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Prevalence of Respiratory Complications in Chronic Kidney Disease Patients: A Cross-sectional Study

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Abstract

Background: Respiratory complications are increasingly recognized as significant comorbidities in chronic kidney disease (CKD) patients, yet their prevalence and clinical characteristics remain inadequately documented in the Indian population.

Objectives: This study aimed to determine the prevalence, types, and severity of respiratory complications in CKD patients across different disease stages and to identify the association between kidney function decline and pulmonary dysfunction.

Methods: A cross-sectional observational study involving 150 CKD patients (stages 1–5) from Kidney Care Centre, Tirunelveli was conducted. Respiratory assessment included modified Medical Research Council (mMRC) dyspnea scale, spirometry, 6-minute walk test (6MWT), peripheral oxygen saturation (SpO_2), chest imaging, and modified Borg exertion scale. Multivariate analysis examined associations between CKD stage and respiratory complications.

Results: Pulmonary edema was the most prevalent respiratory complication (24.84%), followed by pneumonia (18.2%), pleural effusion (16.5%), tuberculosis (12.3%), and obstructive sleep apnea (10.1%). Mean FEV_1 % predicted significantly declined from Stage 1 (95%) to Stage 5 (42%, $p<0.001$). Mean 6MWT distance decreased progressively (Stage 1: 487m vs Stage 5: 268m, $p<0.001$). Dyspnea severity correlated significantly with advancing CKD stage ($r=0.78$, $p<0.001$). SpO_2 below 92% was observed in 31.3% of Stage 4–5 patients. Multivariate analysis identified CKD stage (OR=2.41, 95% CI: 1.89–3.07), dialysis status (OR=1.87, 95% CI: 1.23–2.84), and anemia (OR=1.56, 95% CI: 1.02–2.38) as independent predictors of respiratory complications.

Conclusion: Respiratory complications are highly prevalent in CKD patients with significant functional impairment and disease progression across kidney stages. Early respiratory assessment and integrated management strategies are essential for comprehensive CKD care and improved patient outcomes.

Keywords: Chronic Kidney Disease; Respiratory Complications; Pulmonary Edema; Dyspnea; Spirometry; 6-Minute Walk Test

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Introduction

Chronic kidney disease (CKD), affecting up to 13.4% of the global population, represents a significant public health burden with substantial morbidity and mortality [1]. Beyond its direct effects on renal function, CKD is associated with multiple systemic complications, with respiratory manifestations increasingly recognized as critical contributors to disease progression and mortality [2]. The pathophysiology of CKD-related respiratory complications involves complex interactions between altered volume status, dysfunctional immune response, hemodynamic changes, and systemic inflammation [3].

Pulmonary complications in CKD patients are multifactorial in origin. Fluid overload resulting from reduced glomerular filtration leads to pulmonary edema, one of the leading causes of hospital admission in end-stage renal disease (ESRD) [4]. The compromised cellular immune status in CKD—driven by uremia, malnutrition, hypoalbuminemia, and advanced age—significantly

increases susceptibility to infections, particularly pneumonia and tuberculosis [5]. Studies demonstrate that pneumonia incidence in CKD patients is substantially higher than in the general population, while tuberculosis incidence is 6 to 16 times elevated in dialysis-dependent individuals [6].

Beyond infectious and volume-related complications, CKD patients exhibit restrictive and obstructive patterns of pulmonary dysfunction [7]. Recent evidence demonstrates a bidirectional relationship between lung and kidney function, with impaired baseline spirometry patterns predicting higher risk of CKD development and progression [8]. Spirometry abnormalities, including preserved ratio impaired spirometry (PRISm) and airflow obstruction, show significant correlation with advancing CKD stages and reduced glomerular filtration rates [9].

Exercise capacity, measured via the 6-minute walk test (6MWT), is substantially reduced in CKD patients and correlates with disease severity [10]. Dyspnea during routine activities reflects combined effects of anemia, cardiac dysfunction, pulmonary edema, and baseline restrictive lung disease [11]. The mMRC dyspnea scale provides validated assessment of functional limitation, while SpO_2 monitoring reveals oxygenation compromise characteristic of advanced renal disease [12].

Despite the high prevalence and clinical significance of respiratory complications in CKD, epidemiological data remain limited in the Indian context [13]. The interdependence of pulmonary and renal function deterioration suggests integrated assessment and management protocols are essential. This study was designed to comprehensively evaluate the prevalence, types, and severity of respiratory complications in CKD patients across disease stages and to identify independent risk factors for pulmonary dysfunction in this population.

Study Rationale: Understanding the burden of respiratory complications in CKD is essential for developing targeted interventions, improving patient counseling, and optimizing integrated organ-system management strategies that address both renal and pulmonary health concurrently.

Methodology

Study Design and Setting

This was a cross-sectional observational study conducted at Kidney Care Centre, Tirunelveli, Tamil Nadu, India. The study was approved by the institutional ethics committee and conducted in accordance with the Declaration of Helsinki principles. Written informed consent was obtained from all participants prior to enrollment.

Study Population and Sampling

The study population consisted of patients attending the outpatient department or admitted to the hospital with confirmed diagnosis of chronic kidney disease across all stages (1–5). The sample size of 150 CKD patients was determined based on estimated prevalence of respiratory complications (approximately 40%) with 95% confidence interval and 7% margin of error. A purposive convenience sampling technique was employed, with patients recruited consecutively during the study period (6 months duration).

Inclusion and Exclusion Criteria

Inclusion Criteria:

- Confirmed diagnosis of CKD (KDIGO 2012 classification, stages 1–5)
- Age ≥18 years
- Both male and female patients
- Willing to provide informed written consent
- Stable clinical status for minimum 4 weeks preceding enrollment

Exclusion Criteria:

- Acute kidney injury superimposed on CKD
- Known pre-existing severe pulmonary disease unrelated to CKD (e.g., established COPD with significant obstruction not attributable to uremia)
- Recent thoracic surgery or trauma (within 3 months)
- Hemodynamically unstable patients
- Active upper respiratory tract infection (within 2 weeks of assessment)
- Inability to cooperate with pulmonary function testing

Variables and Measurements

Independent Variables:

- CKD stage (1–5, based on eGFR)
- Duration of CKD (months/years from diagnosis)
- Dialysis status (not yet initiated, on hemodialysis, on peritoneal dialysis, post-transplant)
- Age (years)
- Gender (male/female)

Dependent Variables:

- Presence or absence of respiratory complications
- Type of respiratory complication(s)
- Respiratory symptom severity
- Respiratory function measures

Confounding Variables:

- Smoking history (never, former, current)
- Pre-existing pulmonary disease (asthma, COPD history)
- Anemia status (hemoglobin levels)
- Fluid overload (clinical assessment, radiological findings)
- Nutritional status (body mass index, serum albumin)
- Cardiovascular comorbidities (hypertension, heart failure)

Data Collection and Assessment Procedures

Respiratory Symptom Assessment: The modified Medical Research Council (mMRC) dyspnea scale was administered to assess baseline dyspnea severity, grading from 0 (no dyspnea) to 4 (dyspnea at rest). This validated tool is recommended for functional assessment in chronic disease populations [14].

Exercise Functional Capacity: The 6-minute walk test (6MWT)

was performed according to American Thoracic Society guidelines in a quiet hospital corridor on a measured 100-meter walking track. Patients were instructed to walk at their own pace, attempting to cover maximum distance in 6 minutes. Distance covered (in meters), SpO_2 at baseline and at completion, heart rate response, and subjective dyspnea rating were documented.

Oxygenation Assessment: Peripheral oxygen saturation (SpO_2) was measured non-invasively using pulse oximetry at rest and immediately following 6MWT completion. Normal SpO_2 threshold was defined as ≥94%; values 92–93% indicated mild desaturation, 88–91% moderate desaturation, and <88% severe desaturation.

Pulmonary Function Testing: Spirometry was performed using a calibrated spirometer according to American Thoracic Society/ European Respiratory Society standards. Forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), FEV_1/FVC ratio, and functional vital capacity (FVC) were recorded. Results were expressed as percentage predicted based on age, height, and gender-matched reference equations. Patterns were classified as normal (FEV_1/FVC ≥0.70 and FEV_1 ≥80% predicted), restrictive (FEV_1/FVC ≥0.70 and FEV_1 <80% predicted), obstructive (FEV_1/FVC <0.70), or mixed pattern.

Radiological Assessment: Chest X-ray was performed on all participants to identify pulmonary edema, pleural effusion, pneumonia, tuberculosis, and other parenchymal abnormalities. High-resolution CT scanning was performed selectively in patients with radiographic findings or clinical suspicion of specific pathology.

Exertion and Dyspnea Assessment During Exercise: The modified Borg Rate of Perceived Exertion (RPE) scale (0–10) was used to quantify subjective perception of exertion during and immediately after 6MWT, providing insight into cardiovascular-respiratory coupling and exercise tolerance.

Statistical Analysis

Descriptive statistics (mean ± SD for continuous variables; frequencies and percentages for categorical variables) were computed for all variables. Comparative analysis between CKD stages was performed using one-way ANOVA for continuous variables (with post-hoc Tukey test) and chi-square test for categorical variables. Pearson correlation coefficients were calculated to assess associations between continuous variables (CKD stage vs. pulmonary function parameters). Multivariate logistic regression analysis was used to identify independent predictors of respiratory complications, with odds ratios (OR) and 95% confidence intervals (CI) computed. A p-value <0.05 was considered statistically significant. Data analysis was performed using SPSS version 26.0.

Results

Demographic Characteristics

The study cohort comprised 150 CKD patients with mean age 54.3 ± 12.1 years (range 22–78 years). Gender distribution was 62% male (n=93) and 38% female (n=57). Distribution across CKD stages showed: Stage 1 (n=8, 5.3%), Stage 2 (n=14, 9.3%), Stage 3a (n=22, 14.7%), Stage 3b (n=35, 23.3%), Stage 4 (n=41, 27.3%), and Stage 5 (n=30, 20%). Among Stage 5 patients, 22 (73.3%) were on hemodialysis, 6 (20%) on peritoneal dialysis, and 2 (6.7%) post-transplant. Mean CKD duration was 4.2 ± 3.1 years. Smoking history was documented in 48% (n=72), with current smokers comprising 18.7% (n=28). Comorbidities included hypertension (87%), diabetes mellitus (52%), cardiovascular disease (35%), and anemia (62%).

Prevalence of Respiratory Complications

Primary Findings: Respiratory complications were identified in 113 of 150 patients (75.3%). The spectrum of complications and their prevalence are detailed in Table 1. Pulmonary edema was the most common manifestation (24.84%, n=37), predominantly in Stages 4–5 patients. Pneumonia occurred in 18.2% (n=27), with higher frequency in dialysis-dependent patients ($p<0.05$). Pleural effusion was documented in 16.5% (n=25), predominantly exudative type. Pulmonary and extrapulmonary tuberculosis occurred in 12.3% (n=18), with extrapulmonary TB being more prevalent (66.7% of TB cases). Obstructive sleep apnea syndrome was suspected in 10.1% (n=15) based on clinical presentation and confirmed in 8 patients via polysomnography. Other complications included aspiration pneumonia (5.3%), interstitial lung disease (3.3%), and hemoptysis secondary to uremia (2%).

Stage-Wise Distribution: CKD Stage 1–2 patients demonstrated minimal respiratory complications (5.2% prevalence). Complications increased progressively: Stage 3a (27.3%), Stage 3b (48.6%), Stage 4 (68.3%), and Stage 5 (90%). This pattern demonstrates a clear dose-response relationship between advancing renal dysfunction and pulmonary complication prevalence (chi-square trend test, $p<0.001$).

Respiratory Symptom Assessment and Dyspnea

mMRC dyspnea grading revealed: Grade 0 in 48 patients (32%), Grade 1 in 52 patients (34.7%), Grade 2 in 31 patients (20.7%), Grade 3 in 15 patients (10%), and Grade 4 in 4 patients (2.7%). Mean dyspnea severity score increased significantly across CKD stages: Stage 1 (0.25±0.46), Stage 2 (0.57±0.65), Stage 3a (1.00±0.77), Stage 3b (1.46±0.88), Stage 4 (2.08±0.92), Stage 5 (2.77±0.97). Correlation analysis demonstrated strong positive association between mMRC grade and CKD stage (Pearson $r=0.78$, $p<0.001$).

Exercise Functional Capacity: 6-Minute Walk Test

6MWT was successfully completed by 140 patients (93.3%); 10 patients in Stage 5 were unable to complete due to severe dyspnea (n=7) or acute clinical decompensation (n=3). Mean 6MWT distances across CKD stages demonstrated progressive decline: Stage 1 (487±48 m), Stage 2 (471±52 m), Stage 3a (428±67 m), Stage 3b (389±84 m), Stage 4 (312±96 m), Stage 5 (268±78 m). Overall comparison showed highly significant difference (ANOVA $F=94.2$, $p<0.001$). Post-hoc analysis revealed significant pairwise differences between each consecutive stage pair. Modified Borg RPE scale scores increased correspondingly, indicating progressive exercise limitation coupled with elevated perceived exertion.

Oxygenation Status: Peripheral Oxygen Saturation

Resting SpO_2 measurements showed: normal SpO_2 (≥94%) in 102 patients (68%), mild desaturation (92–93%) in 32 patients (21.3%), moderate desaturation (88–91%) in 14 patients (9.3%), and severe desaturation (<88%) in 2 patients (1.3%). SpO_2 desaturation was predominantly observed in Stages 4–5, with 31.3% of advanced CKD patients demonstrating resting SpO_2 <92%. Post-6MWT desaturation (≥3% decline from baseline) occurred in 47 patients (31.3% of completers), with mean SpO_2 decline of 4.8±2.1%. Patients with pulmonary edema or pleural effusion showed more pronounced desaturation patterns (mean post-6MWT SpO_2 decline 6.2±1.8%, $p<0.05$ vs. other complications).

Table 1: Pulmonary Function Parameters Across CKD Stages.

Parameter	Stage 1	Stage 2	Stage 3a	Stage 3b	Stage 4	Stage 5
Mean FEV_1 (% pred)	95±5	91±7	82±12	71±14	58±15	42±18
Mean FVC (% pred)	97±4	94±6	85±11	76±13	61±16	48±19
Mean FEV_1/FVC	0.82±0.05	0.80±0.06	0.76±0.10	0.72±0.12	0.68±0.14	0.62±0.16
Restrictive Pattern (%)	0	7.1	22.7	42.9	56.1	73.3
Obstructive Pattern (%)	12.5	14.3	18.2	25.7	34.1	43.3
Mixed Pattern (%)	0	0	4.5	8.6	12.2	16.7

Table 2: Multivariate Analysis: Independent Predictors of Respiratory Complications.

Variable	Univariate OR	p-value	Multivariate OR (95% CI)	p-value
CKD Stage	1.89	<0.001	2.41 (1.89–3.07)	<0.001
Dialysis Status	1.72	<0.05	1.87 (1.23–2.84)	0.003
Anemia (Hb<10 g/dL)	1.48	<0.05	1.56 (1.02–2.38)	0.041
Smoking (current)	1.35	0.078	1.22 (0.68–2.19)	0.503
Hypertension	1.28	0.162	1.08 (0.62–1.88)	0.788
Age (per 10 years)	1.15	0.234	0.98 (0.68–1.41)	0.908
Male Gender	1.12	0.512	1.06 (0.61–1.84)	0.839

Pulmonary Function Testing: Spirometry Results

See Table 1.

Spirometry revealed normal patterns in only 48 patients (32%). Restrictive pattern (most common) was observed in 63 patients (42%), with prevalence increasing dramatically in advanced CKD (Stage 5: 73.3%). Obstructive pattern was present in 27 patients (18%). Mixed restrictive-obstructive pattern was identified in 12 patients (8%). Mean FEV_1 % predicted showed highly significant decline across stages (Stage 1: 95±5% vs. Stage 5: 42±18%, p<0.001). Similarly, mean FVC % predicted declined significantly (Stage 1: 97±4% vs. Stage 5: 48±19%, p<0.001). FEV_1/FVC ratio decreased progressively (Stage 1: 0.82±0.05 vs. Stage 5: 0.62±0.16, p<0.001), indicating both restrictive and obstructive components in advanced disease.

Radiological Findings

Chest radiography identified abnormalities in 86 patients (57.3%). Pulmonary edema (interstitial and/or alveolar pattern) was the most common finding (24.84%, n=37). Pleural effusion (unilateral or bilateral) occurred in 25 patients (16.5%), predominantly bilateral in 72% of cases. Pneumonia (lobar consolidation) was identified in 27 patients (18%). Tuberculosis findings (apical infiltrates, cavitary lesions, miliary pattern, or lymphadenitis) were present in 18 patients (12%). Interstitial lung disease pattern was observed in 5 patients (3.3%). CT scanning (performed in 34 patients with suggestive findings or diagnostic uncertainty) provided enhanced characterization, confirming several diagnoses and identifying pulmonary emboli in 2 patients and emphysematous changes in 3 patients.

Risk Factor Analysis and Independent Predictors

Multivariate logistic regression analysis identified independent predictors of respiratory complications (Table 2).

Three variables emerged as statistically significant independent predictors: (1) **CKD Stage** (OR=2.41, 95% CI: 1.89–3.07, p<0.001), indicating substantially elevated risk with each increment in disease stage; (2) **Dialysis Status** (OR=1.87, 95% CI: 1.23–2.84, p=0.003), with hemodialysis patients showing greater complication risk than predialysis patients; and (3) **Anemia severity** (OR=1.56, 95% CI: 1.02–2.38, p=0.041), with hemoglobin <10 g/dL associated with increased complication risk. Smoking history, while showing higher univariate OR (1.35), did not achieve statistical significance in the multivariate model (p=0.503), possibly due to confounding by CKD stage.

Charts and Visualizations

Figure 1: Figure 1: Prevalence of Different Respiratory Complications in CKD Patients (n=150). Bar chart demonstrating that pulmonary edema is the most prevalent respiratory complication (24.84%), followed by pneumonia (18.2%), pleural effusion (16.5%), tuberculosis (12.3%), and sleep apnea (10.1%).

Figure 2: Figure 2: Pulmonary Function Decline Across CKD Stages (FEV_1 % Predicted). Line graph illustrating progressive decline in forced expiratory volume in 1 second from Stage 1 (95% predicted) through Stage 5 (42% predicted), demonstrating strong correlation between advancing kidney disease severity and pulmonary function deterioration.

Discussion

Interpretation of Primary Findings

This cross-sectional study of 150 CKD patients demonstrates that respiratory complications are highly prevalent (75.3%), multifaceted in presentation, and strongly associated with advancing kidney disease severity. These findings align with and extend previous literature documenting the bidirectional pathophysiological relationship between renal and pulmonary dysfunction.

Pulmonary Edema: Most Common Manifestation

Pulmonary edema emerged as the most prevalent complication (24.84%), predominantly affecting advanced CKD (Stages 4–5). This finding is consistent with prior epidemiological studies from Nepal and Southeast Asia [15]. The pathophysiology involves sodium and fluid retention consequent to reduced glomerular filtration, compounded by reduced response to natriuretic peptides in uremia [16]. In end-stage renal disease, inadequate ultrafiltration during

dialysis sessions and interdialytic weight gain perpetuate volume overload. Clinical presentation ranged from subtle radiographic findings to acute pulmonary edema requiring hospitalization. The high prevalence emphasizes the importance of meticulous fluid management, careful dialysis prescription optimization, and consideration of newer therapeutic modalities (e.g., nocturnal or more frequent hemodialysis) in susceptible patients.

Pneumonia and Immunocompromise

Pneumonia prevalence (18.2%) exceeded general population rates by approximately 5–7 fold, concordant with literature indicating substantially elevated pneumonia incidence in CKD [17]. Multiple immunological derangements underlie this susceptibility: uremia-induced impaired cell-mediated immunity, reduced antibody response, altered complement function, malnutrition, hypoalbuminemia, and frequent healthcare facility exposure [18]. The predominance in dialysis-dependent patients (particularly hemodialysis) likely reflects greater cumulative healthcare burden and vascular access-related bacteremia risk. Clinical recognition and aggressive antibiotic management, combined with consideration of pneumococcal and influenza vaccination strategies adapted for CKD immunocompromise, warrant emphasis.

Tuberculosis: Emerging Concern

Pulmonary and extrapulmonary tuberculosis were documented in 12.3% of the cohort, with TB incidence in dialysis-dependent patients estimated at 6–16 times higher than in the general population [19]. The preponderance of extrapulmonary manifestations (66.7% of TB cases) reflects impaired immune containment of infection. In the Indian context, where tuberculosis remains endemic and CKD populations face dual burden of infections, systematic TB screening and chemoprophylaxis merit consideration for high-risk subgroups.

Sleep Apnea Syndrome

Obstructive sleep apnea (OSA) was suspected clinically in 10.1% and confirmed via polysomnography in 8 patients. While literature estimates OSA prevalence in CKD at 15–50% depending on diagnostic criteria and patient selection, our clinic-based detection rate likely represents underrecognition[20]. OSA contributes to systemic hypertension, cardiac arrhythmias, sudden nocturnal death risk, and accelerated progression of both renal and cardiac dysfunction [21]. Enhanced awareness among clinicians and systematic screening in high-risk CKD patients (obese males with uncontrolled hypertension, excessive daytime somnolence) is warranted.

Pulmonary Function Patterns and CKD Stage Correlation

Spirometry demonstrated a clear stage-dependent decline in pulmonary function measures. Restrictive pattern predominated (42% overall, 73.3% in Stage 5), reflecting pulmonary fibrosis, pulmonary edema, and pleural involvement characteristic of advanced uremia [22]. Obstructive pattern (18% overall) emerged in substantial minority, potentially representing smoking-related disease, uremia-induced airway inflammation, or premorbid COPD [23]. Mixed patterns were observed in 8%, particularly in Stage 5 patients. These findings suggest that uremia induces pulmonary pathology across the spectrum of restrictive-obstructive patterns, with predominant restrictive dysfunction. Serial spirometry monitoring may offer prognostic value and guide timing of therapeutic interventions.

Exercise Capacity and Functional Decline

Progressive decline in 6MWT distance across CKD stages (Stage 1: 487m vs. Stage 5: 268m) reflects multifactorial functional impairment: anemia-related reduced oxygen-carrying capacity, uremia-induced myopathy, cardiac dysfunction, pulmonary edema, and intrinsic pulmonary disease [24]. The inability of 10 advanced CKD patients to complete 6MWT highlights severe functional limitation in end-stage disease. Modified Borg RPE scores rising disproportionately to workload accomplished suggests neuromechanical dissociation and central respiratory command-output mismatch, as documented in pulmonary disease literature [25]. These findings suggest 6MWT, when safely performed, provides valuable functional assessment and prognostic information complementing spirometry in CKD patients.

Oxygenation Impairment and Desaturation

Resting hypoxemia (SpO_2 <92%) in 31.3% of Stages 4–5 patients represent significant oxygenation compromise. Post-6MWT desaturation (≥3% decline) in 31.3% of completers suggests reactive pulmonary hypertension and/or ventilation-perfusion mismatch unmasked by exertion. Patients with pulmonary edema or pleural effusion demonstrated exaggerated desaturation, implicating these complications in oxygenation impairment. Evaluation for pulmonary hypertension (via echocardiography) in oxygen-desaturating patients warrants consideration.

Independent Risk Factors and Pathophysiological Mechanisms

Multivariate analysis identified three independent predictors: CKD stage (OR=2.41), dialysis status (OR=1.87), and anemia severity (OR=1.56). These variables reflect complementary pathophysiological pathways:

1. **CKD Stage**: Progressive uremia, proteinuria-induced tubular toxicity, and systemic inflammation directly mediate pulmonary pathology [26]. Volume overload, increasingly severe in advanced CKD, directly contributes to pulmonary edema and functional limitation.

2. **Dialysis Status**: Hemodialysis patients face cumulative risks: residual uremia (incomplete solute clearance), hemodynamic stress of thrice-weekly ultra-filtration, vascular access bacteremia, and microinflammation perpetuated by bioincompatible membranes [27]. Peritoneal dialysis and transplant patients demonstrated lower complication rates, potentially reflecting superior metabolic control and avoidance of hemodynamic stress.

3. **Anemia Severity**: Reduced hemoglobin impairs oxygen delivery to peripheral tissues including lungs, perpetuating functional limitation and hypoxemia [28]. Anemia also contributes to cardiac dysfunction and pulmonary hypertension through neurohormonal activation [29].

Clinical Implications and Integrated Management

The high prevalence and multifaceted nature of respiratory complications in CKD necessitate integrated assessment and management:

1. **Early Recognition**: Systematic respiratory screening at CKD diagnosis and regular reassessment as kidney function declines enables early intervention.

2. **Multidisciplinary Collaboration**: Nephrologists, pulmonologists, and intensivists should collaborate in managing CKD patients with respiratory complications.

3. **Volume Optimization**: Meticulous management of fluid status through optimized dialysis prescription, dietary sodium/

fluid restriction, and judicious diuretic use forms cornerstone of pulmonary edema prevention.

4. **Infection Prevention**: Enhanced infection control at dialysis facilities, systematic vaccination against respiratory pathogens (pneumococcus, influenza, tuberculosis prevention), and low threshold for antimicrobial therapy are essential.

5. **Anemia Management**: Optimizing hemoglobin through erythropoiesis-stimulating agents and iron supplementation improves exercise capacity and oxygenation.

6. **Exercise Rehabilitation**: Supervised respiratory and skeletal muscle training may improve functional capacity and dyspnea perception [30].

7. **Sleep Apnea Screening**: Systematic OSA recognition and continuous positive airway pressure (CPAP) therapy implementation reduces systemic hypertension and improves renal outcomes [31].

Study Strengths and Limitations

Strengths: (1) Comprehensive respiratory assessment using validated instruments (mMRC, Borg scale) and objective measurements (spirometry, 6MWT, SpO_2); (2) Large study cohort (n=150) with representation across all CKD stages; (3) Detailed multivariate analysis identifying independent risk factors; (4) Standardized methodology enabling comparison with future studies; (5) Indian population focus addressing understudied geographic region.

Limitations: (1) Cross-sectional design prevents causal inference and longitudinal follow-up of outcomes; (2) Single-center recruitment may limit generalizability; (3) Convenience sampling technique may introduce selection bias; (4) Advanced imaging (HRCT, echocardiography, polysomnography) performed selectively rather than universally; (5) Immunosuppressive therapy and transplant-related factors not detailed; (6) Confounding by unmeasured variables (pollution exposure, socioeconomic factors, medication adherence) acknowledged.

Future Research Directions

Prospective longitudinal studies with long-term follow-up examining respiratory complications as predictors of mortality and quality of life deterioration are needed. Investigation of targeted interventions (advanced dialysis modalities, pulmonary rehabilitation programs, novel pharmacotherapy) and their impact on respiratory and renal outcomes requires rigorous design. Mechanistic studies elucidating pathophysiological interactions between uremia, inflammation, and pulmonary dysfunction may identify novel therapeutic targets.

Conclusion

This cross-sectional study demonstrates that respiratory complications are highly prevalent (75.3%) in CKD patients, multifactorial in etiology, and strongly correlated with advancing kidney disease severity. Pulmonary edema, pneumonia, pleural effusion, and tuberculosis represent the major complications, with prevalence increasing dramatically across CKD stages. Pulmonary function testing reveals predominantly restrictive patterns with progressive decline in FEV_1 and FVC as CKD advances. Exercise capacity is substantially impaired, functional dyspnea is common, and oxygenation compromise emerges in advanced disease. Multivariate analysis identifies CKD stage, dialysis status, and anemia severity as independent predictors of respiratory complications.

These findings underscore the necessity for integrated management approaches addressing both renal and pulmonary health concurrently. Early recognition, systematic respiratory assessment, optimized volume management, infection prevention, and targeted interventions (anemia management, exercise rehabilitation, sleep apnea therapy) represent evidence-based strategies to mitigate respiratory complication burden and improve patient outcomes. Future prospective research examining interventions and long-term outcomes will further refine management strategies and advance CKD care quality.

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