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The Effects of Cycling Exercise Combined with Low-Temperature Adjustable Sodium Mode on Quality of Life and Negative Emotions in Patients Undergoing Maintenance Hemodialysis

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Abstract

Objective: To investigate the effects of bicycle exercise combined with low-temperature adjustable sodium mode on the quality of life and negative emotions of patients undergoing maintenance hemodialysis.

Methods: Forty patients undergoing maintenance hemodialysis at our hospital were randomly assigned to two groups (n = 20 each) using a random number table. The control group received routine care, while the intervention group underwent supine bicycle exercise combined with a low-temperature adjustable sodium regimen. Depression, anxiety, quality of life, and patient satisfaction were assessed using the Depression Scale, Anxiety Scale, Quality of Life Questionnaire, and Patient Satisfaction Survey, respectively.

Results: Pre-intervention depression and anxiety scores showed no statistically significant differences between groups (t= 0.712 and 0.885; P = 0.747 and 0.722). After 12 weeks of intervention, the observation group exhibited significantly lower depression and anxiety scores than the control group (t = -5.963 and -5.332; P = 0.000 and 0.000). Pre-intervention quality of life scores across all dimensions and total scores showed no statistically significant differences between groups (P > 0.05). After 12 weeks of intervention, the observation group exhibited significantly higher total quality of life scores and scores across all dimensions compared to the control group (P < 0.05). The observation group also demonstrated a statistically significantly higher overall satisfaction score compared to the control group (P < 0.05).

Conclusion: Combining bicycle exercise with a low-temperature adjustable sodium mode improves quality of life and alleviates negative emotions in patients undergoing maintenance hemodialysis, thereby enhancing their well-being.

Keywords: hemodialysis, cycling exercise, low-temperature adjustable sodium, quality of life

1. Introduction

Chronic kidney disease (CKD) is a progressive syndrome of renal impairment resulting from various etiologies, including glomerulonephritis, gouty nephropathy, polycystic kidney disease, and systemic lupus erythematosus nephritis(GBD Chronic Kidney Disease Collaboration,2022). The KDIGO guidelines indicate that when a patient's glomerular filtration rate (GFR) remains persistently below 60 mL/min/1.73m^2 for over three months, it signifies progression to CKD stages G3a-G5(Inker LA et al.,2021). At this stage, significant renal decline leads to metabolic waste accumulation, electrolyte imbalances, and metabolic acidosis. Without timely and effective intervention, the condition inevitably progresses to end-stage renal disease (ESRD), posing a severe threat to patient health and life(Levin A et al., 2017).

Maintenance hemodialysis (MHD) remains the primary treatment for ESRD, utilizing diffusion and convection principles to remove uremic toxins and maintain internal environment stability(Pecoits-Filho R et al., 2020). Long-term, regular dialysis imposes multiple burdens on patients: recurrent dialysis-related hypotension, muscle cramps, cardiovascular events, and protein-energy wasting syndrome significantly reduce treatment tolerance(Kooman JP et al., 2018). The substantial long-term medical costs generate “financial burden,” impairing treatment adherence(Vanholder R et al., 2021). Uncertainty about the disease, restricted social activities, and survival pressures lead to a high prevalence of anxiety and depression. Studies indicate that 40-55% of MHD patients exhibit depressive symptoms, with 30-45% also experiencing anxiety disorders(Dziubek W et al., 2016). Collectively, these factors cause a significant decline in patients' quality of life.

Cycling during dialysis shows promising potential as a non-pharmacological intervention. Supine cycling during treatment enhances skeletal muscle blood flow and muscle pump action, facilitating the transfer of solutes like urea and creatinine into the vascular space, thereby improving dialysis adequacy (Kt/V)(Greenwood SA et al., 2015). Studies indicate that regular aerobic exercise improves cardiopulmonary endurance, reduces inflammatory markers like C-reactive protein, and alleviates fatigue while enhancing mood through endorphin release(Chung SH et al., 2020; Howden EJ et al., 2022). Hemodynamic instability under conventional dialysis often limits exercise implementation.

The low-temperature adjustable sodium dialysis mode offers a solution. Maintaining dialysate temperature at 35.5°C reduces vasodilation associated with heat accumulation, lowering hypotension risk. The sodium concentration curve mode (starting at 145 mmol/L, decreasing to 140 mmol/L 30 minutes before the end) stabilizes plasma osmolarity, reduces thirst and inter-dialysis weight gain, and improves cardiovascular stability(Wong MMY et al., 2022; Zhou YL et al., 2016). While both techniques demonstrate individual benefits, their combined synergistic effects on quality of life and psychological status remain understudied. This study investigates the impact of integrating bicycle exercise with low-temperature sodium-adjustable therapy on quality of life and negative emotions in maintenance hemodialysis patients, aiming to provide a safe, economical, and sustainable hemodialysis strategy. Findings are reported below.

2. Materials and Methods

2.1 General Data

Forty eligible patients were consecutively enrolled and randomly assigned (1:1) to the observation or control group (n = 20 each) using a random number table. No screening exclusions occurred prior to enrollment. The participant flow is presented in Figure 1.The observation group comprised 11 males and 9 females, with an average age of (48.60 ± 5.14) years and a dialysis duration of (35.90 ± 5.96) months. The control group included 10 males and 10 females, averaging (48.30 ± 4.46) years of age and (35.10 ± 5.24) months of dialysis. Inclusion criteria: Ability to walk independently; stable duration of dialysis treatment; informed consent from both patients and families. Exclusion criteria: History of psychiatric disorders; elevated or low blood pressure; incomplete clinical data; patients with concurrent brain tumors. Comparison of general data between groups showed no statistically significant differences (P > 0.05), indicating comparability (see Table 1). This study was approved by our hospital's ethics committee, ethics approval number: 2025-04-163-k01.

Table 1. Comparison of General Characteristics Between the Two Patient Groups (n=20)

Project	observation group	Control Group	χ^2/t-value	P-value
Age (years)	48.60±5.14	48.30±4.46	0.138	0.881
Gender			0.057	0.822
Male	11	10		
Female	9	10		
Education level			0.235	0.864
Junior high school and below	12	11		
High school/Vocational school	6	5		
Associate degree or higher	2	4		
Primary diagnosis			0.165	0.953
Diabetic Nephropathy	9	10		
Chronic Glomerulonephritis	7	6		
Hypertensive Nephropathy	3	2		
Polycystic Kidney Disease	1	2		
Dialysis Duration (Months)	35.90±5.96	35.10±5.24	-0.477	0.632
Dry weight (kg)	58.33±5.34	57.16±6.78	0.320	0.742
Ultrafiltration volume (L)	2.30±0.42	2.05±0.30	0.182	0.071

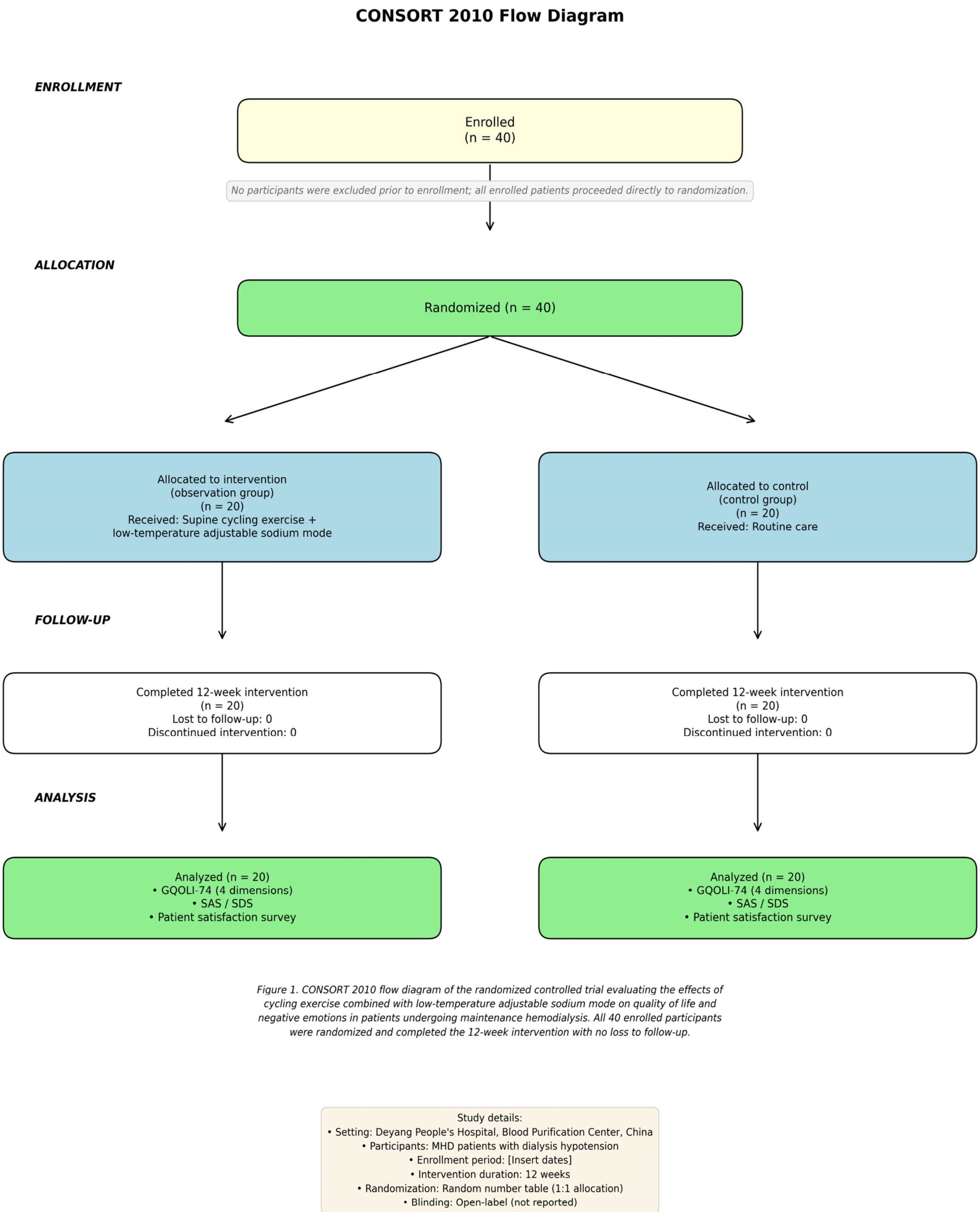

Figure 1. CONSORT 2010 flow diagram of participant progression through the randomized controlled trial.

2.2 Methods

2.2.1 Control Group

The control group received routine care, primarily involving close monitoring of vital signs during regular hemodialysis sessions, strict adherence to medical orders, and accurate operation of hemodialysis machines. Nursing staff closely observed patients for complications such as hypotension, muscle cramps, nausea, and vomiting during dialysis, promptly addressing any abnormalities. Enhanced monitoring and care were provided at the arteriovenous fistula puncture site to prevent bleeding, thrombosis, and infection. Patients were instructed to strictly control dry weight, ensuring inter-dialysis weight gain did not exceed 3%–5% of dry weight, while adhering to a low-salt, high-quality protein, low-phosphorus, and low-potassium diet. Medications were administered as prescribed to regulate blood pressure, correct anemia, and manage calcium-phosphorus metabolism, monitoring both therapeutic effects and adverse reactions. Routine health education was concurrently provided, health education covering self-monitoring of vascular access, fluid control techniques, and the importance of regular follow-up assessments of renal function and electrolyte levels.

2.2.2 Observation Group

The observation group implemented bicycle exercise combined with low-temperature adjustable sodium intervention based on the control group, with specific measures as follows. The observation group underwent dialysis using the low-temperature adjustable sodium mode, with temperature controlled at 35.5°C. The dialysate sodium concentration utilized the machine's built-in curve mode, starting at 145 mmol/L and decreasing to 140 mmol/L 30 minutes before dialysis completion. Theobservation group combined low-temperature adjustable sodium dialysis with bicycle exercise. During the middle 2 hours of hemodialysis, patients performed supine bicycle exercise in four sets: 15 minutes per set with3-5 minutes rest between sets. Pre-exercise instruction: Assist patients with supine bicycle exercise based on their condition; emphasize precautions during exercise. Record exercise duration and vital signs (blood pressure, heart rate, pulse, respiration) before dialysis and at the 1st, 2nd, 3rd, and 4th hours during dialysis to determine exercise continuation. During Exercise: Guide patients in cycling during dialysis, adjusting settings to 15 minutes per hour and 30–60 rpm. Gradually increase speed from slow to fast, then reduce speed toward the end until stopping. Exercise Monitoring: Throughout the cycling session, continuously monitor vital signs, including heart rate and blood pressure. Exercise completion: As exercise nears completion, gradually reduce cycling intensity and speed to promote blood return and prevent cardiovascular events. Re-monitor blood pressure and pulse15-20 minutes after cessation. Abnormal readings may indicate insufficient or excessive cycling. Psychological and Health Education Care: Encourage patients to actively engage in social interactions andschedule patients with similar interests to attend concurrent therapy sessions. Maintain proactive communication with patients and their families to address negative emotions and guide role transitions. Assess patients' and families' understanding of nephrology knowledge, then deliver targeted education through lectures, bulletin boards, WeChat groups, etc., based on assessment results. Both groups received continuous intervention for 12 weeks.

2.3 Observation Indicators

(1) Compare the quality of life between the two patient groups. Quality of life was assessed using the General Quality of Life Index (GQOLI-74), a 74-item scale specifically developed by Li and Yang for the Chinese population. The questionnaire assesses four dimensions: physical functioning (e.g., sleep, energy, physical discomfort), psychological functioning (e.g., anxiety, depression, positive emotions, self-esteem), social functioning (e.g., social support, interpersonal relationships, marital life), and material living conditions (e.g., housing, community environment, economic status). Items are rated on a 5-point Likert scale (1 = "very poor/very dissatisfied" to 5 = "very good/very satisfied"), with some items reverse-scored. Raw scores are converted into standardized scores ranging from 0 to 100, where higher scores in each dimension indicate better quality of life(Li LJ&Yang DS,1998;Xie Y et al.,2020). The scale demonstrates Cronbach's α reliability coefficients ranging from 0.92 to 0.95.

(2) Assessment of anxiety and depression. The Self-Rating Anxiety Scale (SAS) and Self-Rating Depression Scale (SDS) were employed for evaluation. Both scales are 20-item self-report instruments developed by Zung to assess symptoms experienced by subjects over the preceding week. Each item is scored on a 4-point Likert scale (1 = "rarely or occasionally" to 4 = "almost constantly or completely"). The SAS includes 5 reverse-scored items (Questions 5, 9, 13, 17, 19), with Cronbach's α ranging from 0.82 to 0.91. While the SDS includes 10 reverse-scored items (Questions 2, 5, 6, 11, 12, 14, 16, 17, 18, 20),with Cronbach's α = 0.84–0.92. Raw scores are converted to standardized scores (25–100) by multiplying by 1.25. The cutoff points for clinical significance are SAS ≥ 50 and SDS ≥ 53, indicating mild or greater anxiety and depression, respectively. Higher scores indicate greater severity of anxiety and depression(Zung WW, 1971; Zung WW, 1965).

(3) Evaluation of patient satisfaction. A hospital-developed satisfaction survey questionnaire was used, with a total score of 100 points. Scores of 90–100 were classified as Very Satisfied, 80–89 as Satisfied, 70–79 as Fairly Satisfied, and below 70 as Dissatisfied. Overall satisfaction rate = (Number of Very Satisfied + Satisfied + Fairly Satisfied cases) / Total number of cases × 100%.

2.4 Statistical Methods

Statistical analysis was performed using SPSS 24.0 software. Count data are expressed as percentages and analyzed using the chi-square test. Continuous data are presented as mean ± standard deviation and analyzed using the t-test. A P-value < 0.05was considered statistically significant.

3. Results

Quality of Life Comparison Following the intervention, the observation group demonstrated statistically significantly higher scores across all quality of life dimensions compared to the control group ($P < 0.05$) (see Table 2).

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Table 2. Comparison of GQOLI-74 scores between groups (mean ± SD)

Group	n	Physical Functions	Psychological Function	Social Function	Material life	Total Score
observation group	20	73.20±4.93	80.40±7.05	77.20±4.70	73.70±4.80	76.80±4.70
Control Group	20	64.00±4.83	66.20±5.63	63.70±4.57	62.60±4.19	63.50±4.55
t		4.211	4.972	6.504	5.501	6.421
P		0.001	0.000	0.000	0.000	0.000

Comparison of Negative Emotions There were no statistically significant differences in negative emotion scores between the two groups before the intervention (P > 0.05). After intervention, negative emotion scores in the observation group were lower than those in the control group, with a statistically significant difference (P < 0.05) (see Table 3).

Table 3. Comparison of Anxiety and Depression Scores Before and After Intervention in Two Patient Groups (mean ± SD)

Group	n	Anxiety	Anxiety	Depression	Depression
Group	n	Before intervention	After intervention	Before intervention	After intervention
observation group	20	62.10±3.47	43.50±3.37	61.90±3.66	45.20±3.01
Control Group	20	61.60±3.33	52.50±3.37	62.50±3.74	53.30±3.74
t		0.712	-5.963	0.885	-5.332
P		0.747	0.000	0.722	0.000

Comparison of Patient Satisfaction Patient satisfaction in the observation group was 100.00%, significantly higher than the 90% in the control group. This difference was statistically significant (z = -5.108, P < 0.05). See Table 4.

Table 4. Comparison of Patient Satisfaction Between Two Groups [n/%]

Group	n	Very Satisfied	Satisfied	Fairly satisfied	Not satisfied
observation group	20	10（50.00）	9（45.00）	1（5.00）	0（0）
Control Group	20	8（40.00）	8（40.002）	2（10.00）	2（10.00）
z	-5.108	-5.108	-5.108	-5.108	-5.108
p	0.000	0.000	0.000	0.000	0.000

4. Discussion

Hemodialysis serves as a vital renal replacement therapy for sustaining the lives of patients with End-Stage Renal Disease (ESRD). It effectively removes metabolic waste from the body, corrects disturbances in water-electrolyte and acid-base balance, and significantly prolongs patient survival. However, the long-term dialysis treatment process is accompanied by numerous complications (such as dialysis-related hypotension, muscle cramps, anemia, malnutrition, and chronic low-grade inflammation), along with persistent accumulation of uremic toxins leading to internal environment disruption,resulting in severe physiological dysfunction and psychological burden for patients (Tonelli M et al., 2015; Fouque D et al., 2014). Prolonged, recurrent endocrine imbalances, metabolic abnormalities, and loss of social role function weaken patients' immune function and exercise endurance, triggering severe negative emotions like anxiety and depression. This creates a vicious “physiological-psychological” cycle, ultimately leading to a comprehensive decline in quality of life (Luyckx VA et al., 2017). This study innovatively combines recumbent bicycle exercise with a low-temperature adjustable sodium dialysis model to establish a multidimensional, individualized, and comprehensive nursing intervention system. Results demonstrated that after 12 weeks of intervention, patients in the observation group exhibited significantly higher scores across all dimensions of the GQOLI-74 questionnaire (physical functioning, mental health, social functioning, and material well-being) compared to the control group ($P<0.01$). Their SAS and SDS scores were significantly lower than those of the control group ($P<0.01$), and nursing satisfaction was markedly higher ($P < 0.01$). These findings indicate that combined bicycle exercise and low-temperature adjustable sodium intervention effectively improves psychological status, alleviates negative emotions, and comprehensively enhances quality of life in maintenance hemodialysis patients, demonstrating significant clinical application value.

4.1 Analysis of the Mechanism by Which Cycling Combined with Low-Temperature Adjustable Sodium Mode Affects Quality of Life

Quality of life serves as a core comprehensive indicator for evaluating the prognosis and rehabilitation outcomes of hemodialysis patients, encompassing multiple dimensions including physiological function, psychological state, social adaptation, and material environment. In this study, patients in the observation group demonstrated significantly improved physical function scores, primarily attributable to the positive regulatory effects of bicycle exercise on multiple bodily systems. Regular aerobic exercise significantly increases skeletal muscle blood flow, facilitating the transfer of uremic toxins such as blood urea nitrogen and creatinine from tissue cells into the bloodstream. This enhances solute clearance during dialysis, thereby improving dialysis adequacy (Kt/V) (Greenwood SA et al., 2015; Ting SM et al., 2019). The enhanced muscle pump effect during exercise facilitates venous return, reduces inter-dialysis water and sodium retention, and lowers the incidence of dialysis-related hypotension(Luk TH et al., 2020). Recumbent cycling, as a low-impact aerobic exercise, effectively trains lower limb muscles without compromising dialysis circuit safety. It prevents muscle atrophy and osteoporosis, improves joint mobility, and enhances cardiopulmonary endurance. Research indicates that exercising during dialysis enhances insulin sensitivity, improves lipid metabolism disorders, reduces levels of inflammatory markers such as C-reactive protein and interleukin-6, and alleviates the state of low-grade inflammation. These effects contribute to improved nutritional status and immune function in patients (Viana JL et al., 2014; Wilund KR et al., 2019). Exercise-induced endorphin release provides natural analgesic and mood-enhancing effects, alleviating post-dialysis fatigue and boosting patients' sense of self-efficacy (Hristea G et al., 2016).

The synergistic application of the low-temperature adjustable sodium mode further enhances the improvement in quality of life. Conventional standard sodium concentration dialysis (Na^+ 138–140 mmol/L) often leads to a rapid decrease in serum sodium concentration during dialysis, causing a reduction in plasma osmolarity, stimulating the thirst center, increasing inter-dialysis weight gain, and exacerbating cardiovascular burden (Wong MMY et al., 2022). The curve-shaped adjustable sodium mode employed in this study (starting at 145 mmol/L, decreasing to 140 mmol/L 30 minutes before completion) effectively stabilizes plasma osmolarity by maintaining a higher dialysate sodium concentration. This reduces fluid shift into cells, preserves intravascular volume stability, and significantly lowers the incidence of acute complications such as hypotension and muscle cramps (Maggiore Q et al., 2002). Appropriately lowering dialysate temperature to 35.5°C enhances vasoconstriction, increases peripheral vascular resistance, improves myocardial contractility, and reduces arrhythmia risk, providing stable hemodynamic support for safe bicycle exercise (Twardowski ZJ, 2018). Enhanced physical comfort directly influences patients' psychological function and willingness to participate in social activities, creating a positive feedback loop.

4.2 Psychosocial Mechanisms for Improving Negative Emotions

The prevalence of depression among patients undergoing maintenance hemodialysis can reach 20%–40%, while anxiety occurs in approximately 25%–45% of cases, significantly higher than in the general population (Feng L et al., 2014). The emergence of negative emotions stems not only from concerns about disease prognosis and financial burdens but is also closely associated with physical functional limitations, role dysfunction, and social isolation resulting from long-term treatment. In this study, the observation group exhibited significantly reduced anxiety and depression scores, suggesting that this intervention model possesses unique advantages in psychological rehabilitation.

Exercise promotes the release of neurotransmitters such as serotonin, dopamine, and norepinephrine in the brain's limbic system, regulates the hypothalamic-pituitary-adrenal axis(HPA) function, reduces cortisol levels, and alleviates psychological stress responses (Wipfli BM et al., 2008; Schuch FB et al., 2016). Exercise-induced upregulation of brain-derived neurotrophic factor (BDNF) expression helps protect hippocampal neurons, improving cognitive function and emotional regulation (Cassilhas RC et al., 2016). Psychological support and health education within nursing interventions utilize cognitive behavioral therapy principles to help patients correct misconceptions about their illness and develop positive coping strategies. Group exercise formats foster peer support and emotional exchange among patients, reducing loneliness and enhancing a sense of belonging (Cukor D et al., 2014).

The structured exercise rehabilitation program restores patients' daily rhythms and enhances their sense of control over their lives. Nursing staff organizes group therapy sessions based on patients' interests and hobbies, building peer support networks and expanding social support systems. Health education involving family members improves care quality, enhances family functioning, and collectively promotes the reconstruction and reintegration of patients' social roles (Straiton JA et al., 2015).

4.3 Safety and Feasibility Advantages of Implementing Cycling Exercise During Dialysis

Compared to traditional rehabilitation exercises, bicycle exercise during dialysis offers distinct advantages: Supine exercise avoids traction and compression on the dialysis vascular access, ensuring uninterrupted treatment continuity. Comprehensive medical monitoring during dialysis allows healthcare providers to real-time track vital signs and promptly adjust exercise intensity, minimizing cardiovascular event risks. Utilizing otherwise idle dialysis time for exercise enhances time efficiency, reduces the burden of additional hospital visits, and significantly improves treatment adherence (Bennett PN et al., 2016; Clarkson MJ et al., 2019).

The exercise protocol employed in this study (conducted during the second dialysis hour, comprising four 15-minute sets with 3-5 minute rest intervals, at 30-60 rpm) has been demonstrated to be safe and effective. Mid-dialysis (second hour) presents relatively stable hemodynamics, allowing exercise to avoid the initial instability phase and the fatigue phase at the end of treatment (Bohm CJ et al., 2014). Progressive speed adjustment (slow to fast then back to slow) aligns with exercise physiology principles, preventing cardiovascular stress from abrupt intense activity. This study emphasizes the importance of pre-exercise assessment and post-exercise recovery. A 15-20 minute recovery period effectively prevents blood stasis and orthostatic hypotension that may occur from immediately stopping the machine after exercise (Dungey M et al., 2017).

4.4 Consistency, Differences, and Innovation Compared to Previous Studies

The findings of this study are largely consistent with the conclusions of Chung et al.'s (Chung SH et al., 2020) systematic review on exercise improving physical function in hemodialysis patients, both confirming the efficacy of exercise rehabilitation in dialysis patients. The innovation lies in the following: Integrating exercise intervention with a hypothermic adjustable sodium mode to address concerns that exercise during conventional dialysis may exacerbate hemodynamic instability, thereby creating a synergistic effect of "physiological stability-exercise rehabilitation"; Establishing a holistic care model encompassing physiological monitoring, psychological support, and health education, rather than a single exercise prescription; Providing detailed specifications for exercise timing, intensity, frequency, and monitoring indicators, offering a replicable standardized operating procedure. Compared to Barcellos et al.'s (Heiwe S et al., 2014) meta-analysis of exercise training in CKD patients, the recumbent bicycle used in this study allows easier control of exercise load than resistance training and is more suitable for patients with unstable cardiovascular function. Zhou et al. (Zhou Y et al., 2014) found that hypothermic sodium adjustment alone reduces dialysis complications but did not observe long-term effects on quality of life. This study confirms that combining both approaches produces a synergistic effect, enhancing dialysis safety and fundamentally improving patient quality of life by increasing dialysis adequacy and physical function.

4.5 Clinical Significance and Implications for Practice

This study holds significant clinical implications. The combination of bicycle exercise with the low-temperature adjustable sodium mode is simple and cost-effective (requiring only a recumbent ergometer and the temperature control function of a standard dialysis machine), making it easily scalable in primary care hospitals and aligned with China's current distribution of medical resources. This model embodies a holistic, patient-centered nursing philosophy, transforming passive treatment into active rehabilitation. It fosters self-management behaviors and enhances treatment adherence (Bonner A et al., 2018). Nursing satisfaction surveys (100% satisfaction in the observation group) indicate high patient acceptance of this intervention and improved nurse-patient rapport.

Key considerations in nursing practice include the development of individualized exercise prescription, adjusting intensity based on the NYHA heart function classification, dialysis duration, and underlying conditions. Exercise should be deferred for patients with NYHA Class III or higher heart failure, severe arrhythmias, or acute infections (Thomas N et al., 2019). The establishment of multidisciplinary teams (comprising nephrologists, rehabilitation therapists, nutritionists, and psychologists) to achieve comprehensive management, and the development of continuity-of-care models utilizing information technology for post-discharge exercise guidance and psychological support to consolidate intervention outcomes (Choi SR et al., 2018).

5. Study Limitations and Future Prospects

This study has certain limitations: the sample size was relatively small (20 patients per group), and as a single-center study, it may be subject to selection bias. Future multi-center, large-sample randomized controlled trials are needed to validate the generalizability of these findings. Follow-up was limited to the intervention period (12 weeks), lacking long-term data to assess the sustainability of intervention effects and their impact on patient long-term survival rates and cardiovascular event incidence (Cheng L et al., 2019). The study did not employ blinding, potentially introducing implementation and measurement biases.

Future research directions include: exploring optimal combinations of different exercise modalities (e.g., resistance training combined with aerobic exercise); incorporating objective evaluation metrics such as grip strength, 6-minute walk test, and bioelectrical impedance analysis (BIA) to assess body composition changes, alongside laboratory testing of inflammatory markers (IL-6, TNF-α, hs-CRP) to elucidate underlying mechanisms; and conducting cost-effectiveness analyses to evaluate the cost-benefit ratio of this model from a health economics perspective, thereby providing evidence for healthcare policy formulation (Liao MT et al., 2020).

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Competing interests

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Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Macrothink Institute.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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