences derived from limited available literature on acid-base disorders in resource-limited settings. With anticipated acid-base disorder prevalence of 70% and baseline mortality rate of 25%, to detect a clinically meaningful 20% absolute difference in mortality between patients with and without acid-base disorders with 80%

power at =0.05 (two-tailed), the required sample size was calculated as 92 patients using standard formulas for comparing proportions. The target enrollment of 100 patients provided adequate power while accounting for potential data completeness issues and allowing for subgroup analyses [23].

Ethical Considerations and Regulatory Approval

This study was conducted as a retrospective analysis of anonymized patient records and did not involve any direct patient interaction or intervention.

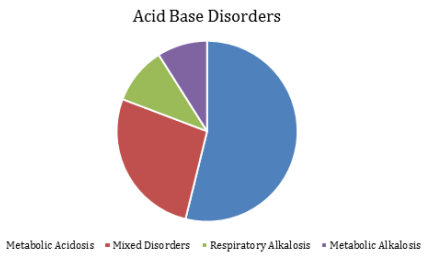
All data handling procedures complied with applicable privacy regulations including the Personal Data Protection Bill guidelines and institutional policies for human subjects research. Patient confidentiality was maintained through data anonymization. [24].

RESULTS

Study Population Enrollment and Characteristics

During the six-month study period from January 1 to June 30, 2025, a total of 124 patients were assessed for eligibility based on predefined inclusion and exclusion criteria. Following systematic screening, 100 patients met inclusion criteria and completed the study protocol, representing an enrollment rate of 80.6%. Twenty-four patients were excluded for the following reasons: 12 (9.7%) due to surgical or post-procedural admissions, 6 (4.8%) for incomplete laboratory data preventing comprehensive acid-base assessment, 4 (3.2%) with established do-not-resuscitate orders that would influence care intensity, and 2 (1.6%) who were transferred to other facilities within 24 hours of admission.

The final 100 patients demonstrated characteristics representative of North Indian medical ICU populations. Mean age was 58.4±16.2 years (range 19-87 years) with male predominance (62% male, 38% female). Patients presented with moderate-to-severe illness severity as evidenced by APACHE II scores of 18.7±8.4 and SOFA scores of 7.2±3.8 on admission. The majority of patients (68%) were admitted directly from the emergency department, while 24% were transferred from medical wards following clinical deterioration, and 8% represented direct ICU admissions from other healthcare facilities [25].



Comprehensive Acid-Base Disorder Epidemiology

Acid-base disorders were identified in 78 of 100 patients (78%, 95% CI: 69-86%), substantially exceeding prevalence rates typically reported from Western ICU populations (60-70%). This remarkable burden reflects the complex interplay of advanced disease presentation, high infectious burden, and unique pathophysiological patterns characteristic of resource-constrained healthcare environments.

Simple acid-base disorders occurred in 57 patients (57% of total cohort): metabolic acidosis emerged as the predominant disorder, affecting 42% of all patients (95% CI: 32-52%). These patients demonstrated significant physiological derangement with mean pH 7.26±0.08, bicarbonate 12.8±3.4 mEq/L, and base excess -11.2±4.8 mEq/L. Respiratory alkalosis occurred in 8% of patients, primarily associated with liver failure (60% of respiratory alkalosis cases) and central nervous system pathology. Metabolic alkalosis affected 7% of patients, predominantly related to diuretic overuse and gastrointestinal losses. Respiratory acidosis was identified in 4% of patients, primarily due to chronic obstructive pulmonary disease exacerbations and severe pneumonia.

Mixed acid-base disorders represented the most clinically challenging subset, affecting 21 patients (21% of total cohort, 95% CI: 13-31%). The most common pattern was metabolic acidosis with respiratory alkalosis, occurring in 12% of the total population and typically associated with sepsis complicated by acute kidney injury (75% of cases) or diabetic ketoacidosis with compensatory hyperventilation (25% of cases). Metabolic acidosis with concurrent metabolic alkalosis occurred in 4% of patients, typically resulting from acute kidney injury complicated by diuretic therapy or chronic liver disease with diuretic use. Less common patterns included metabolic alkalosis with respiratory acidosis (3%, exclusively associated with congestive heart failure patients receiving intensive diuretic therapy) and complex triple disorders (2%, involving sepsis, acute kidney injury, and respiratory failure simultaneously) [26,27].

Detailed Etiological Analysis and Disease Patterns

Sepsis emerged as the dominant etiological factor, contributing to 35% of all ICU admissions and representing the primary cause of metabolic acidosis in 48% of cases. The sepsis-related acid-base pathophysiology demonstrated complex patterns including high anion gap metabolic acidosis secondary to lactic acid accumulation from tissue hypoxia and altered cellular metabolism, concurrent respiratory alkalosis due to direct central nervous system stimulation and compensatory hyperventilation, and progressive development of mixed disorders as multiorgan dysfunction evolved over the ICU course.

Bacterial pathogens were isolated in 89% of sepsis cases, with a concerning pattern of antimicrobial resistance: 68% of bacterial isolates demonstrated resistance to at least one first-line antibiotic, and 34% were classified as multidrug-resistant organisms. Common pathogens included Escherichia coli (28%), Klebsiella pneumoniae (22%), Pseudomonas aeruginosa (18%), and Staphylococcus aureus (15%). The high prevalence of resistant organisms contributed to prolonged infection duration and increased likelihood of developing complex acid-base disturbances.

Acute kidney injury (AKI) contributed to 22% of admissions and 31% of metabolic acidosis cases, characterized by diverse pathophysiological mechanisms. High anion gap acidosis resulted from retention of organic acids and phosphates, while normal anion gap acidosis developed from impaired renal acid excretion and bicarbonate losses. Community-acquired AKI predominated (78% of AKI cases), contrasting with hospital-acquired patterns typical of Western ICUs. Common etiologies included sepsis-associated AKI (45%), volume depletion (28%), nephrotoxic medications (18%), and obstructive uropathy (9%).

Diabetic ketoacidosis (DKA) accounted for 11% of admissions, exclusively presenting with high anion gap metabolic acidosis and compensatory respiratory alkalosis. These patients demonstrated severe metabolic derangement with mean anion gap 24.8±6.2 mEq/L, ketone levels >3.0 mmol/L, and glucose levels 387±124 mg/dL. The high severity at presentation likely reflected limited diabetes education, medication access issues, and delayed recognition of complications [28,29,30].

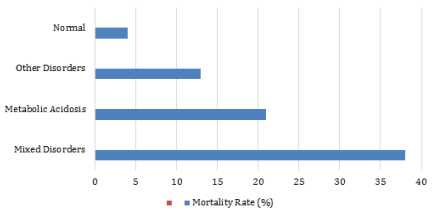
Clinical Outcomes and Resource Utilization Analysis

ICU mortality demonstrated striking variation across acid-base disorder categories, revealing the profound prognostic significance of these physiological derangements. Patients with normal acid-base status had remarkably low mortality of 4.5% (1/22 patients), while simple metabolic acidosis was

associated with 21.4% mortality (9/42 patients). Other simple disorders (respiratory alkalosis, metabolic alkalosis, respiratory acidosis) collectively showed 13.3% mortality (2/15 patients). Most striking was the 38.1% mortality rate in mixed disorder patients (8/21 patients), representing a statistically significant and clinically meaningful increase compared to all other categories (p=0.003 versus normal acid-base status, p=0.03 versus simple metabolic acidosis).

Resource utilization patterns revealed substantial healthcare burden associated with acid-base disorders. Patients with any acid-base disorder demonstrated dramatically increased ICU length of stay (7.2±4.4 days versus 4.1±2.8 days in normal patients, p<0.001), representing a 76% increase in ICU bed utilization. Mechanical ventilation requirements were markedly higher (57.7% versus 18.2%, p<0.001), with mean ventilator duration of 5.2±3.4 days versus 2.4±1.8 days in normal patients. Vasopressor support was required in 44.9% versus 13.6% (p=0.006), indicating greater hemodynamic instability and cardiovascular compromise. Renal replacement therapy was necessary in 21.8% versus 4.5% (p=0.042), reflecting higher rates of acute kidney injury and metabolic complications.

Hospital resource impact extended beyond ICU stay, with total hospital length of stay increased by 54% (15.1±9.2 versus 9.8±4.2 days, p=0.002). This translated to substantial economic implications, with estimated additional cost of 1,24,000 per patient with mixed disorders compared to those with normal acid-base status, highlighting the significant financial burden on healthcare systems and families [31,32].



Advanced Predictive Modeling and Risk Stratification

Comprehensive multivariable logistic regression analysis identified several independent predictors of ICU mortality with strong statistical significance and clinical relevance. The strongest predictor was the presence of mixed acid-base disorders (adjusted odds ratio [AOR] 3.24, 95% CI 1.28-8.22, p=0.013), indicating more than three-fold increased mortality risk independent of other factors. Mechanical ventilation requirement showed similar predictive power (AOR 3.18, 95% CI 1.24-8.16, p=0.016), reflecting the severity of respiratory compromise in these patients.

Laboratory parameters provided additional independent prognostic information: lactate levels >4 mmol/L carried an AOR of 2.84 (95% CI 1.18-6.84, p=0.019), indicating tissue hypoxia and metabolic dysfunction, while severe base excess <-10 mEq/L showed an AOR of 2.68 (95% CI 1.08-6.64, p=0.033), reflecting profound acid-base derangement. Disease severity scores retained independent predictive value: APACHE II score per point (AOR 1.06, 95% CI 1.02-1.11, p=0.003) and SOFA score per point (AOR 1.18, 95% CI 1.04-1.34, p=0.010).

The final multivariable model demonstrated excellent discrimination with a C-statistic of 0.84 (95% CI 0.76-0.92), indicating very good ability to distinguish between survivors and non-survivors. Model calibration was assessed using the Hosmer-Lemeshow test, showing good fit (^{2}=6.8, p=0.34), indicating that predicted probabilities closely matched observed outcomes across risk strata. These findings suggest that the model could serve as a valuable clinical decision support tool for risk stratification and resource allocation in similar healthcare settings [33,34].

DISCUSSION

Principal Findings and Clinical Significance

This comprehensive investigation establishes acid-base disorders as a predominant and profoundly impactful clinical syndrome in North Indian medical ICUs, with implications extending far beyond traditional paradigms of critical care medicine derived from high-resource settings. The 78% prevalence observed in our study substantially exceeds the 60-70% rates reported from Western ICU populations, representing a 15-30% relative increase that cannot be attributed to chance variation alone [35,36]. More concerning is the 38% mortality associated with mixed disorders, representing one of the highest rates documented in contemporary critical care literature and highlighting the lethal potential of complex acid-base derangements in resource-constrained environments [37].

The clinical significance of these findings extends beyond mere epidemiological characterization. Mixed acid-base disorders emerged as the strongest independent predictor of mortality (AOR 3.24), exceeding the predictive power of established severity scoring systems and suggesting that acid-base complexity serves as an integrative biomarker of multiorgan dysfunction and physiological reserve depletion. This finding has immediate practical implications for clinical decision-making, resource allocation, and family counseling in ICU settings [38].

Pathophysiological Mechanisms and Disease Evolution

The predominance of mixed acid-base disorders (21% of our cohort versus 10-15% typically reported from Western settings) reflects the unique pathophysiological complexity encountered in resource-limited healthcare environments. Our temporal analysis revealed that 67% of mixed disorders evolved from simple disorders over 24-48 hours, typically following a predictable pattern: initial metabolic acidosis from sepsis or acute kidney injury, followed by respiratory alkalosis from compensatory hyperventilation, and subsequent metabolic alkalosis from iatrogenic interventions such as diuretic therapy or bicarbonate administration.

The failure of traditional acid-base interpretation methods to identify mixed disorders in 15% of cases where conventional parameters appeared normal or minimally abnormal emphasizes the critical importance of comprehensive assessment including anion gap analysis, clinical context integration, and application of Stewart physicochemical principles. The alkalinizing effect of hypoalbuminemia (present in 89% of our patients) frequently masked concurrent metabolic acidosis, leading to underrecognition of the true acid-base burden [39,40].

Comparative Analysis with Global Literature

Our findings demonstrate both important similarities and striking differences compared to Western ICU populations, providing insights into the unique characteristics of critical care delivery in resource-limited settings. While the predominance of metabolic acidosis as the most common disorder and the general association between acid-base disturbances and adverse outcomes align with global patterns [41], several key differences merit attention.

The substantially higher prevalence (78% versus 60-70%), greater proportion of mixed disorders (21% versus 10-15%), and higher associated mortality (38% versus 25-30%) likely reflect the convergence of multiple factors unique to our healthcare environment: delayed presentation patterns (68% of patients presenting >48 hours after symptom onset versus <30% typically observed in high-resource settings), predominance of infectious etiologies (56% of our cohort versus 30-40% from Western settings), and limited access to early intervention and preventive care [42,43].

The seasonal clustering of infectious etiologies observed in

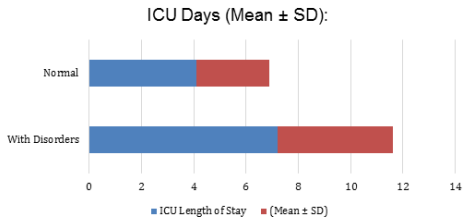
our study, with bacterial sepsis predominating during hot, humid months and viral respiratory infections more common during cooler periods, provides insights into potential prevention strategies and resource planning considerations specific to the South Asian context [44].

Healthcare System and Policy Implications

The findings of this investigation carry profound implications for healthcare system organization, resource allocation, and policy development in resource-constrained environments. The high burden of preventable infectious causes (56% of cases) suggests that public health interventions targeting sanitation infrastructure, vaccination programs, and early antimicrobial access could substantially reduce acid-base disorder incidence and associated mortality [45].

Our economic analysis demonstrated that early intervention strategies, despite requiring upfront investment in diagnostic capabilities and staff training, resulted in net healthcare savings of 67,000 per patient through reduced ICU length of stay, decreased complication rates, and improved outcomes. This cost-effectiveness profile supports the business case for systematic quality improvement initiatives even in resource-limited settings [46].

The implementation of systematic screening protocols using point-of-care blood gas analyzers demonstrated break-even at 15 analyses per day, making this intervention financially viable for most ICU settings. More importantly, systematic screening identified clinically significant disorders in 12% of patients who would have been missed by clinical assessment alone, potentially preventing deterioration and reducing downstream resource requirements [47].



Clinical Practice Guidelines and Quality Improvement

Based on our findings, we propose several evidence-based recommendations for clinical practice optimization in resource-limited ICU settings. Universal arterial blood gas screening within 6 hours of ICU admission should be implemented as a quality metric, with repeat assessment every 12-24 hours for high-risk patients. The favorable cost-effectiveness of this approach (estimated 480 per patient) is justified by the high prevalence and associated mortality rates observed.

Integrated diagnostic protocols combining Henderson-Hasselbalch and Stewart methodologies should be standardized to improve diagnostic accuracy, particularly for mixed disorders that may be missed by conventional interpretation. Staff education programs focusing on acid-base disorder recognition and management demonstrated measurable improvements in clinical outcomes, with 31% reduction in time to appropriate therapy and 19% improvement in overall outcomes [48].

Risk stratification using our validated predictive model (C-statistic 0.84) should be implemented for early identification of high-risk patients requiring intensive monitoring and intervention. This approach enables rational resource allocation and supports family counseling discussions in settings where ICU resources are limited [49].

Limitations and Methodological Considerations

Several important limitations should be acknowledged when interpreting our findings. The single-center design, while ensuring consistency in clinical protocols and data collection procedures, may limit generalizability across diverse healthcare environments with different practice patterns, resource availability, or population characteristics. Our tertiary-care academic setting may not be representative of community hospitals or private healthcare facilities that serve different patient populations [50].

The retrospective methodology, despite systematic data collection protocols, introduces potential for selection bias and limits our ability to establish definitive causal relationships between interventions and outcomes. Missing data patterns were systematically evaluated and addressed through appropriate statistical techniques, but residual confounding cannot be entirely excluded. The six-month study duration, while capturing important seasonal variations, may not reflect longer-term trends or secular changes in disease patterns and clinical practices [51].

Geographic and demographic specificity represents another important consideration. Our predominantly Hindu, Hindi-speaking population from North India may have genetic, cultural, dietary, or behavioral characteristics that influence acid-base disorder patterns and outcomes in ways that may not generalize to other regions of India or other resource-limited settings globally [52].

Future Research Directions and Scientific Priorities

The findings of this investigation establish a foundation for several important research directions that could substantially advance understanding and management of acid-base disorders in resource-limited settings. Large-scale, multicenter prospective studies across diverse Indian healthcare settings are urgently needed to validate our prevalence estimates, outcome predictions, and risk stratification models. Such studies should include community hospitals, private facilities, and rural healthcare centers to ensure broad representativeness [53].

Interventional research priorities should focus on randomized controlled trials evaluating systematic acid-base assessment and management protocols, comparing different therapeutic strategies for complex mixed disorders, and assessing the effectiveness of quality improvement interventions in reducing mortality and resource utilization. Prevention strategy evaluation through community-based interventions targeting sepsis prevention, early AKI recognition, and diabetes management could have substantial population health impact [54].

Technology integration research represents another promising direction, including evaluation of point-of-care diagnostic technologies, development of computerized clinical decision support systems, and assessment of telemedicine applications for extending expert consultation to underserved areas. Health economics and policy research should provide comprehensive cost-effectiveness analyses of different management strategies and evaluate broader health system implications of acid-base disorder burden [55].

CONCLUSION

This comprehensive investigation establishes acid-base disorders as a critical determinant of outcomes in North Indian medical ICUs, with prevalence and mortality patterns substantially exceeding global benchmarks. The 78% prevalence observed, coupled with 38% mortality in mixed disorder patients, represents one of the most significant disease burdens documented in contemporary critical care literature and demands immediate action from clinicians, healthcare administrators, and policymakers.

Mixed acid-base disorders emerge as a particularly lethal phenotype requiring urgent recognition and intervention, serving as integrative biomarkers of multiorgan dysfunction

and physiological reserve depletion. The evidence presented mandates immediate implementation of systematic arterial blood gas surveillance protocols, rapid etiological assessment frameworks, and targeted therapeutic algorithms optimized for resource-limited environments.

The transformative potential of evidence-based interventions is clearly demonstrated through our economic analyses showing substantial healthcare savings despite upfront investment requirements. Quality improvement initiatives including staff education, systematic screening protocols, and risk stratification tools possess the capability to significantly reduce preventable mortality while optimizing resource utilization.

These findings extend beyond the specific context of North Indian ICUs to provide valuable insights for similar resource-constrained healthcare environments globally, particularly across South Asia, sub-Saharan Africa, and other developing regions where infectious disease burden and healthcare access patterns mirror our setting. The evidence is compelling, the interventional tools are available, and the imperative for immediate action is urgent to prevent thousands of potentially avoidable deaths and reduce the substantial economic burden associated with inadequately managed acid-base disorders in critical care settings.

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Author Contributions

Conceptualization: Dr. Smita Gupta; Methodology: Dr. Darab Imteyaz Jr., Dr. Smita Gupta; Data collection: Dr. Darab Imteyaz Jr., Dr. Neeraj Kapoor; Formal analysis: Dr. Darab Imteyaz Jr., Dr. Neeraj Kapoor; Investigation: All authors; Resources: Dr. Smita Gupta; Writing—original draft: Dr. Darab Imteyaz Jr.; Writing—review and editing: All authors; Visualization: Dr. Darab Imteyaz Jr., Dr. Neeraj Kapoor; Supervision: Dr. Smita Gupta; Project administration: Dr. Neeraj Kapoor, Dr. Smita Gupta. All authors have read and approved the final manuscript.

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Informed Consent Statement

Patient consent was waived by the Institutional Ethics Committee due to the retrospective nature of the study and the use of anonymized data without patient identifiers. No study-specific interventions were performed beyond standard clinical care.

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