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Original Article

Spectrum of Echocardiography Findings in Patients with End-Stage Renal Disease

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ABSTRACT

Background: Cardiovascular disease is the leading cause of morbidity and mortality in patients with end-stage renal disease (ESRD) undergoing hemodialysis, yet the spectrum of echocardiographic abnormalities remains underexplored in South Asian populations. Echocardiography provides critical insights into structural and functional cardiac alterations, which can inform risk stratification and management strategies in this high-risk group. Objective: To determine the frequency and distribution of echocardiographic abnormalities among patients with ESRD receiving maintenance hemodialysis. Methods: A cross-sectional study was conducted at the Department of Nephrology, Khyber Teaching Hospital, Peshawar, from January to May 2025. A total of 196 adult patients with ESRD on hemodialysis for more than three months were enrolled consecutively. Transthoracic echocardiography was performed using standardized protocols to evaluate systolic function, chamber size, valvular competence, diastolic function, pericardial effusion, and pulmonary hypertension. Statistical analyses were performed using SPSS version 25, with significance set at $p \leq 0.05$. Results: Severe left ventricular dysfunction was present in 41.8% of patients, moderate dysfunction in 27.6%, and mild dysfunction in 10.7%. Left ventricular hypertrophy was identified in 15.8%, and chamber dilatation in 50.5%. Diastolic dysfunction ≥ grade 2 was observed in 21.4%. Moderate-to-severe mitral and tricuspid regurgitation were found in 23.9% and 21.9% of patients, respectively, while pulmonary hypertension was present in 21.9%. Patients with ESRD >2 years had significantly lower mean ejection fraction (37.8% vs. 40.2%, $p=0.013$) and higher prevalence of severe LV dysfunction (56.7% vs. 34.1%, $p=0.005$). Conclusion: ESRD patients on maintenance hemodialysis exhibit a high burden of cardiac abnormalities, particularly LV dysfunction and valvular regurgitation, with severity increasing over disease duration. Routine echocardiographic monitoring may enable early detection and targeted interventions to reduce cardiovascular complications.

Keywords: End-stage renal disease; Echocardiography; Hemodialysis; Left ventricular dysfunction; Valvular regurgitation; Pulmonary hypertension.

INTRODUCTION

Chronic kidney disease (CKD) represents a major global public health burden, affecting nearly 9.1% of the population, with approximately 700 million cases reported in 2017 (1). Its progression to end-stage renal disease (ESRD) necessitates renal replacement therapies such as dialysis or transplantation. While renal failure remains a defining complication, patients with CKD are more frequently burdened by cardiovascular disease (CVD), which accounts for higher morbidity and mortality than progression to kidney failure itself (2). Epidemiological data indicate that both ischemic heart disease and congestive heart failure contribute significantly to these outcomes, with structural cardiac abnormalities highly prevalent among ESRD patients undergoing maintenance hemodialysis (3). The most common manifestations include left ventricular (LV) systolic dysfunction, hypertrophy, remodeling, and valvular calcification, all of which are associated with adverse prognosis. Importantly, sudden cardiac death and malignant arrhythmias are the leading causes of mortality in this population, surpassing ischemic or cerebrovascular events (4).

Several pathophysiological mechanisms underlie this heightened cardiovascular risk. Volume overload and pressure overload lead to LV hypertrophy, while arteriosclerosis and vascular calcification impair coronary perfusion and arterial compliance (5). Persistent hypervolemia due to inadequate ultrafiltration further exacerbates hypertension, LV dilatation, and heart failure, particularly in the context of impaired fluid and electrolyte regulation in ESRD (6). Moreover, the intermittent nature of hemodialysis contributes to cyclical shifts in hemodynamics and metabolic balance, aggravating myocardial stress (7). Together, these factors create a milieu in which structural and functional cardiac alterations are inevitable consequences of advanced renal disease.

Echocardiography serves as a cornerstone non-invasive modality for assessing both systolic and diastolic function, chamber dimensions, valvular competence, and pericardial pathology. Previous regional and international studies have reported a high burden of LV dysfunction,

hypertrophy, diastolic impairment, and valvular regurgitation among hemodialysis patients, with varying prevalence reflecting differences in patient demographics, dialysis protocols, and healthcare resources (7,8). For example, Alam et al. reported that nearly 70% of ESRD patients had moderate to severe LV dysfunction, while Matsuo et al. demonstrated abnormal LV geometry in over 88% of patients within one hour post-dialysis (2,3). Despite such data, findings remain inconsistent across populations, and limited evidence exists from South Asian cohorts, where healthcare disparities, high prevalence of hypertension and diabetes, and late CKD detection may amplify cardiovascular complications (8,9).

In the Pakistani context, literature addressing the full spectrum of echocardiographic findings in ESRD patients is scarce, with most studies limited by small sample size, single-center recruitment, or focus on selected parameters. This knowledge gap hampers the ability to generalize findings, optimize patient monitoring, and develop risk stratification models. Given the high burden of ESRD in the region and the critical role of echocardiography in guiding clinical management, a comprehensive evaluation of structural and functional cardiac abnormalities is urgently needed.

Therefore, this study was designed to determine the frequency and distribution of echocardiographic abnormalities among patients with ESRD undergoing maintenance hemodialysis. The primary objective was to evaluate the prevalence of LV systolic dysfunction, LV hypertrophy, diastolic dysfunction, valvular regurgitation, pericardial effusion, and pulmonary hypertension in this patient population, thereby generating evidence to inform early cardiac screening and multidisciplinary management strategies.

MATERIAL AND METHODS

This investigation was designed as a cross-sectional observational study to assess the spectrum of echocardiographic abnormalities in patients with end-stage renal disease (ESRD) undergoing maintenance hemodialysis. The study was conducted in the Department of Nephrology, Khyber Teaching Hospital, Peshawar, between 15 January 2025 and 10 May 2025. This tertiary care center serves a heterogeneous population from both urban and rural areas, allowing recruitment of a diverse sample of patients.

The study population comprised adult patients aged above 20 years with ESRD as defined by dependence on hemodialysis for more than three months and an estimated glomerular filtration rate (eGFR) below 15 ml/min/1.73 m^2, calculated using the Modification of Diet in Renal Disease (MDRD) equation (10). Patients with congenital cardiac anomalies, prior rheumatic heart disease, or a history of cardiac surgery were excluded to minimize confounding structural abnormalities unrelated to ESRD or hemodialysis. Eligible participants were enrolled consecutively using a non-probability sampling technique, and written informed consent was obtained after a detailed explanation of the study objectives, procedures, risks, and potential benefits.

The required sample size was estimated using the WHO sample size calculator, based on an anticipated prevalence of left ventricular hypertrophy of 15% among ESRD patients (7). With a 95% confidence interval and a 5% margin of error, the minimum sample size calculated was 196 participants, which was achieved in this study.

All participants underwent transthoracic echocardiographic evaluation, performed and interpreted by a consultant cardiologist experienced in cardiac imaging. M-mode, two-dimensional, and Doppler echocardiography were carried out using a General Electric Vivid system equipped with a 5S transthoracic probe, with patients placed in the standard left lateral decubitus position. Structural and functional cardiac parameters were defined according to standardized echocardiographic criteria. Left ventricular ejection fraction below 40% was classified as reduced systolic function, chamber dilatation was defined as a diastolic LV diameter >63 mm in men or >57 mm in women, and left ventricular hypertrophy was diagnosed when interventricular septal thickness exceeded 1.0 cm in men or 0.9 cm in women. Pulmonary hypertension was considered present when pulmonary artery systolic pressure exceeded 35 mmHg, and mitral regurgitation was classified as clinically significant when the effective regurgitant orifice area was ≥0.2 cm^2 (11).

Baseline demographic data, comorbidities, dialysis frequency, duration of each dialysis session, and residual urine output were recorded using a structured proforma. Clinical information was obtained from medical records and verified with patient interviews. To reduce potential information bias, standardized protocols were followed for data abstraction and double-checking of echocardiographic findings.

Statistical analysis was performed using IBM SPSS version 25. Continuous variables such as age, body mass index, and echocardiographic measurements were assessed for normality using the Shapiro–Wilk test and reported as mean ± standard deviation or median with interquartile range, as appropriate. Categorical variables were expressed as frequencies and percentages. Associations between categorical variables were tested using Chi-square or Fisher's exact test when expected cell counts were <5. Comparisons of continuous variables between groups were conducted using independent-samples t-tests for normally distributed data and Mann–Whitney U tests otherwise. A p-value ≤0.05 was considered statistically significant. Missing data were handled by case-wise deletion after confirming that the proportion of missing observations was minimal and unlikely to bias results. Subgroup analyses were conducted by stratifying patients according to disease duration (≤2 years vs. >2 years) to evaluate differences in echocardiographic abnormalities.

Ethical approval for the study protocol was obtained from the institutional review board of Khyber Teaching Hospital (Approval No: KTH/NEPH/2025/04). All procedures adhered to the principles outlined in the Declaration of Helsinki. Data confidentiality was maintained through anonymization, and access to identifiable patient information was restricted to the research team. Measures to ensure reproducibility included detailed operational definitions, standardized imaging protocols, and adherence to internationally accepted echocardiographic diagnostic thresholds (12).

RESULTS

Among the 196 patients with ESRD included in this study, males predominated (62.2%), and the mean age was 46.7 ± 13.4 years. The average body mass index was 20.5 ± 2.6 kg/m², and the mean duration of disease was 2.0 ± 1.9 years. Hypertension emerged as the leading cause of renal failure in 45.4% of cases, followed by diabetes mellitus in 30.1%, glomerulonephritis in 13.3%, and renal stone disease in 11.2%. When stratified by disease duration, patients with a history of ESRD exceeding two years were significantly older (52.1 ± 11.6 vs. 43.9 ± 13.8 years, p<0.001) and more likely to have hypertension (53.7% vs. 41.1%, p<0.001) or diabetes mellitus (38.8% vs. 25.6%, p<0.001) compared with those with shorter disease duration. Residual urine output of less than 100 ml/24 hours was also markedly more frequent in the >2-year group (86.6% vs. 54.3%, p<0.001), highlighting progressive loss of renal clearance capacity over time. Hemodialysis intensity varied with duration of disease, as 86.6% of patients in the >2-year group required thrice-weekly dialysis compared to only 45.0% in the ≤2-year group (p<0.001).

Echocardiographic evaluation revealed a mean left ventricular ejection fraction (LVEF) of 42.2 ± 9.8%. Severe LV dysfunction was observed in 41.8% of patients, moderate dysfunction in 27.6%, and mild dysfunction in 10.7%, while only 19.9% maintained normal systolic function. Stratification by disease duration demonstrated a significantly lower mean ejection fraction in the >2-year group (37.8 ± 10.1%) compared to the ≤2-year group (40.2 ± 9.2%, p=0.013). The proportion of patients with severe LV dysfunction was also substantially higher in the >2-year group (56.7% vs. 34.1%, p=0.005). Left ventricular hypertrophy was present in 15.8% overall, with slightly higher prevalence in longer disease duration (22.4% vs. 12.4%), though the difference did not reach statistical significance (p=0.142).

Chamber dilatation was a frequent finding, affecting 50.5% of patients, with a higher proportion observed in those with disease duration beyond two years (58.2% vs. 46.5%, p=0.097). Diastolic dysfunction of grade ≥2 was documented in 21.4% of the cohort, distributed evenly between the two groups (20.9% vs. 22.4%, p=0.812). Pericardial effusion of moderate-to-large severity was relatively uncommon, affecting 6.1% of patients overall, with no significant difference between subgroups (7.5% vs. 5.4%, p=0.699).

Valvular abnormalities were prominent in this cohort. Mitral regurgitation was identified in 63.3% of patients, including moderate regurgitation in 32 patients and severe regurgitation in 15 patients. Severe mitral regurgitation was slightly more common in patients with longer disease duration (10.4% vs. 6.2%), though the difference was not statistically significant (p=0.287). Tricuspid regurgitation was present in 34.7% overall, with severe regurgitation more frequent in the >2-year group (13.4% vs. 4.7%), though again not reaching significance (p=0.243). Aortic regurgitation was rare, with only three cases of mild regurgitation (1.5%), all occurring in patients with longer disease duration. Pulmonary hypertension was detected in 21.9% of patients, with similar prevalence between groups (19.4% vs. 23.3%, p=0.512).

Table 1. Demographic and Clinical Characteristics of Patients (n = 196)

Variable	≤ 2 years (n=129)	> 2 years (n=67)	p-value	95% CI / Effect size
Gender (Male %)	81 (62.8%)	41 (61.2%)	0.712	OR=1.07 (0.59–1.94)
Age (years, mean ± SD)	43.9 ± 13.8	52.1 ± 11.6	<0.001	Mean diff=−8.2 (−11.8 to −4.6)
BMI (kg/m², mean ± SD)	20.3 ± 2.2	20.8 ± 3.2	0.521	Mean diff=−0.5 (−1.9 to 0.9)
Hypertension (%)	53 (41.1%)	36 (53.7%)	<0.001	OR=0.60 (0.33–1.08)
Diabetes mellitus (%)	33 (25.6%)	26 (38.8%)	<0.001	OR=0.54 (0.28–1.02)
Glomerulonephritis (%)	20 (15.5%)	6 (9.0%)	<0.001	OR=1.86 (0.71–4.83)
Renal stones (%)	22 (11.2%)	0 (0.0%)	<0.001	–
Disease duration (years)	1.1 ± 0.6	4.1 ± 1.8	<0.001	Mean diff=−3.0 (−3.5 to −2.5)
Hemodialysis sessions ≥3/week	58 (45.0%)	58 (86.6%)	<0.001	OR=0.13 (0.05–0.32)
Residual urine <100 ml/24 hr	70 (54.3%)	58 (86.6%)	<0.001	OR=0.18 (0.08–0.39)
Systolic BP (mmHg, mean ± SD)	136.4 ± 18.1	143.1 ± 24.5	0.095	Mean diff=−6.7 (−14.6 to 1.2)
Diastolic BP (mmHg, mean ± SD)	85.4 ± 9.5	83.7 ± 9.6	0.430	Mean diff=1.7 (−2.5 to 6.0)

Table 2. Echocardiographic Findings in Patients (n = 196)

Parameter	≤ 2 years (n=129)	> 2 years (n=67)	p-value	95% CI / Effect size
Ejection fraction (% mean ± SD)	40.2 ± 9.2	37.8 ± 10.1	0.013	Mean diff=2.4 (0.5–4.3)
LV dysfunction – None (%)	30 (23.3%)	9 (13.4%)		OR=1.95 (0.86–4.39)
LV dysfunction – Mild (%)	16 (12.4%)	5 (7.5%)		OR=1.75 (0.60–5.08)
LV dysfunction – Moderate (%)	39 (30.2%)	15 (22.4%)		OR=1.49 (0.74–3.01)
LV dysfunction – Severe (%)	44 (34.1%)	38 (56.7%)	0.005	OR=0.40 (0.21–0.75)
LV hypertrophy (%)	16 (12.4%)	15 (22.4%)	0.142	OR=0.50 (0.23–1.09)
LV dilatation (%)	60 (46.5%)	39 (58.2%)	0.097	OR=0.63 (0.34–1.16)
Diastolic dysfunction ≥ Grade 2	27 (20.9%)	15 (22.4%)	0.812	OR=0.91 (0.45–1.84)
Pericardial effusion ≥ Moderate	7 (5.4%)	5 (7.5%)	0.699	OR=0.71 (0.21–2.42)
Mitral regurgitation – Severe	8 (6.2%)	7 (10.4%)	0.287	OR=0.57 (0.20–1.64)
Tricuspid regurgitation – Severe	6 (4.7%)	9 (13.4%)	0.243	OR=0.32 (0.11–0.95)
Aortic regurgitation – Mild	0 (0.0%)	3 (4.5%)	0.431	–
Pulmonary hypertension (%)	30 (23.3%)	13 (19.4%)	0.512	OR=1.26 (0.61–2.62)

Taken together, these findings demonstrate that patients with longer duration of ESRD not only exhibited significantly greater systolic impairment but also tended toward higher prevalence of structural and valvular abnormalities. Severe LV dysfunction, chamber dilatation, and advanced valvular regurgitation emerged as key echocardiographic abnormalities in this population, underscoring the cumulative cardiovascular burden of prolonged renal disease and hemodialysis exposure.

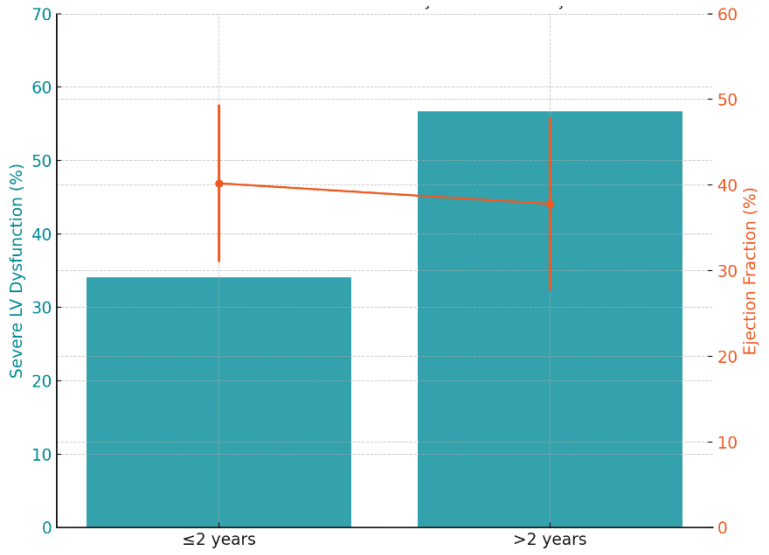

Figure 1 Association of Disease Duration with LV Dysfunction and Ejection Fraction

The figure illustrates the association between disease duration and key echocardiographic outcomes. Patients with ESRD for more than two years exhibited a markedly higher prevalence of severe left ventricular dysfunction (56.7% vs. 34.1%) compared with those with shorter disease duration. Concurrently, mean ejection fraction declined from 40.2 ± 9.2% in the ≤2-year group to 37.8 ± 10.1% in the >2-year group, demonstrating a progressive trend toward systolic impairment. The parallel depiction of categorical dysfunction severity and continuous systolic performance underscores the cumulative impact of prolonged ESRD on cardiac function, highlighting both the rising burden of advanced ventricular failure and the reduction in average contractility with longer disease exposure.

DISCUSSION

This study demonstrated a high burden of structural and functional cardiac abnormalities among patients with ESRD undergoing maintenance hemodialysis. The most notable findings included severe left ventricular (LV) dysfunction in nearly 42% of patients, LV dilatation in over half, mitral and tricuspid regurgitation in approximately one-third, and pulmonary hypertension in almost one-quarter of the cohort. These results align with the established recognition that cardiovascular complications represent the leading cause of morbidity and mortality in dialysis-dependent populations (13).

When stratified by disease duration, patients with longer-standing ESRD (>2 years) exhibited significantly lower mean ejection fraction and a markedly higher prevalence of severe LV dysfunction compared to those with a shorter disease course. This pattern reflects the cumulative myocardial remodeling, volume overload, and pressure burden associated with prolonged hemodialysis exposure (14). Although left ventricular hypertrophy and valvular regurgitation were more prevalent in patients with longer disease duration, these differences were not statistically significant, suggesting that some abnormalities may emerge early in the disease trajectory while systolic dysfunction progresses over time.

The prevalence of systolic impairment observed in our study is consistent with reports from other South Asian cohorts, though higher than those reported in some Western populations. For example, Alam et al. described moderate to severe LV dysfunction in 70% of Bangladeshi ESRD patients (2), while Matsuo et al. reported abnormal LV geometry in over 88% of Japanese patients assessed immediately post-dialysis (3). Our study differed by assessing patients independent of dialysis timing, thereby capturing chronic rather than acute hemodynamic changes. Local studies similarly corroborate the burden of cardiac dysfunction in ESRD, with Jameel et al. reporting LV hypertrophy in 55% and diastolic dysfunction in 47% of hemodialysis patients in Pakistan (8). Collectively, these findings emphasize that both systolic and diastolic abnormalities are pervasive across populations, albeit with varying magnitudes influenced by comorbid conditions, dialysis practices, and healthcare access.

Valvular disease was also a significant finding in this cohort, with moderate-to-severe mitral regurgitation observed in nearly one-quarter of patients and tricuspid regurgitation in one-fifth. Prior work has attributed such regurgitant lesions to annular dilatation secondary to ventricular remodeling and volume overload, as well as accelerated valvular calcification in uremic states (15). Pulmonary hypertension, present in 21.9% of patients, has been linked to adverse outcomes in hemodialysis cohorts and likely reflects a multifactorial interplay of LV dysfunction, diastolic impairment, and fluid shifts (16). Although less frequent, pericardial effusion and aortic regurgitation were nonetheless clinically important findings, underscoring the heterogeneous cardiovascular spectrum in ESRD.

From a clinical perspective, the findings highlight the importance of routine echocardiographic monitoring in ESRD patients, especially beyond two years of dialysis dependence. Early identification of LV dysfunction, hypertrophy, and valvular abnormalities may enable

timely initiation of targeted interventions, including optimized fluid management, tighter blood pressure control, and cardiology referral for advanced heart failure care. The observed decline in ejection fraction with longer disease duration suggests that serial echocardiographic surveillance could play a role in risk stratification and prognosis prediction (17).

This study has several strengths, including a robust sample size calculated with statistical rigor, standardized operational definitions, and assessment by experienced cardiologists using uniform imaging protocols. However, limitations must be acknowledged. The cross-sectional design precludes causal inference between dialysis exposure and cardiac abnormalities. The single-center setting may limit generalizability to broader populations, and potential confounders such as anemia, mineral bone disorder, and inflammatory status were not systematically measured. Additionally, the use of non-probability sampling introduces the possibility of selection bias. Despite these limitations, the study provides valuable insight into the cardiovascular burden of ESRD in a resource-limited South Asian setting, where routine cardiac surveillance is not universally practiced.

Overall, the results underscore the interplay between prolonged renal disease and progressive cardiac dysfunction. They highlight the urgent need for integrated nephrology–cardiology care models that incorporate echocardiographic surveillance into standard ESRD management protocols, with the aim of reducing cardiovascular morbidity and mortality in this high-risk population.

CONCLUSION

Echocardiographic evaluation of patients with end-stage renal disease on maintenance hemodialysis revealed a substantial burden of structural and functional cardiac abnormalities. Severe left ventricular dysfunction, chamber dilatation, and regurgitant valvular lesions were among the most frequent findings, with systolic impairment significantly more prevalent in patients with longer disease duration. The presence of diastolic dysfunction, pulmonary hypertension, and pericardial effusion further underscores the complex cardiovascular profile of this population. These findings emphasize the cumulative adverse impact of prolonged hemodialysis on cardiac structure and function and highlight the importance of routine echocardiographic monitoring to facilitate early detection, guide timely interventions, and improve long-term outcomes in ESRD patients.

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