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Article

Impact of Personalized Anemia Management on Quality of Life and Serum Albumin Levels in Maintenance Hemodialysis Patients

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Abstract

Aims/Background: Anemia is a highly prevalent and clinically significant complication in maintenance hemodialysis (MHD) patients, markedly impairing quality of life and being associated with adverse prognosis. Conventional management strategies often lack sufficient individualization, potentially leading to suboptimal therapeutic outcomes. This study aimed to investigate the impact of personalized anemia management on quality of life and albumin levels in maintenance hemodialysis patients through a retrospective analysis. **Methods:** A retrospective analysis was conducted involving 353 patients who received maintenance hemodialysis at the Affiliated Hospital of North Sichuan Medical College between March 2022 and March 2025. Based on the management approaches documented in their medical records, patients were divided into two groups: Those receiving routine medical care were assigned to the control group (n = 181), while those receiving personalized anemia management strategies were assigned to the observation group (n = 172). The observation group received personalized anemia management in addition to routine dialysis. Specifically, this approach included individualized adjustment of erythropoietin and iron dosages based on a comprehensive evaluation of dynamic hemoglobin and albumin levels, as well as nutritional status. Meanwhile, a multidisciplinary team led by physicians collaboratively formulated nutritional and pharmacological management plans and provided adherence guidance. The study compared changes in hemoglobin levels, hemoglobin target achievement rate, albumin levels, body composition parameters, Self-Rating Anxiety Scale (SAS), Self-Rating Depression Scale (SDS), quality of life scores (assessed using the Kidney Disease Quality of Life 36-Item Short Form Survey, KDQOL-36), and Pittsburgh Sleep Quality Index (PSQI) between the two groups before and after treatment. **Results:** Following the intervention, depression and anxiety scores in the observation group were significantly lower than those in the control group ($p < 0.05$). Regarding physiological indicators, albumin levels, body composition parameters, hemoglobin levels, and the hemoglobin target achievement rate, the observation group showed significant improvements compared with the control group ($p < 0.05$). Additionally, the PSQI score was significantly lower in the observation group, whereas the quality of life scores were significantly higher compared with the control group; all differences were statistically significant ($p < 0.05$). **Conclusion:** Personalized anemia management significantly improves quality of life and albumin levels in maintenance hemodialysis patients and demonstrates potential for clinical application.

Keywords: anemia; personalized management; maintenance hemodialysis; quality of life; albumin

1. Introduction

Chronic kidney disease (CKD) is a progressive kidney dysfunction caused by various etiologies, characterized by a sustained decline in glomerular filtration rate or by structural abnormalities of the kidneys that persist for more than three months [1]. With population aging and the increasing prevalence of metabolic disorders such as diabetes and hypertension, the incidence of CKD continues to rise, posing a major global public health burden [2]. Epidemiological surveys indicate that the prevalence of CKD among adults in China is approximately 8.2%, while globally, millions of patients progress to end-stage renal disease (ESRD) each year [3]. When renal function becomes insufficient to maintain homeostasis, patients require renal replacement therapy (RRT), including hemodialysis (HD), peritoneal dialysis, or kidney transplantation, to sustain survival [4]. Currently, hemodialysis remains the primary treatment modality for ESRD patients. However, although it prolongs survival, it is also associated with multiple complications, among which anemia is the most common and clinically impactful.

Renal anemia is one of the most common complications of CKD. Its pathogenesis is closely associated with insufficient erythropoietin (EPO) secretion, disordered iron metabolism, suppressed erythropoiesis, and chronic inflammatory responses [5,6]. The World Health Organization (WHO) defines anemia as a hemoglobin concentration below 130 g/L in men and below 120 g/L in women. However, some studies suggest that a hemoglobin level below 100 g/L is sufficient to diagnose anemia in hemodialysis patients [7,8]. Evidence indicates that the prevalence of

anemia in stage 3 CKD patients is approximately 20%, increasing to 50%–90% in ESRD [9]. As renal function further declines, anemia progressively worsens, leading not only to symptoms such as fatigue, dizziness, and impaired concentration, but also potentially triggering serious cardiovascular complications, including left ventricular hypertrophy and heart failure [10,11]. Several studies have demonstrated that patients initiating dialysis with hemoglobin levels below 8 g/dL have approximately twice the mortality risk compared with those with hemoglobin levels ≥8 g/dL [12,13]. Moreover, anemia is closely associated with reduced quality of life, increased hospitalization rates, and elevated overall mortality, making it a key factor affecting the long-term prognosis in dialysis patients [14].

In maintenance hemodialysis patients, the pathophysiological mechanisms of anemia are more complex [5]. Renal failure leads to significantly reduced EPO secretion, while iron loss during dialysis, intestinal malabsorption, and chronic inflammation may result in absolute or functional iron deficiency [15]. Additionally, malnutrition, parathyroid dysfunction, and the accumulation of uremic toxins can inhibit bone marrow hematopoiesis or accelerate erythrocyte destruction [16]. Although the application of erythropoiesis-stimulating agents (ESAs) and iron supplementation has significantly improved anemia management, a considerable proportion of patients still exhibit ESA hyporesponsiveness or poor therapeutic response. According to the China Dialysis Outcomes and Practice Patterns Study (DOPPS), approximately 18.8% of hemodialysis patients in China have hemoglobin levels below 9 g/dL, with significant regional variations (Guangzhou 18.5%, Beijing 9.1%, and Shanghai 13.8%) [17]. These findings suggest that anemia control among dialysis patients in China remains suboptimal, and conventional management approaches are insufficient to meet the demands of individualized treatment.

Effective anemia management strategies can not only correct hemoglobin levels but also improve tissue oxygen delivery, reduce cardiovascular risk, and significantly enhance patients' health-related quality of life (HRQOL). However, the occurrence and progression of anemia are closely associated with multiple factors, including sleep quality, inflammatory status, nutritional level, and treatment adherence; therefore, a single therapeutic approach often fails to achieve optimal outcomes [5]. In recent years, the concept of "personalized anemia management" has been gradually introduced and applied in clinical practice [18]. This model is based on individual patient characteristics and comprehensively integrates multi-dimensional information, including hemoglobin dynamics, psychological status, iron reserves, and inflammatory markers, allowing precise anemia control through continuous assessment and treatment adjustment [18].

Furthermore, albumin, as an important biochemical indicator reflecting nutritional and inflammatory status, plays a significant role in the management of hemodialysis patients [19]. Hypoalbuminemia not only reflects insufficient nutritional intake but is also closely associated with chronic inflammation, poor anemia control, and an unfavorable prognosis. Therefore, incorporating albumin into anemia management may provide a more comprehensive evaluation of patients' overall health status and provide a basis for targeted interventions [20].

In summary, anemia is one of the most prevalent and clinically significant complications in maintenance hemodialysis patients. Although conventional treatment strategies can improve hemoglobin levels to a certain extent, they remain limited in addressing interindividual variability and long-term outcomes. Personalized anemia management, through comprehensive multifactorial assessment and precise intervention, may more effectively improve hemoglobin levels, nutritional status, and quality of life. This study aimed to investigate the impact of personalized anemia management on quality of life and albumin levels in maintenance hemodialysis patients, thereby providing a scientific foundation and novel insights for clinical management.

2. Methods

2.1 Research Subjects

This study included 353 patients who received maintenance hemodialysis at the Affiliated Hospital of North Sichuan Medical College between March 2022 and March 2025. This study aimed to evaluate the effect of a personalized anemia management protocol applied to the general maintenance hemodialysis population at our center. Consequently, enrollment was not restricted to patients with anemia at baseline. The protocol was designed for both the treatment of existing anemia and the prevention of anemia in non-anemic patients, through continuous monitoring and individualized interventions.

The inclusion criteria were as follows: (1) Age ≥18 years; (2) Confirmed diagnosis of end-stage renal disease requiring long-term hemodialysis; (3) Intact cognitive, reading, and communication abilities; and (4) Continuous dialysis treatment at this hospital for at least 6 months. The exclusion criteria included: (1) Missing or incomplete clinical data; (2) Cognitive impairment or severe psychiatric disorders; (3) Concomitant malignant tumors; (4) A recent history of major surgery, bleeding, or blood transfusion; and (5) Transfer to another hospital or discontinuation of treatment for any reason (Fig. 1). Based on the different anemia management strategies received during hemodialysis care, eligible patients were divided into a control group and an observation group.

2.2 Management Plan

2.2.1 Control Group (Routine Anemia Management)

Patients in the control group received standard medical care in accordance with the hospital's established hemodialysis clinic protocol. This included three

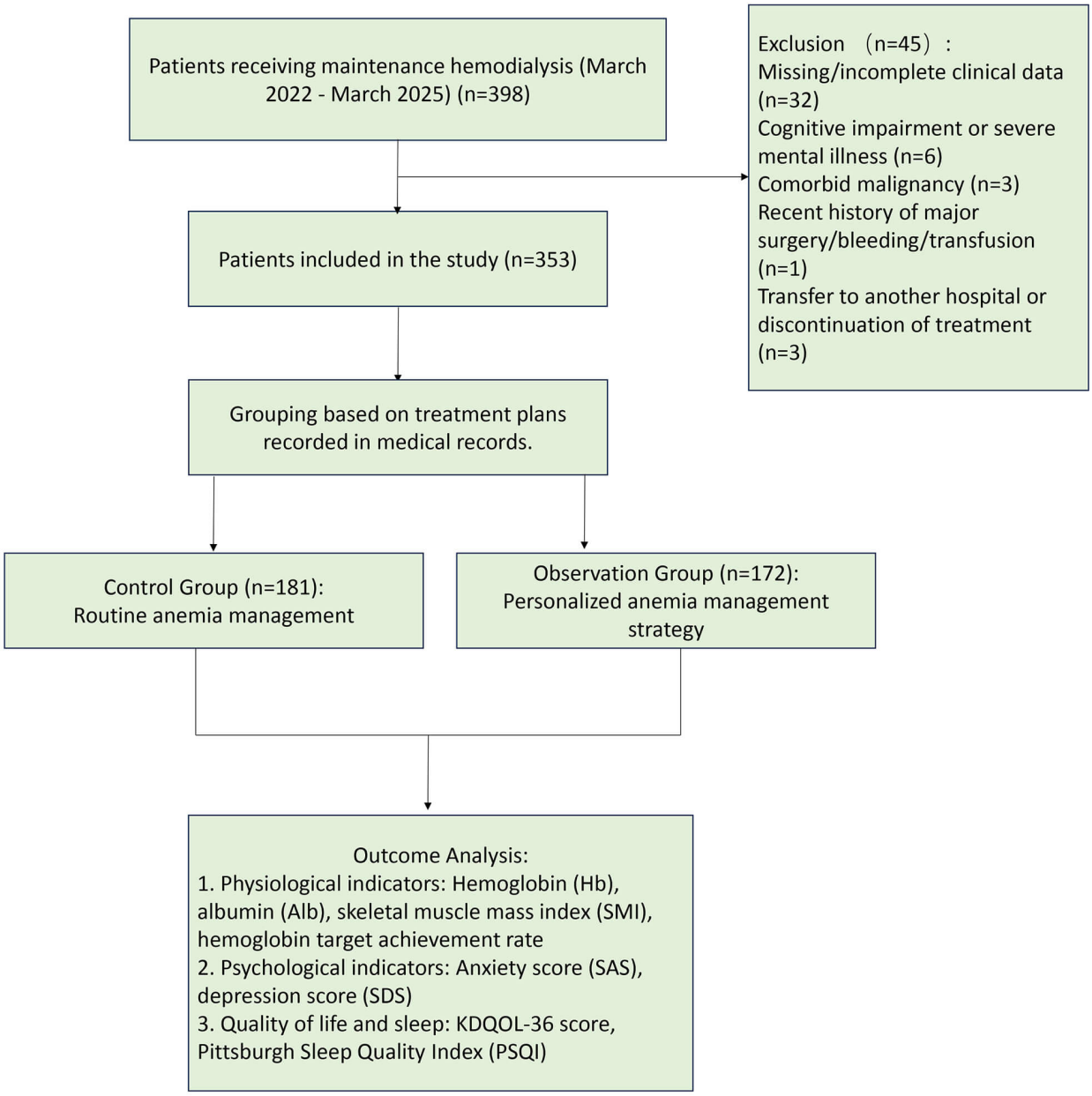

Fig. 1. Study design and implementation framework. SAS, Self-Rating Anxiety Scale; SDS, Self-Rating Depression Scale; KDQOL-36, Kidney Disease Quality of Life 36-Item Short Form Survey.

core components: Standardized lifestyle and dietary education focusing on renal-specific restrictions; pharmacological management with erythropoiesis-stimulating agents (Chengdu Di'ao Jiuhong Pharmaceutical Factory, Chengdu, China, S19991005) and iron supplementation (Chengdu Tiantaishan Pharmaceutical Co., Ltd., Chengdu, China, 21250602B), with dosages adjusted based on monthly laboratory assessments of hemoglobin levels and iron indices in accordance with the hospital's standard protocol, which was developed based on the Kidney Disease: Improving Global Outcomes (KDIGO) clinical practice guidelines; and provision of routine hemodialysis treatment [21].

2.2.2 Observation Group (Personalized Anemia Management Protocol)

Personalized anemia management was implemented by a multidisciplinary team comprising attending physicians, nutritionists, pharmacists, and dialysis technicians. Regular case review meetings were conducted to ensure standardized implementation and quality assurance. The attending physician coordinated the anemia management protocol and supervised data collection, clinical evaluation, and treatment adjustments. Treatment efficacy, adverse events, and resource utilization were systematically reviewed monthly, and individualized management strategies were modified as required. Structured psychological

support was integrated into the management framework. During monthly reviews, the attending physician or a designated nurse evaluated patients' psychological status using validated screening tools or structured clinical interviews. Based on these assessments, targeted interventions were provided, including individualized counseling focused on coping strategies, referrals to mental health specialists, and participation in patient education programs to enhance peer support and self-management capacity.

Early management phase: At initiation, a standardized baseline evaluation was performed, including demographic characteristics, medical history, comorbid conditions, and laboratory parameters related to anemia and iron metabolism. An individualized anemia assessment record was established for each patient based on baseline clinical and laboratory findings.

Intervention and monitoring phase: Patients undergoing maintenance hemodialysis received routine blood testing prior to dialysis sessions to monitor hemoglobin (Hb) levels and iron metabolism indices. In accordance with KDIGO clinical practice guidelines for anemia in chronic kidney disease, personalized anemia management was initiated when two consecutive Hb measurements were <100 g/L, when abnormalities in iron metabolism were identified, or when anemia-related clinical symptoms were observed [22]. The therapeutic target was defined as maintaining Hb levels within the range of 100–110 g/L, which is recommended for most hemodialysis patients to optimize clinical outcomes while minimizing cardiovascular risks associated with higher Hb levels [21]. During this phase, recent hematological indices, nutritional status, and medication use were comprehensively evaluated to guide treatment optimization. Hemoglobin levels were monitored weekly before dialysis during the active intervention period. Comprehensive laboratory assessments, including serum ferritin and transferrin saturation (TSAT), were performed at 2–4-week intervals and served as the primary basis for adjusting ESA and iron therapy. Once Hb levels stabilized within the target range (100–110 g/L), the monitoring frequency was extended to once every 1–2 months during the subsequent maintenance phase.

Maintenance phase: Upon entering the maintenance phase, laboratory monitoring was conducted every 2–4 weeks and subsequently extended to once every two months, depending on clinical stability. All laboratory results were reviewed by the attending physician and documented in an individualized anemia management record to facilitate longitudinal tracking. ESA dose adjustments followed predefined criteria: The dose was reduced by 25%–50% if Hb increased rapidly (e.g., >10 g/L within two weeks) or exceeded 110 g/L. Conversely, the dose was increased by 25%–50% if Hb remained below 100 g/L after four weeks despite adequate iron availability.

Intravenous iron supplementation was initiated when serum ferritin was <200 µg/L and/or TSAT <20%, in the absence of active infection, and was reduced or withheld when serum ferritin exceeded 500 µg/L. All adjustment thresholds were based on KDIGO clinical practice guidelines for anemia in chronic kidney disease [21]. For patients with specific clinical conditions, such as heart failure, diabetes mellitus, or advanced age, therapeutic targets and adjustment strategies were further individualized to minimize the risk of overtreatment and associated cardiovascular complications. Throughout the observation period, treatment adherence and clinical responses were continuously evaluated as part of routine clinical management.

To standardize outcome assessment, a 6-month observation period was defined for both groups. Baseline data, including all physiological and psychological parameters, were collected at the beginning of the observation period (or retrospectively extracted from corresponding medical records). Post-intervention data were collected at the end of the 6-month observation period. This timeframe was considered sufficient to evaluate the clinical effects of the personalized anemia management strategy while maintaining feasibility within the retrospective study design.

2.3 Statistical Analysis of Baseline Data

Baseline demographic and clinical characteristics were compared between the two groups, including age, gender, body mass index (BMI), comorbidities (such as hypertension, diabetes mellitus, and coronary artery disease), education level, marital status, employment status, smoking history, family history of kidney disease, and dialysis duration. Baseline comparability between the two groups was assessed prior to outcome analysis. In the absence of statistically significant differences in baseline variables, subsequent intergroup comparisons were considered appropriate.

2.4 Assessment of Emotional State

To comprehensively evaluate the participants' health-related status, validated instruments were used to assess anxiety and depression. The Self-Rating Anxiety Scale (SAS), developed by Zung in 1971 [23], was employed. This instrument consists of 20 items, including 15 positively worded and 5 negatively worded items. Participants rated each item based on symptom frequency using a 4-point Likert scale. The raw total score was multiplied by 1.25 to obtain a standardized score (range: 25–100), with higher scores indicating greater anxiety levels. According to established thresholds, scores <50 indicate no anxiety, 50–59 mild anxiety, 60–69 moderate anxiety, and ≥70 severe anxiety [23].

Depressive symptoms were assessed using the Self-Rating Depression Scale (SDS) [24], which includes 20 items with an equal number of positively and negatively worded statements. Participants completed the scale based on the frequency of pre-treatment mood or symptoms using a 4-point Likert scale. The total score was multiplied by 1.25 and rounded to the nearest integer to obtain the

standardized score (range: 25–100). Higher scores indicate more severe depressive symptoms. According to commonly applied criteria, scores <50 indicate no depression, 50–59 mild depression, 60–69 moderate depression, and ≥70 severe depression [24].

2.5 Measurement of Patient Physiological Indicators

To comprehensively and objectively evaluate the effectiveness of personalized anemia management, key physiological and nutritional indicators were monitored, including hemoglobin (Hb), C-reactive protein (CRP), and serum albumin (Alb). Based on KDIGO clinical practice guidelines [21], the recommended Hb target for anemia management is 100–110 g/L. However, considering physiological fluctuations in clinical practice and that Hb levels slightly above this range (up to 120 g/L) are considered acceptable based on the Canadian commentary on KDIGO [25], the hemoglobin target achievement rate was defined as the proportion of patients with Hb ≥100 g/L at the end of the 6-month observation period. This threshold aligns with international guideline recommendations and reflects effective anemia correction while avoiding cardiovascular risks associated with persistently elevated Hb levels (>130 g/L).

Skeletal muscle mass index (SMI) was measured using bioelectrical impedance analysis (BIA) with a body composition analyzer (BC care 830, Jinan Huiyi Ronggong Technology Co., Ltd., Jinan, China). This parameter was used to assess muscle reserves and nutritional status in dialysis patients, thereby facilitating a comprehensive evaluation of the effects of the anemia management strategy on hemoglobin levels, target achievement, and nutritional optimization.

2.6 Assessment of Quality of Life

To systematically evaluate patients' quality of life and sleep status, the Kidney Disease Quality of Life 36-Item Short Form Survey (KDQOL-36) was used to assess health-related quality of life in patients with kidney disease. Given that anemia and kidney disease may adversely affect sleep, and that sleep quality can influence overall recovery, cognitive function, and daily activities, the Pittsburgh Sleep Quality Index (PSQI) was also used to assess sleep quality.

The KDQOL-36 is a self-administered instrument designed for patients with kidney disease to assess health-related quality of life [26]. It integrates the general 12-Item Short Form Health Survey (SF-12) with kidney disease-specific domains and includes five subscales: Physical component summary (PCS), mental component summary (MCS), burden of kidney disease (BKD), symptoms and problems of kidney disease (SPKD), and effects of kidney disease (EKD). The PCS and MCS scores are reported as T-scores (norm-based scoring), with a mean of 50 and a standard deviation of 10 in the general population. The kidney disease-specific subscales (BKD, SPKD, and EKD) are transformed to a 0–100 scale. For all domains, higher scores indicate better perceived quality of life and lower disease burden, symptoms, and impact from kidney disease [26].

The PSQI is a self-reported instrument used to evaluate the overall sleep quality of adults over the previous month. Developed by Buysse et al. in 1989 [27], it includes 19 self-reported items (and additional items completed by a partner, if applicable) and evaluates seven dimensions: Subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep aids, and daytime dysfunction. Each dimension is scored from 0 to 3 (0 indicates no difficulty or never occurs, 3 indicates severe difficulty or frequent occurrence). The component scores for each dimension are summed to yield a total score ranging from 0 to 21. Higher total scores indicate poorer sleep quality [27]. A total score <5 indicates good sleep quality, while a score ≥5 indicates poor sleep quality.

2.7 Assessment Procedures and Personnel

To ensure the quality and consistency of data collection, all assessments were performed by qualified personnel. Physiological measurements, including blood sample collection for hemoglobin and albumin analysis, were performed by clinical laboratory technicians following standard hospital protocols. Body composition analysis was performed by dialysis unit nurses trained in the operation of the bioelectrical impedance analyzer.

The SAS, SDS, KDQOL-36, and PSQI were administered as patient-reported outcome measures. A dedicated research nurse, trained in the administration and scoring rules of these instruments, was responsible for distributing the questionnaires, providing standardized verbal instructions to patients, ensuring independent completion in a quiet environment, and collecting completed forms. Clarification of item content was provided upon request without influencing patient responses. These standardized procedures were implemented to minimize measurement bias and enhance the reliability and validity of self-reported data.

2.8 Statistical Analysis Methods

Statistical analysis was performed using SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was initially tested using the Kolmogorov–Smirnov test to determine normality and evaluate whether the assumptions for parametric analysis, including normal distribution and homogeneity of variance, were satisfied. For variables with a normal distribution, homogeneity of variance was further assessed using Levene's test. When data conformed to a normal distribution with equal variances, intergroup comparisons were conducted using the independent-samples *t*-test. If the assumption of homogeneity of variance was violated, the Welch *t*-test was applied. Normally distributed continuous variables were expressed as mean ± standard deviation (mean ± SD),

whereas non-normally distributed variables were presented as median and interquartile range [M (Q_1, Q_3)] and analyzed using the Mann–Whitney *U* test.

Categorical variables were expressed as frequencies (n) and percentages (%). Intergroup differences were analyzed using the chi-square (χ^2) test or Fisher's exact test, as appropriate, and corresponding χ^2 values and *p*-values were reported. All statistical tests were two-tailed, and a *p*-value < 0.05 was considered statistically significant.

For within-group comparisons (i.e., changes from baseline to post-intervention within the same group), a paired-samples *t*-test was used for normally distributed continuous variables, while the Wilcoxon signed-rank test was applied for non-normally distributed data.

3. Results

3.1 Comparison of Patient Baseline Characteristics

A total of 353 patients were included in this study and were divided into two groups according to the treatment strategies received during maintenance hemodialysis: The control group (n = 181), which received routine anemia management, and the observation group (n = 172), which received personalized anemia management. Analysis of baseline characteristics demonstrated no statistically significant differences between the two groups ($p > 0.05$), indicating that the two groups were comparable at baseline (Table 1).

3.2 Emotional State of Patients

At baseline, no statistically significant differences were observed in depression and anxiety levels between the two groups ($p > 0.05$). Following the intervention, both groups demonstrated significant reductions in SAS and SDS scores compared with their respective baselines (all $p < 0.05$, within-group comparisons), indicating an overall improvement in emotional status. Furthermore, post-intervention SAS and SDS scores in the observation group were significantly lower than those in the control group (between-group comparison) ($p < 0.05$). Correspondingly, the proportion of patients without anxiety or depression increased, while the proportion with moderate to severe symptoms decreased in the observation group, with statistically significant differences ($p < 0.05$) (Table 2).

3.3 Improvement in Anemia Among Patients

Before the intervention, no statistically significant differences were observed between the two groups in albumin levels, hemoglobin levels, hemoglobin target achievement rate, or skeletal muscle mass index (SMI) ($p > 0.05$). After the intervention, both groups exhibited significant improvements in hemoglobin, albumin, and SMI compared with baseline (all $p < 0.05$, within-group comparisons). However, compared with the control group, the observation group showed significantly greater improvements in these core indicators (between-group comparisons) ($p < 0.05$). Furthermore, a significantly higher proportion of patients in the observation group achieved hemoglobin levels within the predefined target range compared with the control group, with a statistically significant difference between groups ($p < 0.05$) (Table 3).

3.4 Quality of Life of Patients

At baseline, no statistically significant differences were observed between the two groups across any KDQOL-36 subscales ($p > 0.05$). After the intervention, significant within-group improvements were observed in most KDQOL-36 domains (PCS, SPKD, EKD, and BKD) in both groups (all $p < 0.05$), reflecting enhanced health-related quality of life. For the MCS, a statistically significant improvement was noted only in the observation group ($p < 0.05$), whereas the control group did not demonstrate a significant change. At the post-intervention assessment, the observation group achieved significantly higher scores than the control group across all five KDQOL-36 domains (between-group comparisons), indicating a superior improvement in overall quality of life ($p < 0.05$) (Table 4).

3.5 Sleep Status of Patients

At baseline, total PSQI scores and the distribution of sleep quality (good vs. poor) were comparable between the observation and control groups, with no statistically significant differences ($p > 0.05$). After treatment, both groups showed significant reductions in total PSQI scores relative to baseline (both $p < 0.05$, within-group comparisons), indicating an overall improvement in sleep quality. However, the reduction in PSQI score was more pronounced in the observation group, which also demonstrated a higher proportion of patients with good sleep quality compared with the control group at the end of the observation period (between-group comparison) ($p < 0.05$) (Table 5).

4. Discussion

Patients undergoing maintenance hemodialysis are typically in the ESRD stage. Progressive renal failure ultimately leads to a persistently reduced glomerular filtration rate, accompanied by metabolic disorders, toxin accumulation, and fluid retention, thereby adversely affecting quality of life and increasing the risk of multiple complications [28]. Because these patients require long-term or lifelong dialysis, the extended treatment course not only imposes substantial daily burdens but also exposes them to a range of clinical challenges, including anemia, malnutrition, chronic inflammation, and cardiovascular complications [29]. A previous study has shown that the incidence of anemia is markedly high among patients with ESRD [30]. In this population, anemia not only reduces the oxygen-carrying capacity of erythrocytes but is also significantly associated with left ventricular hypertrophy, progression of heart failure, increased hospitalization, and mortality [31].

Table 1. Baseline characteristics of patients in the two groups.

Variables	Control group (n = 181)	Observation group (n = 172)	Statistic	*p*-value
Age (years)	56.19 ± 3.69	56.35 ± 3.69	$t = -0.410$	0.682
BMI (kg/m^2)	24.28 ± 1.93	24.41 ± 1.69	$t = -0.660$	0.510
Dialysis duration (months)	24.24 ± 4.67	23.73 ± 5.04	$t = 0.999$	0.319
CRP (mg/L)	3.40 (2.04, 4.49)	3.19 (2.41, 4.01)	$Z = -0.867$	0.386
Hemoglobin (g/L)	80.80 (70.80, 100.80)	87.20 (75.90, 100.93)	$Z = -1.885$	0.059
Gender, n (%)			$\chi^2 = 1.863$	0.172
Female	64 (35.36)	73 (42.44)		
Male	117 (64.64)	99 (57.56)		
Marital status, n (%)			$\chi^2 = 0.581$	0.901
Married	118 (65.19)	118 (68.60)		
Unmarried	23 (12.71)	21 (12.21)		
Divorced	30 (16.57)	24 (13.95)		
Widowed	10 (5.52)	9 (5.23)		
Educational level, n (%)			$\chi^2 = 0.857$	0.836
≤6 years	15 (8.29)	17 (9.88)		
7–9 years	20 (11.05)	17 (9.88)		
10–12 years	127 (70.17)	116 (67.44)		
≥13 years	19 (10.50)	22 (12.79)		
Employment status, n (%)			$\chi^2 = 3.022$	0.221
Employed	102 (56.35)	111 (64.53)		
Vacation/Retired	30 (16.57)	27 (15.70)		
Unemployed/Job-seeking	49 (27.07)	34 (19.77)		
Diabetes mellitus, n (%)			$\chi^2 = 0.525$	0.469
No	110 (60.77)	98 (56.98)		
Yes	71 (39.23)	74 (43.02)		
Hypertension, n (%)			$\chi^2 = 0.419$	0.517
Yes	137 (75.69)	125 (72.67)		
No	44 (24.31)	47 (27.33)		
Coronary artery disease, n (%)			$\chi^2 = 0.114$	0.736
No	167 (92.27)	157 (91.28)		
Yes	14 (7.73)	15 (8.72)		
Smoking history, n (%)			$\chi^2 = 0.000$	0.998
No	81 (44.75)	77 (44.77)		
Yes	100 (55.25)	95 (55.23)		
Family history of kidney disease, n (%)			$\chi^2 = 0.452$	0.501
No	162 (89.50)	150 (87.21)		
Yes	19 (10.50)	22 (12.79)		

BMI, body mass index; CRP, C-reactive protein.

Conventional management approaches often lack sufficiently targeted and comprehensive strategies; therefore, the implementation of proactive and precise anemia management in maintenance hemodialysis (MHD) patients is of considerable importance to improve their quality of life and albumin levels. In the present retrospective study, the clinical effects of personalized anemia management were compared with those of conventional management in MHD patients. The findings showed that the observation group receiving personalized anemia management achieved superior physiological outcomes compared with the control group, including improvements in hemoglobin, albumin, skeletal muscle mass index, and hemoglobin target achievement rate. Additionally, the observation group exhibited significant improvements in quality of life, sleep quality, and depression/anxiety status. These findings suggest that a physician-led, dynamically adjusted anemia management strategy based on individual patient characteristics is associated with improvements in both anemia-related parameters and psychological well-being.

The personalized anemia management program in this study emphasized close multidisciplinary monitoring of iron levels and dynamic changes in hemoglobin (Hb) levels. The attending physician adjusted ESA dosage and intravenous iron supplementation strategies in a timely manner based on laboratory findings. Simultaneously, nutritionists

Table 2. Comparison of depression and anxiety status between the two groups.

Variables	Control group (n = 181)	Observation group (n = 172)	Statistic	*p*-value
SAS score				
Before intervention	48.50 ± 13.46	49.23 ± 16.28	$t = -0.458$	0.647
After intervention	45.19 ± 12.82*	42.34 ± 11.01*	$t = 2.245$	0.025
SDS score				
Before intervention	52.90 ± 9.60	52.12 ± 10.09	$t = 0.743$	0.458
After intervention	48.12 ± 13.54*	44.30 ± 13.36*	$t = 2.666$	0.008
Anxiety classification				
Before intervention, n (%)			$\chi^2 = 5.032$	0.169
No	100 (55.25)	82 (47.67)		
Mild	44 (24.31)	37 (21.51)		
Moderate	23 (12.71)	32 (18.60)		
Severe	14 (7.73)	21 (12.21)		
After intervention, n (%)			Fisher	0.018
No	111 (61.33)	125 (72.67)		
Mild	45 (24.86)	37 (21.51)		
Moderate	20 (11.05)	10 (5.81)		
Severe	5 (2.76)	0 (0.00)		
Depression classification				
Before intervention, n (%)			$\chi^2 = 2.484$	0.478
No	64 (35.36)	71 (41.28)		
Mild	74 (40.88)	59 (34.30)		
Moderate	34 (18.78)	36 (20.93)		
Severe	9 (4.97)	6 (3.49)		
After intervention, n (%)			Fisher	0.007
No	92 (50.83)	108 (62.79)		
Mild	45 (24.86)	37 (21.51)		
Moderate	36 (19.89)	27 (15.70)		
Severe	8 (4.42)	0 (0.00)		

*$p < 0.05$ vs. before intervention within the same group. SAS, Self-Rating Anxiety Scale; SDS, Self-Rating Depression Scale.

Table 3. Comparison of anemia-related indicators between the two groups.

Variables	Control group (n = 181)	Observation group (n = 172)	Statistic	*p*-value
Hemoglobin (g/L), median (Q_1, Q_3)				
Before intervention	80.80 (70.80, 100.80)	87.20 (75.90, 100.93)	$Z = -1.885$	0.059
After intervention	89.90 (76.20, 101.90)*	97.05 (85.08, 111.97)*	$Z = -4.339$	<0.001
Albumin (g/L), median (Q_1, Q_3)				
Before intervention	33.90 (28.70, 40.40)	34.55 (30.78, 38.65)	$Z = -0.551$	0.582
After intervention	35.50 (30.40, 39.80)*	38.55 (32.33, 45.68)*	$Z = -4.346$	<0.001
SMI (kg/m^2), median (Q_1, Q_3)				
Before intervention	6.40 (6.00, 6.80)	6.30 (5.90, 6.80)	$Z = -0.837$	0.402
After intervention	6.80 (5.60, 8.10)*	7.50 (5.68, 8.90)*	$Z = -2.553$	0.011
Hemoglobin target achievement rate, n (%)				
Before intervention			$\chi^2 = 0.033$	0.857
Unqualified	131 (72.38)	123 (71.51)		
Qualified	50 (27.62)	49 (28.49)		
After intervention			$\chi^2 = 8.367$	0.004
Unqualified	123 (67.96)	91 (52.91)		
Qualified	58 (32.04)	81 (47.09)		

*$p < 0.05$ vs. before intervention within the same group. SMI, skeletal muscle mass index.

Table 4. Comparison of the quality of life between the two groups.

Variables	Control group (n = 181)	Observation group (n = 172)	Statistic	*p*-value
PCS				
Before intervention	31.11 ± 10.04	32.18 ± 7.20	$t = -1.151$	0.251
After intervention	35.67 ± 10.10*	38.35 ± 9.68*	$t = -2.550$	0.011
MCS				
Before intervention	39.48 ± 11.59	38.93 ± 12.99	$t = 0.418$	0.676
After intervention	41.68 ± 11.39	44.03 ± 9.43*	$t = -2.111$	0.036
SPKD				
Before intervention	67.75 ± 9.68	68.74 ± 8.25	$t = -1.034$	0.302
After intervention	72.35 ± 11.97*	78.29 ± 7.72*	$t = -5.572$	<0.001
EKD				
Before intervention	53.73 ± 7.07	53.44 ± 7.93	$t = 0.365$	0.715
After intervention	56.15 ± 8.88*	58.09 ± 8.67*	$t = -2.081$	0.038
BKD				
Before intervention	25.52 ± 7.39	26.45 ± 8.10	$t = -1.125$	0.261
After intervention	30.80 ± 5.78*	33.95 ± 7.34*	$t = -4.456$	<0.001

Note: *$p < 0.05$ vs. before intervention within the same group. PCS, physical component summary; MCS, mental component summary; SPKD, symptoms and problems of kidney disease; EKD, effects of kidney disease; BKD, burden of kidney disease.

Table 5. Comparison of sleep quality between the two groups.

Variables	Control group (n = 181)	Observation group (n = 172)	Statistic	*p*-value
PSQI score, median (Q_1, Q_3)				
Before intervention	5.00 (3.00, 9.00)	4.00 (3.00, 10.00)	$Z = -0.775$	0.439
After intervention	4.00 (3.00, 6.00)*	3.00 (2.00, 5.00)*	$Z = -5.096$	<0.001
Sleep quality, n (%)				
Before intervention			$\chi^2 = 1.757$	0.185
Good	112 (61.88)	118 (68.60)		
Poor	69 (38.12)	54 (31.40)		
After intervention			$\chi^2 = 5.170$	0.023
Good	125 (69.06)	137 (79.65)		
Poor	56 (30.94)	35 (20.35)		

Note: *$p < 0.05$ vs. before intervention within the same group. PSQI, Pittsburgh Sleep Quality Index.

formulated individualized dietary plans that included adequate protein intake, controlled phosphorus levels, and enrichment with hematopoiesis-related micronutrients. Nutritional support, including oral or intravenous supplementation, was provided when necessary.

Following the intervention, the observation group showed significantly higher hemoglobin levels, albumin levels, and hemoglobin target achievement rates compared with the control group, with statistically significant differences. These findings suggest that the personalized management protocol effectively improved anemia-related outcomes. This outcome is consistent with a previous study. For example, Pramod and Goldfarb [32] reported that iron supplementation strategies tailored to individual iron load and metabolic status can enhance Hb response and reduce fluctuations in ESA dosage; the findings of the present study are consistent with these observations.

Compared with the control group, the observation group also showed significantly greater increases in SMI and Alb. However, SMI measured by BIA may be influenced by hydration status, and the retrospective design did not allow for strict standardization of measurement timing relative to dialysis sessions. Similarly, Alb is a negative acute-phase reactant; thus, its increase may reflect not only improved nutritional intake but also a concomitant reduction in systemic inflammation, which was not directly assessed in this study. Nevertheless, the observed improvements in these clinically relevant prognostic markers suggest potential benefits of the personalized management approach, which warrant further validation in prospective studies.

The superior outcomes associated with personalized management may be attributed to its comprehensive approach, which addresses several key determinants of anemia control beyond pharmacological adjustment. This approach can be conceptualized as a systematic and proactive care model. Although pharmacologic targets (e.g., Hb and iron indices) were aligned with KDIGO guidelines for

both groups, the personalized management protocol differed fundamentally in its implementation. Specifically, it integrated frequent monitoring with a structured multidisciplinary team (physician, nutritionist, pharmacist, and nurse) and incorporated psychological support, thereby establishing a dynamic, responsive system to prevent deviations and address barriers to anemia control in a timely manner. By design, this strategy likely enhanced medication adherence through closer monitoring and increased patient engagement, optimized the management of intercurrent infections or inflammatory states that may contribute to ESA hyporesponsiveness, and allowed timely nutritional intervention. Improvements in these intermediary factors, including adherence, control of infection/inflammation, and nutritional status, may have synergistically contributed to the more effective correction of anemia and hypoalbuminemia observed in the observation group.

The relatively low baseline scores observed in the kidney disease-specific domains of the KDQOL-36, particularly the EKD and BKD, reflect the substantial disease-related burden inherent to the maintenance hemodialysis population in this study. These findings indicate that, at baseline, patients experienced considerable limitations in daily activities and perceived a significant burden from both the disease and its treatment. This context underscores the challenging clinical starting point for therapeutic interventions and highlights the clinical relevance of the improvements observed following treatment.

Kidney failure and anemia can lead to fatigue, impaired sleep quality, and reduced exercise tolerance, which, in turn, negatively affect activity levels and nutritional intake, thereby forming a vicious cycle [33,34,35]. In the present study, patients' quality of life, sleep quality, and emotional status were assessed using the KDQOL-36, PSQI, SAS, and SDS scales. The observation group demonstrated significantly better outcomes in quality of life, sleep quality, and psychological status compared with the control group. These associations may be explained by several interrelated factors. The comprehensive nature of the personalized management strategy, which addresses anemia, nutritional status, and psychological support, may have contributed to alleviating physical symptoms and enhancing patients' perceived control over their condition. However, given the retrospective and observational design, these potential mechanisms remain hypothetical and warrant further investigation.

Additionally, increased attention by clinicians to patients' psychological status, along with proactive monitoring and communication, may enhance patients' willingness to engage with treatment, improve health literacy, and strengthen understanding of disease management. This, in turn, may promote a greater sense of control and improve adherence to therapeutic regimens. Such effects may reduce anxiety and depression associated with chronic illness, thus generating a positive feedback loop that further supports psychological well-being and sleep quality. Improved emotional status and sleep quality may also have beneficial effects on nutritional indicators such as Hb, Alb, and SMI. Consistent with this, the findings of Zhang et al. [36] suggest that improvements in emotional status contribute to enhanced health-related quality of life in patients. Taken together, these findings indicate that personalized anemia management strategies not only improve anemia-related parameters but also contribute to broader improvements in physical function, psychological well-being, and overall quality of life in maintenance hemodialysis patients.

This study has several limitations inherent to its retrospective, single-center design. First, the non-randomized allocation introduces a potential risk of selection bias and unmeasured confounding; patients in the observation group may have differed in unmeasured characteristics, such as motivation or health literacy, which could have independently influenced the outcomes. Second, the intervention was multifaceted, combining personalized anemia management with multidisciplinary supportive care. Consequently, although the comprehensive approach was associated with improved outcomes, it remains challenging to attribute the observed benefits, particularly in quality of life and psychological status, exclusively to the anemia management component. Third, the relatively modest sample size and single-center setting may limit the generalizability of the findings, and the relatively short follow-up period precludes assessment of long-term outcomes, such as cardiovascular events or overall survival. Fourth, certain measurement limitations should be acknowledged: The absence of comprehensive inflammatory biomarkers restricts mechanistic interpretation, and variability in BIA measurements due to fluctuations in fluid status warrants cautious interpretation of changes in body composition. Finally, the lower prevalence of coronary artery disease in our cohort, compared with large registry studies, suggests that the findings may not be fully generalizable to older populations with a heavier cardiovascular burden. Future multicenter, randomized controlled trials with extended follow-up periods and more comprehensive biomarker assessments are warranted to validate these findings and establish causal relationships.

5. Conclusion

In conclusion, this study demonstrates that a physician-led, personalized anemia management approach, integrating nutrition support, dynamic monitoring, psychological intervention, and individualized medication adjustments, can significantly improve hemoglobin and albumin levels, skeletal muscle mass, and quality of life in maintenance hemodialysis patients over the short- to medium-term. These findings support the clinical application of personalized anemia management in dialysis clinical practice. Future management strategies for maintenance hemodialysis patients should emphasize a

holistic, patient-centered approach that integrates therapeutic targets with functional status, nutritional status, and psychological well-being.

Key Points

• This study shows that a structured personalized anemia management protocol is associated with improvements in both physiological and psychosocial outcomes in maintenance hemodialysis patients.

• The findings provide preliminary evidence supporting the clinical value of comprehensive personalized anemia management in this population.

• The findings highlight the clinical value of an integrated, patient-centered approach that addresses the multifaceted burden of anemia in end-stage renal disease, extending beyond conventional standardized treatment.

• The findings of the present study offer supportive evidence for the implementation of comprehensive personalized anemia management strategies in hemodialysis practice to optimize overall patient outcomes.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

Author Contributions

KY and HPZ designed the research study. WXP and IIAAS performed the research. KY analyzed the data. HPZ and IIAAS drafted this article. All authors contributed to the important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study protocol was reviewed and approved by the Ethics Committee of the Affiliated Hospital of North Sichuan Medical College (approval number: 2025ER606-1), and all procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki for biomedical research involving human subjects. This study is a retrospective design, collecting and analyzing only patients' previous routine medical data. No prospective interventions were involved, and all data were de-identified to avoid increasing patient risk or infringing on patient privacy. Given the difficulty of obtaining informed consent from discharged or lost-to-follow-up patients in retrospective studies, the Ethics Committee of the Affiliated Hospital of North Sichuan Medical College approved an exemption from the informed consent requirement for this study.

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Conflicts of Interest

The authors declare no conflicts of interest.

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