Journal of Inflammation Research

Dovepress
Taylor & Francis Group

Open Access Full Text Article

ORIGINAL RESEARCH

Cardiac Function Transition in Patients with Chronic Kidney Disease Undergoing Maintenance Hemodialysis in a High-Altitude Multi-Ethnic Region: A Comparative Study Between Yi and Non-Yi Ethnic Groups

Jingjing Zhang[1–3,*], Zhaoyu Li[4,*], Xueliang Xiao[5], Xuesong Liu[6], Qian Qiao[1–3], Lu Cheng[1–3], Jun Sha[5], Yufei Yang[7], Wangzheqi Zhang[8], Haoling Zhang[9], Xuerui Ye[1–3]

[1]Fuwai Yunnan Hospital, Chinese Academy of Medical Sciences, Affiliated Cardiovascular Hospital of Kunming Medical University, Kunming, 650000, People's Republic of China; [2]Yunnan Provincial Cardiovascular Clinical Medical Center, Kunming, 650000, People's Republic of China; [3]Yunnan Provincial Cardiovascular Clinical Medical Research Center, Kunming, 650000, People's Republic of China; [4]College of Acupuncture-Moxibustion and Tuina, Gansu University of Chinese Medicine, Lanzhou, 730000, People's Republic of China; [5]Internal Medicine Department II, Ninglang Yi Autonomous County People's Hospital, Ninglang, 674300, People's Republic of China; [6]Basic Medical College, Gansu University of Chinese Medicine, Lanzhou, 730000, People's Republic of China; [7]School of Public Health, Gansu University of Chinese Medicine, Lanzhou, 730000, People's Republic of China; [8]School of Anesthesiology, Naval Medical University, Shanghai, People's Republic of China; [9]Department of Biomedical Sciences, Advanced Medical and Dental Institute, Universiti Sains Malaysia, Kepala Batas, Penang, 13200, Malaysia

*These authors contributed equally to this work

Correspondence: Haoling Zhang; Xuerui Ye, Email zhanghaolingedu@163.com; yexueruiyxr@163.com

Background: Cardiovascular disease is the leading cause of mortality in patients with chronic kidney disease (CKD), particularly among those undergoing maintenance hemodialysis (MHD). High-altitude exposure may further aggravate cardiovascular stress through chronic hypoxia. However, longitudinal data in multi-ethnic high-altitude dialysis populations remain limited.

Objective: To evaluate changes in cardiac function in CKD stage 5/end-stage renal disease patients receiving MHD at high altitude and to compare findings between Yi and non-Yi ethnic groups.

Methods: This retrospective study included 161 patients (103 Yi, 58 non-Yi) undergoing MHD in Ninglang Yi Autonomous County (mean altitude >2800 m). Clinical characteristics, laboratory parameters—including homocysteine (HCY)—and echocardiographic indices were assessed at baseline, 3 months, and 12 months. Longitudinal trends and ethnic differences were analyzed.

Results: In the overall cohort, pulmonary artery systolic pressure (PASP) increased significantly over time (P=0.049), while the E/A ratio declined, indicating progressive diastolic impairment. Left ventricular ejection fraction (LVEF) remained stable At 12 months, Yi patients had higher HCY levels (P=0.034), lower albumin (P=0.010) and apolipoprotein A levels (P=0.044), and a higher incidence of aortic regurgitation (AR) (P=0.012). Baseline E/A ratio was higher in Yi patients (P=0.032).

Conclusion: CKD patients undergoing MHD at high altitude exhibit dynamic changes in cardiac function, predominantly involving pulmonary pressure and diastolic parameters. Ethnic differences in selected biochemical and echocardiographic indices suggest the need for tailored cardiovascular monitoring in high-altitude multi-ethnic dialysis populations.

Keywords: chronic kidney disease, maintenance hemodialysis, high altitude, ethnic differences, cardiac function, pulmonary artery systolic pressure

Maintenance hemodialysis (MHD) remains a commonly used renal replacement therapy for patients with chronic renal failure (CRF) and end-stage renal disease (ESRD). Despite therapeutic advances, cardiovascular disease (CVD) remains the leading cause of mortality in this population.[1] CRF/ESRD can result in left ventricular hypertrophy, heart failure, and

https://doi.org/10.2147/JIR.S584599
Received: 4 December 2025
Accepted: 16 April 2026
Published: 4 May 2026

tachyarrhythmias. The accumulation of uremic toxins, chronic inflammation, oxidative stress, anemia, and volume overload further aggravates cardiac and renal injury, contributing to the development of cardiorenal syndrome.[2,3] Previous studies have demonstrated that patients with chronic kidney disease (CKD) have a markedly increased risk of cardiovascular events, and the incidence of CVD in MHD patients is approximately 10–20 times higher than that of the general population.[4,5] Heart failure and sudden cardiac death are particularly prevalent among dialysis patients.

Globally, CKD has become a major public health challenge. According to the Global Burden of Disease Study 2023, CKD affects nearly 800 million people worldwide and continues to rise in prevalence and mortality.[6] In China, a large nationwide survey reported that the prevalence of CKD among adults reached approximately 8.2–10.8%, corresponding to more than 80 million individuals, with relatively low awareness and treatment rates.[7] These epidemiological data underscore the urgent need to better understand cardiovascular complications in CKD populations, especially in geographically and socioeconomically vulnerable areas.

Cold regions at high altitudes (≥2400 m) predispose individuals to pulmonary arterial hypertension and myocardial remodeling due to chronic hypobaric hypoxia and increased sympathetic activity.[8,9] Cold exposure further increases systemic vascular resistance and cardiac workload, thereby exacerbating cardiovascular stress in CKD patients.[10] The Ninglang Yi Autonomous County, with a mean altitude above 2800 m, is a high-altitude multi-ethnic region predominantly inhabited by the Yi ethnic minority, with relatively limited medical resources. Delayed diagnosis, restricted healthcare accessibility, and differences in lifestyle and environmental adaptation may contribute to higher incidence and severity of cardiovascular complications compared with populations living in low-altitude regions.[11]

However, the longitudinal patterns of cardiac functional transition and related risk factors in MHD patients from this high-altitude minority region remain insufficiently characterized. Clarifying the interaction between dialysis-related factors, environmental exposure, and ethnic background is essential for improving cardiovascular prevention strategies.

Therefore, this study systematically investigates the transition of cardiac function in CKD patients undergoing MHD in Ninglang. Ethnicity (Yi versus non-Yi) was prespecified as a descriptive and comparative variable. By evaluating laboratory parameters and echocardiographic indices over time, this study aims to elucidate the determinants of cardiac functional changes in a high-altitude multi-ethnic population and to provide evidence for targeted cardiovascular monitoring and early intervention strategies.

Materials and Methods

Study Design and Participants

This retrospective study was conducted at Ninglang Yi Autonomous County People's Hospital, a high-altitude medical center located at a mean altitude of approximately 2800 meters.

A total of 161 patients with CKD stage 5 or ESRD who were receiving MHD between September 2017 and March 2024 were included. Among them, 103 patients were of Yi ethnicity and 58 belonged to other ethnic groups (non-Yi). There were 108 male and 53 female patients. Ethnicity was recorded in the hospital electronic medical records at the time of treatment.

Inclusion criteria were:

(1) age ≥18 years;
(2) diagnosis of CKD stage 5 or ESRD;
(3) regular MHD treatment for at least 3 months.

Exclusion criteria included:

(1) acute cardiovascular events within 3 months prior to enrollment;
(2) acute kidney injury;
(3) severe infection, malignancy, or systemic inflammatory disease;
(4) incomplete clinical or echocardiographic data.

The study protocol was approved by the institutional ethics committee (approval number: 2024-01) and was conducted in accordance with the Declaration of Helsinki. The requirement for written informed consent was waived due to the retrospective nature of the study.

Hemodialysis Procedure

All patients underwent bicarbonate-based hemodialysis using a Fresenius 4008S dialysis machine (Fresenius Medical Care, Germany). Dialysis was performed two to three times per week, with each session lasting 4–5 hours. Blood flow rate was maintained at 200–250 mL/min. Dialysis prescriptions were adjusted individually according to clinical status.

Laboratory Assessments

Venous blood samples were collected prior to the midweek dialysis session at baseline, 3 months, and 12 months.

Serum biochemical parameters, including serum creatinine (CREA), blood urea nitrogen (BUN), albumin (ALB), calcium (Ca), magnesium (Mg), lipid profile, homocysteine (HCY), and ferritin (FER), were measured using a Hitachi 7180 automatic biochemical analyzer (Hitachi High-Technologies Corporation, Tokyo, Japan).

HCY was determined using an enzymatic cycling method. ALB was measured by the bromocresol green method. Lipid parameters were analyzed using standard enzymatic colorimetric assays.

Hematological parameters, including hemoglobin (HGB) and hematocrit (HCT), were measured using a Sysmex XT-1800i five-part differential hematology analyzer (Sysmex Corporation, Kobe, Japan).

All assays were performed in accordance with the manufacturers' instructions. Routine internal quality control procedures were conducted to ensure analytical accuracy.

Echocardiographic Evaluation

Transthoracic echocardiography was performed using a MYLAB90 color Doppler ultrasound system (Esaote S.p.A., Genoa, Italy) equipped with a 2.5–3.5 MHz transducer. The following parameters were recorded: Left atrial diameter (LAd), Left ventricular end-diastolic diameter (LVd), Right ventricular diameter (RVd), Left ventricular ejection fraction (LVEF), Pulmonary artery systolic pressure (PASP), E/A ratio (early-to-late diastolic filling velocity ratio), Valvular regurgitation (mitral, tricuspid, and aortic). All examinations were performed by experienced cardiologists who were unaware of the patients' ethnic classification.

Follow-Up and Data Availability

Clinical, laboratory, and echocardiographic data were collected at baseline, 3 months, and 12 months after enrollment. Due to the retrospective design, some patients had incomplete follow-up data. Therefore, sample sizes varied across parameters and time points. Statistical analyses were performed using available-case data for each comparison.

Statistical Analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD) for normally distributed data or as median (interquartile range) for non-normally distributed data. Normality was assessed using the Shapiro–Wilk test. For comparisons between Yi and non-Yi groups, independent-samples t tests or Mann–Whitney *U*-tests were applied as appropriate. Categorical variables were analyzed using the chi-square test. Comparisons across baseline, 3 months, and 12 months were conducted using one-way analysis of variance (ANOVA) or non-parametric equivalents, based on data distribution and availability. A two-sided P value <0.05 was considered statistically significant.

Results

Baseline Characteristics

A total of 161 patients with CKD stage 5/ESRD undergoing MHD were included in the analysis. Among them, 103 were Yi (64.0%) and 58 were non-Yi (36.0%). There were 108 males (67.1%) and 53 females (32.9%), with a mean age of 44.56 ± 14.95 years.

The prevalence of hypertension and diabetes was 20.4% and 16.2%, respectively, indicating a relatively high cardiovascular risk profile in this cohort (Table 1).

Overall Changes in Laboratory Parameters

Comparisons of laboratory parameters at baseline, 3 months, and 12 months are presented in Table 2. CREA increased progressively over time (946.91 → 1041.83 → 1128.01 μmol/L, P<0.001). Mg also showed a stepwise increase (0.98 → 1.05 → 1.12 mmol/L, P<0.001). In contrast, ALB improved significantly during follow-up (39.44 → 42.65 → 43.54 g/L,

Table 1 Baseline Characteristics of Patients Undergoing Maintenance Hemodialysis (n=161)

Variable	Value
Sex	
Male, n	108
Female, n	53
Age (years), mean ± SD	44.56±14.95
BMI (kg/m^2), mean ± SD	22.25±3.61
Personal history	
Smoking, n	54
Alcohol consumption, n	52
Duration of diagnosed uremia (years), median (IQR)	4.00 (3.00, 7.00)
Comorbidities	
Hypertension, n	34
Diabetes mellitus, n	27
Coronary heart disease, n	4
Cerebrovascular disease, n	3
Malignancy, n	4
Other systemic diseases, n	23

Notes: Continuous variables are presented as mean ± standard deviation (SD) or median (interquartile range), as appropriate. Categorical variables are presented as number (percentage).

Abbreviations: BMI, body mass index; CKD, chronic kidney disease; ESRD, end-stage renal disease.

Table 2 Comparison of Laboratory Parameters at Baseline, 3 Months, and 12 Months

Laboratory Parameter	Baseline ($\bar{x} \pm S$)	3 Months Post-Dialysis ($\bar{x} \pm S$)	12 Months Post-Dialysis ($\bar{x} \pm S$)	F/H value	*P* value
HGB (g/L)	105.24±23.10	107.73±21.50	111.15±45.00	1.388	0.251
HCT (%)	31.82±6.83	32.70±7.05	32.91±6.39	1.165	0.313
CREA (μmol/L)	946.91±383.35	1041.83±364.37	1128.01±427.76	8.417	<0.001
BUN/CREA (mmol/L/μmol/L)	7.00±3.44	5.93±2.36	5.49±1.64	13.802	<0.001
K (mmol/L)	4.69±0.74	4.79±0.74	4.90±0.77	2.581	0.077
CA (mmol/L)	2.21±0.29	2.31±0.29	2.34±0.31	5.978	0.003
MG (mmol/L)	0.98±0.20	1.05±0.22	1.12±0.27	12.554	<0.001

(*Continued*)

Table 2 (Continued).

Laboratory Parameter	Baseline ($\bar{x} \pm S$)	3 Months Post-Dialysis ($\bar{x} \pm S$)	12 Months Post-Dialysis ($\bar{x} \pm S$)	F/H value	*P* value
ALT (U/L)	16.00 (10.00, 21.95)	13.00 (9.05, 22.78)	12.30 (9.00, 220.00)	4.542	0.103
AST (U/L)	16.60 (13.00, 24.00)	14.35 (10.00, 20.80)	13.00 (9.00, 19.00)	10.587	0.005
ALB (g/L)	39.44±5.85	42.65±6.44	43.54±5.30	16.062	<0.001
LDL (mmol/L)	2.48±0.86	2.41±0.92	2.49±0.82	0.136	0.873
APOA (mmol/L)	1.38±0.39	1.28±0.33	1.32±0.34	1.128	0.326
HCY (μmol/L)	26.40 (22.06, 33.45)	28.80 (20.14, 47.45)	32.14 (22.10, 38.77)	4.931	0.085
FER (ng/mL)	172.35 (57.75, 324.25)	92.40 (27.00, 250.70)	47.55 (19.85, 210.00)	12.307	0.002

Notes: Comparisons across time points were performed using one-way analysis of variance (ANOVA) or non-parametric equivalents, depending on data distribution. Due to incomplete follow-up, sample sizes varied across parameters and time points. Analyses were conducted using available-case data.
Abbreviations: HGB, hemoglobin; HCT, hematocrit; CREA, serum creatinine; BUN, blood urea nitrogen; K, potassium; Ca, calcium; Mg, magnesium; ALT, alanine aminotransferase; AST, aspartate aminotransferase; ALB, albumin; LDL, low-density lipoprotein; APOA, apolipoprotein A; HCY, homocysteine; FER, ferritin.

P<0.001). FER levels declined significantly over time (P=0.002), whereas HGB and HCT remained relatively stable No significant longitudinal changes were observed in low density lipoprotein (LDL), apolipoprotein A (APOA), or HCY in the overall population.

Overall Changes in Echocardiographic Parameters

Echocardiographic findings are summarized in Table 3. PASP increased significantly over time (26.49 → 31.84 → 33.17 mmHg, P=0.049). Meanwhile, the E/A ratio gradually declined (0.96 → 0.83 → 0.79), suggesting progressive impairment of left ventricular diastolic function. No significant changes were observed in LAd, LVd, RVd, or LVEF during follow-up.

Table 3 Comparison of Echocardiographic Parameters at Baseline, 3 Months, and 12 Months

Echocardiographic Parameter	Baseline ($\bar{x} \pm S$)	3 Months Post-Dialysis ($\bar{x} \pm S$)	12 Months Post-Dialysis ($\bar{x} \pm S$)	F/H value	*P* value
LAd (mm)	32.40±5.28	32.95±6.49	31.95±5.69	0.296	0.744
LVd (mm)	44.78±7.22	47.00±6.66	46.12±5.66	1.037	0.357
RVd (mm)	20.59±2.41	20.58±2.52	20.28±2.28	0.322	0.725
LVEF (%)	60.63±12.87	62.37±8.74	61.55±12.03	0.155	0.857
PASP (mmHg)	26.49±6.71	31.84±13.54	33.17±16.47	3.069	0.049
E/A	0.96 (0.66, 1.41)	0.83 (0.63, 1.26)	0.79 (0.65, 1.29)	0.952	0.621
MR				1.026	0.599
NO	19	10	48		
YES	21	8	63		
TR				5.358	0.069
NO	34	12	73		
YES	6	6	38		
AR				0.265	0.876
NO	31	13	82		
YES	9	5	29		

Notes: Longitudinal comparisons were conducted using one-way ANOVA or non-parametric equivalents based on data distribution. Echocardiographic data were available for a subset of patients at each time point due to missing follow-up examinations. Analyses were performed using available-case data.
Abbreviations: LAd, left atrial diameter; LVd, left ventricular end-diastolic diameter; RVd, right ventricular diameter; LVEF, left ventricular ejection fraction; PASP, pulmonary artery systolic pressure; E/A, ratio of early to late diastolic transmitral flow velocity; MR, mitral regurgitation; TR, tricuspid regurgitation; AR, aortic regurgitation.

https://doi.org/10.2147/JIR.S584599

Longitudinal Changes in Yi Patients

In Yi patients (n=103), significant changes were observed in CREA, BUN/CREA, Ca, Mg, ALB, ALT, AST, and FER (Table 4). Mg increased consistently across time points (P<0.001), and ALB improved significantly (P<0.001). Echocardiographic parameters did not show significant longitudinal differences within the Yi group (Table 5).

Table 4 Longitudinal Changes in Laboratory Parameters in Yi Patients (n=103)

Laboratory Parameter	Baseline ($\bar{x} \pm S$)	3 Months Post-Dialysis ($\bar{x} \pm S$)	12 Months Post-Dialysis ($\bar{x} \pm S$)	F/H value	*P* value
HGB (g/L)	106.41±20.35	110.06±21.95	107.60±19.82	0.809	0.446
HCT (%)	31.87±6.10	33.35±6.12	32.39±5.82	1.561	0.212
CREA (μmol/L)	987.75±408.15	1079.42±374.94	1167.45±471.90	4.594	0.011
BUN/CREA (mmol/L/μmol/L)	6.86±3.41	5.55±1.97	5.36±1.73	10.710	<0.001
K (mmol/L)	4.67±0.70	4.76±0.76	4.86±0.76	1.367	0.257
CA (mmol/L)	2.24±0.28	2.34±0.31	2.35±0.34	3.190	0.043
MG (mmol/L)	0.98±0.19	1.07±0.25	1.15±0.30	9.720	<0.001
ALT (U/L)	16.20 (10.80, 25.00)	13.00 (9.30, 22.90)	12.10 (8.20, 19.00)	6.368	0.041
AST (U/L)	16.70 (13.72, 26.00)	13.95 (10.00, 19.00)	12.45 (8.00, 17.00)	12.937	0.002
ALB (g/L)	38.79±6.09	42.60±5.49	42.55±5.82	11.133	<0.001
LDL (mmol/L)	2.52±0.89	2.39±0.96	2.46±0.91	0.182	0.833
APOA (mmol/L)	1.37±0.42	1.22±0.26	1.25±0.28	2.083	0.130
HCY (μmol/L)	25.95 (21.50, 33.55)	28.40 (20.14, 45.25)	35.60 (24.70, 44.77)	5.900	0.052
FER (ng/mL)	209.65 (58.75, 358.90)	80.50 (24.75, 256.10)	58.20 (20.70, 225.00)	10.566	0.005

Notes: Comparisons across baseline, 3 months, and 12 months were performed using one-way ANOVA or non-parametric equivalents. Sample sizes varied across parameters due to incomplete follow-up.

Abbreviations: HGB, hemoglobin; HCT, hematocrit; CREA, serum creatinine; BUN, blood urea nitrogen; K, potassium; Ca, calcium; Mg, magnesium; ALT, alanine aminotransferase; AST, aspartate aminotransferase; ALB, albumin; LDL, low-density lipoprotein; APOA, apolipoprotein A; HCY, homocysteine; FER, ferritin.

Table 5 Longitudinal Changes in Echocardiographic Parameters in Yi Patients

Echocardiographic Parameter	Baseline ($\bar{x} \pm S$)	3 Months Post-Dialysis ($\bar{x} \pm S$)	12 Months Post-Dialysis ($\bar{x} \pm S$)	F/H value	*P* value
LAd (mm)	32.81±5.85	32.60±7.49	31.94±5.96	0.209	0.811
LVd (mm)	45.46±8.40	46.40±7.82	46.34±5.93	0.163	0.849
RVd (mm)	20.71±2.71	19.70±2.06	20.09±2.19	0.880	0.418
LVEF (%)	59.80±15.37	62.50±9.06	60.56±12.41	0.155	0.857
PASP (mmHg)	26.04±7.16	29.00±10.86	30.68±13.86	1.248	0.292
E/A	1.25 (0.72, 1.52)	0.90 (0.62, 1.58)	1.01 (0.68, 1.32)	1.333	0.513
MR				1.114	0.573
NO	11	6	27		
YES	14	4	37		
TR				2.726	0.256
NO	21	6	45		
YES	4	4	19		
AR				3.831	0.147
NO	20	10	53		
YES	5	0	11		

Notes: Analyses were conducted using available-case data. Statistical comparisons were performed using ANOVA or non-parametric tests as appropriate.

Abbreviations: LAd, left atrial diameter; LVd, left ventricular end-diastolic diameter; RVd, right ventricular diameter; LVEF, left ventricular ejection fraction; PASP, pulmonary artery systolic pressure; E/A, ratio of early to late diastolic transmitral flow velocity; MR, mitral regurgitation; TR, tricuspid regurgitation; AR, aortic regurgitation.

Longitudinal Changes in Non-Yi Patients

Among non-Yi patients (n=58), significant changes were observed in CREA, BUN/CREA, Ca, and ALB (Table 6). ALB improved significantly during follow-up (P=0.002).

No significant longitudinal changes in echocardiographic indices were observed in this group (Table 7).

Table 6 Longitudinal Changes in Laboratory Parameters in Non-Yi Patients (n=58)

Laboratory Parameter	Baseline ($\bar{x} \pm S$)	3 Months Post-Dialysis ($\bar{x} \pm S$)	12 Months Post-Dialysis ($\bar{x} \pm S$)	F/H value	*P* value
HGB (g/L)	103.20±27.29	103.85±20.32	116.95±68.47	1.821	0.165
HCT (%)	31.72±8.00	31.64±8.33	33.76±7.19	1.347	0.263
CREA (μmol/L)	874.22±325.41	978.57±339.55	1061.11±33.45	4.559	0.012
BUN/CREA (mmol/L/μmol/L)	7.23±3.52	6.58±2.80	5.71±1.47	4.400	0.014
K (mmol/L)	4.73±0.82	4.83±0.71	4.97±0.78	1.164	0.315
CA (mmol/L)	2.17±0.30	2.25±0.25	2.32±0.26	3.656	0.028
MG (mmol/L)	0.98±0.22	1.03±0.18	1.08±0.20	2.948	0.056
ALT (U/L)	16.00 (8.70, 21.00)	15.00 (9.00, 23.65)	12.65 (9.00, 23.02)	0.121	0.941
AST (U/L)	16.60 (12.20, 22.90)	16.00 (9.25, 24.75)	16.10 (10.00, 21.00)	0.322	0.851
ALB (g/L)	40.58±5.27	42.76±8.23	45.29±3.69	6.644	0.002
LDL (mmol/L)	2.41±0.80	2.47±0.80	2.53±0.71	0.152	0.859
APOA (mmol/L)	1.42±0.33	1.45±0.47	1.43±0.39	0.022	0.978
HCY (μmol/L)	27.00 (23.10, 33.60)	30.60 (20.70, 52.92)	29.92 (20.25, 34.83)	1.270	0.530
FER (ng/mL)	117.50 (39.00, 184.75)	92.40 (27.00, 214.00)	47.00 (17.85, 127.00)	2.343	0.310

Notes: Statistical comparisons across time points were performed using ANOVA or non-parametric equivalents. Sample sizes varied due to missing follow-up data.

Abbreviations: HGB, hemoglobin; HCT, hematocrit; CREA, serum creatinine; BUN, blood urea nitrogen; K, potassium; Ca, calcium; Mg, magnesium; ALT, alanine aminotransferase; AST, aspartate aminotransferase; ALB, albumin; LDL, low-density lipoprotein; APOA, apolipoprotein A; HCY, homocysteine; FER, ferritin.

Table 7 Longitudinal Changes in Echocardiographic Parameters in Non-Yi Patients

Echocardiographic Parameter	Baseline ($\bar{x} \pm S$)	3 Months Post-Dialysis ($\bar{x} \pm S$)	12 Months Post-Dialysis ($\bar{x} \pm S$)	F/H value	*P* value
LAd (mm)	31.64±4.09	33.33±5.61	31.96±5.38	0.326	0.723
LVd (mm)	43.50±4.27	47.67±5.48	45.81±5.31	1.931	0.153
RVd (mm)	20.38±1.80	21.56±2.74	20.54±2.40	0.799	0.545
LVEF (%)	62.00±7.30	62.22±8.93	62.87±11.51	0.046	0.955
PASP (mmHg)	27.20±6.10	35.00±16.07	36.57±19.14	1.751	0.182
E/A	0.75 (0.58, 1.22)	0.76 (0.63, 1.07)	0.73 (0.61, 1.18)	0.023	0.989
MR				0.371	0.831
NO	8	4	21		
YES	7	4	26		
TR				4.443	0.108
NO	13	6	28		
YES	2	2	19		
AR				2.811	0.245
NO	11	3	29		
YES	4	5	18		

Notes: Echocardiographic data were analyzed using available-case methodology. Differences were assessed using appropriate parametric or non-parametric tests.

Abbreviations: LAd, left atrial diameter; LVd, left ventricular end-diastolic diameter; RVd, right ventricular diameter; LVEF, left ventricular ejection fraction; PASP, pulmonary artery systolic pressure; E/A, ratio of early to late diastolic transmitral flow velocity; MR, mitral regurgitation; TR, tricuspid regurgitation; AR, aortic regurgitation.

https://doi.org/10.2147/JIR.S584599

Ethnic Comparisons

Baseline

At baseline, the E/A ratio was significantly higher in Yi patients compared with non-Yi patients (1.25 vs 0.75, P=0.032), indicating possible compensatory diastolic adaptation (Tables 8 and 9). No other significant baseline differences were observed.

Table 8 Baseline Laboratory Parameters in Yi and Non-Yi Patients

Laboratory Parameter	Yi Group ($\bar{x} \pm S$)	Non-Yi Group ($\bar{x} \pm S$)	t/Z value	*P* value
HGB (g/L)	106.41±20.35	103.20±27.29	0.848	0.398
HCT (%)	31.87±6.10	31.72±8.00	0.129	0.897
CREA (μmol/L)	987.75±408.15	874.22±325.41	1.833	0.069
BUN/CREA (mmol/L/μmol/L)	6.86±3.41	7.23±3.52	−0.662	0.509
K (mmol/L)	4.67±0.70	4.73±0.82	−0.428	0.670
CA (mmol/L)	2.24±0.28	2.17±0.30	1.295	0.198
MG (mmol/L)	0.98±0.19	0.98±0.22	−0.181	0.857
ALT (U/L)	16.20 (10.80, 25.00)	16.00 (8.70, 21.00)	−1.018	0.309
AST (U/L)	16.70 (13.72, 26.00)	16.60 (12.20, 22.90)	−0.343	0.732
ALB (g/L)	38.79±6.09	40.58±5.27	−1.678	0.096
LDL (mmol/L)	2.52±0.89	2.41±0.80	0.445	0.658
APOA (mmol/L)	1.37±0.42	1.42±0.33	−0.464	0.644
HCY (μmol/L)	25.95 (21.50, 33.55)	27.00 (23.10, 33.60)	−0.304	0.761
FER (ng/mL)	209.65 (58.75, 358.90)	117.50 (39.00, 184.75)	−1.613	0.107

Notes: Between-group comparisons were performed using independent-samples t tests or Mann–Whitney *U*-tests, depending on data distribution.

Abbreviations: HGB, hemoglobin; HCT, hematocrit; CREA, serum creatinine; BUN, blood urea nitrogen; K, potassium; Ca, calcium; Mg, magnesium; ALT, alanine aminotransferase; AST, aspartate aminotransferase; ALB, albumin; LDL, low-density lipoprotein; APOA, apolipoprotein A; HCY, homocysteine; FER, ferritin.

Table 9 Baseline Echocardiographic Parameters in Yi and Non-Yi Patients

Echocardiographic Parameter	Yi Group ($\bar{x} \pm S$)	Non-Yi Group ($\bar{x} \pm S$)	t/Z value	*P* value
LAd (mm)	32.81±5.85	31.64±4.09	0.661	0.512
LVd (mm)	45.46±8.40	43.50±4.27	0.816	0.420
RVd (mm)	20.71±2.71	20.38±1.80	0.386	0.702
LVEF (%)	59.80±15.37	62.00±7.30	−0.518	0.607
PASP (mmHg)	26.04±7.16	27.20±6.10	−0.519	0.607
E/A	1.25 (0.72, 1.52)	0.75 (0.58, 1.22)	−2.149	0.032
MR			0.327	0.567
NO	11	8		
YES	14	7		
TR			0.001	0.999
NO	21	13		
YES	4	2		
AR			0.010	0.922
NO	20	11		
YES	5	4		

Notes: Continuous variables were compared using t tests or non-parametric equivalents. Categorical variables were analyzed using the chi-square test.

Abbreviations: LAd, left atrial diameter; LVd, left ventricular end-diastolic diameter; RVd, right ventricular diameter; LVEF, left ventricular ejection fraction; PASP, pulmonary artery systolic pressure; E/A, ratio of early to late diastolic transmitral flow velocity; MR, mitral regurgitation; TR, tricuspid regurgitation; AR, aortic regurgitation.

https://doi.org/10.2147/JIR.S584599

Three-Month Follow-Up

At 3 months, BUN/CREA and APOA differed significantly between groups (P=0.014 and P=0.041, respectively). The incidence of aortic regurgitation (AR) was higher in the Yi group (P=0.016) (Tables 10 and 11).

Twelve-Month Follow-Up

At 12 months, Yi patients had significantly higher HCY levels than non-Yi patients (35.60 vs 29.92 μmol/L, P=0.034). ALB and APOA levels were lower in the Yi group (P=0.010 and P=0.044, respectively).

Table 10 Laboratory Parameters at 3 Months in Yi and Non-Yi Patients

Laboratory Parameter	Yi Group ($\bar{x} \pm S$)	Non-Yi Group ($\bar{x} \pm S$)	t/Z value	*P* value
HGB (g/L)	110.06±21.95	103.85±20.32	1.780	0.077
HCT (%)	33.35±6.12	31.64±8.33	1.491	0.138
CREA (μmol/L)	1079.42±374.94	978.57±339.55	1.708	0.090
BUN/CREA (mmol/L/μmol/L)	5.55±1.97	6.58±2.80	−2.503	0.014
K (mmol/L)	4.76±0.76	4.83±0.71	−0.606	0.546
CA (mmol/L)	2.34±0.31	2.25±0.25	1.934	0.055
MG (mmol/L)	1.07±0.25	1.03±0.18	1.190	0.236
ALT (U/L)	13.00 (9.30, 22.90)	15.00 (9.00, 23.65)	−0.027	0.979
AST (U/L)	13.95 (10.00, 19.00)	16.00 (9.25, 24.75)	−1.045	0.296
ALB (g/L)	42.60±5.49	42.76±8.23	−0.121	0.904
LDL (mmol/L)	2.39±0.96	2.47±0.80	−0.258	0.798
APOA (mmol/L)	1.22±0.26	1.45±0.47	−2.105	0.041
HCY (μmol/L)	28.40 (20.14, 45.25)	30.60 (20.70, 52.92)	−0.337	0.736
FER (ng/mL)	80.50 (24.75, 256.10)	92.40 (27.00, 214.00)	−0.092	0.927

Notes: Between-group comparisons were conducted using independent-samples t tests or Mann–Whitney *U*-tests. Sample sizes differ across parameters due to incomplete follow-up.

Abbreviations: HGB, hemoglobin; HCT, hematocrit; CREA, serum creatinine; BUN, blood urea nitrogen; K, potassium; Ca, calcium; Mg, magnesium; ALT, alanine aminotransferase; AST, aspartate aminotransferase; ALB, albumin; LDL, low-density lipoprotein; APOA, apolipoprotein A; HCY, homocysteine; FER, ferritin.

Table 11 Echocardiographic Parameters at 3 Months in Yi and Non-Yi Patients

Echocardiographic Parameter	Yi Group ($\bar{x} \pm S$)	Non-Yi Group ($\bar{x} \pm S$)	t/Z value	*P* value
LAd (mm)	32.60±7.49	33.33±5.61	−0.239	0.814
LVd (mm)	46.40±7.82	47.67±5.48	−0.404	0.691
RVd (mm)	19.70±2.06	21.56±2.74	−1.679	0.111
LVEF (%)	62.50±9.06	62.22±8.93	0.067	0.947
PASP (mmHg)	29.00±10.86	35.00±16.07	−0.963	0.349
E/A	0.90 (0.62, 1.58)	0.76 (0.63, 1.07)	−0.722	0.470
MR			0.001	0.999
NO	6	4		
YES	4	4		
TR			0.028	0.867
NO	6	6		
YES	4	2		
AR			5.819	0.016
NO	10	3		
YES	0	5		

Notes: Continuous variables were compared using t tests or non-parametric equivalents; categorical variables were analyzed using the chi-square test.

Abbreviations: LAd, left atrial diameter; LVd, left ventricular end-diastolic diameter; RVd, right ventricular diameter; LVEF, left ventricular ejection fraction; PASP, pulmonary artery systolic pressure; E/A, ratio of early to late diastolic transmitral flow velocity; MR, mitral regurgitation; TR, tricuspid regurgitation; AR, aortic regurgitation.

https://doi.org/10.2147/JIR.S584599

Table 12 Laboratory Parameters at 12 Months in Yi and Non-Yi Patients

Laboratory Parameter	Yi Group ($\bar{x} \pm S$)	Non-Yi Group ($\bar{x} \pm S$)	t/Z value	*P* value
HGB (g/L)	107.60±19.82	116.95±68.47	−1.237	0.218
HCT (%)	32.39±5.82	33.76±7.19	−1.274	0.205
CREA (μmol/L)	1167.45±471.90	1061.11±33.45	1.481	0.141
BUN/CREA (mmol/L/μmol/L)	5.36±1.73	5.71±1.47	−1.282	0.202
K (mmol/L)	4.86±0.76	4.97±0.78	−0.814	0.417
CA (mmol/L)	2.35±0.34	2.32±0.26	0.632	0.528
MG (mmol/L)	1.15±0.30	1.08±0.20	1.504	0.135
ALT (U/L)	12.10 (8.20, 19.00)	12.65 (9.00, 23.02)	−0.887	0.375
AST (U/L)	12.45 (8.00, 17.00)	16.10 (10.00, 21.00)	−1.958	0.050
ALB (g/L)	42.55±5.82	45.29±3.69	−2.621	0.010
LDL (mmol/L)	2.46±0.91	2.53±0.71	−0.373	0.711
APOA (mmol/L)	1.25±0.28	1.43±0.39	−2.066	0.044
HCY (μmol/L)	35.60 (24.70, 44.77)	29.92 (20.25, 34.83)	−2.123	0.034
FER (ng/mL)	58.20 (20.70, 225.00)	47.00 (17.85, 127.00)	−0.640	0.522

Notes: Between-group comparisons were performed using independent-samples t tests or Mann–Whitney *U*-tests. Analyses were based on available-case data.

Abbreviations: HGB, hemoglobin; HCT, hematocrit; CREA, serum creatinine; BUN, blood urea nitrogen; K, potassium; Ca, calcium; Mg, magnesium; ALT, alanine aminotransferase; AST, aspartate aminotransferase; ALB, albumin; LDL, low-density lipoprotein; APOA, apolipoprotein A; HCY, homocysteine; FER, ferritin.

Table 13 Echocardiographic Parameters at 12 Months in Yi and Non-Yi Patients

Echocardiographic Parameter	Yi Group ($\bar{x} \pm S$)	Non-Yi Group ($\bar{x} \pm S$)	t/Z value	*P* value
LAd (mm)	31.94±5.96	31.96±5.38	−0.018	0.986
LVd (mm)	46.34±5.93	45.81±5.31	0.491	0.624
RVd (mm)	20.09±2.19	20.54±2.40	−1.021	0.310
LVEF (%)	60.56±12.41	62.87±11.51	−0.999	0.320
PASP (mmHg)	30.68±13.86	36.57±19.14	−1.773	0.080
E/A	1.01 (0.68, 1.32)	0.73 (0.61, 1.18)	−2.308	0.021
MR			0.069	0.793
NO	27	21		
YES	37	26		
TR			1.388	0.239
NO	45	28		
YES	19	19		
AR			6.257	0.012
NO	53	29		
YES	11	18		

Notes: Continuous variables were compared using independent-samples t tests or non-parametric equivalents. Categorical variables were analyzed using the chi-square test.

Abbreviations: LAd, left atrial diameter; LVd, left ventricular end-diastolic diameter; RVd, right ventricular diameter; LVEF, left ventricular ejection fraction; PASP, pulmonary artery systolic pressure; E/A, ratio of early to late diastolic transmitral flow velocity; MR, mitral regurgitation; TR, tricuspid regurgitation; AR, aortic regurgitation.

The incidence of AR remained significantly higher in Yi patients (P=0.012). In addition, the E/A ratio was lower in non-Yi patients (P=0.021) (Tables 12 and 13).

Discussion

This study evaluated longitudinal changes in cardiac function in 161 patients with CKD stage 5/ESRD undergoing MHD in a high-altitude, multi-ethnic region. Over 12 months of follow-up, PASP increased progressively, while the E/A ratio declined, indicating worsening diastolic function. In contrast, LVEF remained relatively stable In addition, ethnic differences were observed in HCY levels, apolipoprotein A, and the incidence of AR.

Cardiovascular involvement in CKD is well established and represents a major determinant of morbidity and mortality.[1,12] Contemporary evidence supports the concept of uremic cardiomyopathy, characterized by myocardial remodeling, fibrosis, and impaired relaxation, often presenting as diastolic dysfunction with preserved systolic function.[13] The pattern observed in our cohort—declining E/A ratio without significant reduction in ejection fraction—is consistent with this phenotype.

Dialysis-related factors may further contribute to cardiac stress. Repeated intradialytic volume shifts and hemodynamic fluctuations have been associated with cumulative myocardial injury and structural remodeling.[12,14] Although direct markers of myocardial injury were not assessed in this study, the gradual rise in PASP may reflect the combined influence of renal dysfunction and dialysis-related hemodynamic burden.

The high-altitude setting of this cohort adds another relevant dimension. Chronic hypobaric hypoxia is known to promote pulmonary vasoconstriction and vascular remodeling, potentially leading to sustained elevation of pulmonary artery pressure.[15] The progressive increase in PASP observed here is compatible with such adaptive or maladaptive responses. In patients already exposed to CKD-related cardiovascular stress, chronic hypoxic exposure may further modify cardiopulmonary dynamics.

Ethnic differences warrant cautious interpretation. Yi patients exhibited higher HCY levels and a greater incidence of AR during follow-up. Recent studies continue to associate dysregulated HCY metabolism with endothelial dysfunction and vascular remodeling.[16] However, this study does not establish causality. Differences in dietary patterns, micronutrient intake, genetic background, and healthcare access may contribute to these findings. Rather than suggesting inherent susceptibility, the results highlight the importance of context-specific cardiovascular evaluation in ethnically and geographically distinct populations.

Although clinical observation extended beyond 12 months in some patients, follow-up completeness declined after 12 months. To maintain consistency and minimize bias related to missing data, analyses were restricted to baseline, 3-month, and 12-month time points. This approach provides a more reliable assessment of temporal trends within the available dataset.

Globally, the cardiovascular burden associated with CKD continues to increase.[6] However, data from minority populations residing in high-altitude regions remain limited. By focusing on a geographically and ethnically distinct dialysis cohort, this study provides region-specific evidence that may inform cardiovascular monitoring strategies in similar environmental contexts.

Several limitations should be considered. The retrospective design led to variable sample sizes across parameters due to incomplete follow-up. Echocardiographic data were available only for a subset of patients. Inflammatory and molecular biomarkers were not systematically assessed, limiting mechanistic interpretation. Prospective studies with standardized follow-up and comprehensive biomarker evaluation are needed to further clarify the interplay between altitude, dialysis, and cardiac function.

Conclusion

In this cohort of 161 MHD patients residing in a high-altitude region, progressive changes in cardiac function were observed over 12 months, characterized primarily by increasing PASP and declining diastolic function parameters, while systolic function remained relatively preserved.

Ethnic differences were identified in HCY levels, apolipoprotein A, and the incidence of AR, suggesting variation in cardiovascular risk profiles between Yi and non-Yi patients.

These findings contribute to the understanding of cardiac functional changes in dialysis populations exposed to chronic hypoxic environments and underscore the importance of individualized cardiovascular monitoring in geographically and ethnically distinct settings.

Data Sharing Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. Due to ethical and privacy restrictions (including patient confidentiality and the retrospective nature of the study conducted in a high-altitude multi-ethnic region), the data are not publicly available.

Author Contributions

Jingjing Zhang and Zhaoyu Li contributed equally to this work and share first authorship. Jingjing Zhang and Zhaoyu Li; conceptualization, methodology, investigation, formal analysis, and writing – original draft. Xueliang Xiao and Jun Sha; investigation resources, project administration, and writing – review & editing. Qian Qiao and Lu Cheng; investigation, data curation, visualization, and writing – review & editing. Wangzheqi Zhang contributed to validationsupervision, and writing – review & editing. Haoling Zhang and Xuerui Ye contributed to conceptualization, supervision, project administration, funding acquisition, and writing – review & editing, and share corresponding authorship. All authors made substantial contributions to the work reported; participated in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

Yunnan Fundamental Research Kunming Medical University Projects, China, No.202401AY070001-164; and Yunnan Provincial Department of Science and Technology Science and Technology Plan Project—Major Science and Technology Special Projects, China, No. 202405AJ310003.

Disclosure

The authors declare no competing interests in the publication of this work.

References

1. Swarnalatha G, Ram R, Prasad N, Dakshinamurty KV. End-stage renal disease patients on hemodialysis: a study from a tertiary care center in a developing country. *Hemodialysis Int*. 2011;15:312–319. doi:10.1111/j.1542-4758.2011.00546.x
2. Taguchi K, Elias BC, Brooks CR, Ueda S, Fukami K. Uremic toxin-targeting as a therapeutic strategy for preventing cardiorenal syndrome. *Circ J*. 2019;84:2–8. doi:10.1253/circj.CJ-19-0872
3. Zhang L-H, Cen Z-F, Qiao Q, et al. Risk factors and predictive model for mortality in acute myocardial infarction with ventricular septal rupture at high altitudes. *World J Cardiol*. 2025;17:109044. doi:10.4330/wjc.v17.i7.109044
4. Dilsizian V, Gewirtz H, Marwick TH, et al. Cardiac imaging for coronary heart disease risk stratification in chronic kidney disease. *Cardiovasc Imaging*. 2021;14:669–682. doi:10.1016/j.jcmg.2020.05.035
5. Johansen KL, Gilbertson DT, Li S, et al. US Renal Data System 2023 Annual Data Report: epidemiology of kidney disease in the United States. *Am J Kidney Dis*. 2024;83:A8–a13. doi:10.1053/j.ajkd.2024.01.001
6. Mark PB, Stafford LK, Grams ME. Global, regional, and national burden of chronic kidney disease in adults, 1990-2023, and its attributable risk factors: a systematic analysis for the Global Burden of Disease Study 2023. *Lancet*. 2025;406:2461–2482. doi:10.1016/s0140-6736(25)01853-7
7. Wang L, Xu X, Zhang M, et al. Prevalence of Chronic Kidney Disease in China: results from the sixth China chronic disease and risk factor surveillance. *JAMA Intern Med*. 2023;183:298–310. PMC9941971. doi:10.1001/jamainternmed.2022.6817
8. Aggarwal K, Pathan MS, Dhalani M, et al. Elevated perspectives: unraveling cardiovascular dynamics in high-altitude realms. *Curr Cardiol Rev*. 2024.
9. Bärtsch P, Gibbs JS. Effect of altitude on the heart and the lungs. *Circulation*. 2007;116:2191–2202. doi:10.1161/circulationaha.106.650796
10. Ikäheimo TM. Cardiovascular diseases, cold exposure and exercise. *Temperature*. 2018;5:123–146. doi:10.1080/23328940.2017.1414014
11. Hou J, Wen X, Long P, et al. The role of post-translational modifications in driving abnormal cardiovascular complications at high altitude. *Front Cardiovasc Med*. 2022;9:886300. doi:10.3389/fcvm.2022.886300
12. Marx-Schütt K, Cherney DZI, Jankowski J, Matsushita K, Nardone M, Marx N. Cardiovascular disease in chronic kidney disease. *Eur Heart J*. 2025;46:2148–2160. PMC12167664. doi:10.1093/eurheartj/ehaf167
13. Wang X, Shapiro JI. Evolving concepts in the pathogenesis of uraemic cardiomyopathy. *Nat Rev Nephrol*. 2019;15:159–175. doi:10.1038/s41581-018-0101-8
14. Hamrahian SM, Vilayet S, Herberth J, Fülöp T. Prevention of intradialytic hypotension in hemodialysis patients: current challenges and future prospects. *Int J Nephrol Renovasc Dis*. 2023;16:173–181. PMC10404053. doi:10.2147/ijnrd.S245621
15. Yang X, Liu H, Wu X. High-altitude pulmonary hypertension: a comprehensive review of mechanisms and management. *Clin Exp Med*. 2025;25:79. doi:10.1007/s10238-025-01577-3
16. Cao X, Wang T, Mu G, et al. Dysregulated homocysteine metabolism and cardiovascular disease and clinical treatments. *Mol Cell Biochem*. 2025;480:4907–4920. doi:10.1007/s11010-025-05284-1