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The effects of oral L-carnitine supplementation on echocardiographic parameters in hemodialysis patients with pulmonary hypertension; a double-blind clinical trial investigation

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ABSTRACT

Introduction: Hemodialysis patients face progressive reductions in carnitine levels due to the removal of carnitine during hemodialysis and decreased endogenous synthesis, which may contribute to impaired fatty acid oxidation and endothelial dysfunction, potentially playing a role in the development of pulmonary hypertension.

Objectives: This study sought to assess the impact of oral L-carnitine supplementation on echocardiographic index in hemodialysis patients diagnosed with pulmonary hypertension.

Patients and Methods: This double-blind, placebo-controlled, randomized clinical trial was conducted on hemodialysis patients diagnosed with pulmonary hypertension who were referred to dialysis centers in 2022, in Shahrekord, Iran. Eligible participants were randomly assigned to receive either L-carnitine or placebo for 12 weeks. Informed written consent was taken from all patients and demographic characteristics were collected. Echocardiographic parameters were measured at baseline and after the intervention, including ejection fraction, systolic pulmonary artery pressure (SPAP), mean pulmonary artery pressure (MPAP), and New York Heart Association (NYHA) functional class. Data were collected and compared between control and intervention groups using statistical tests.

Results: The study included 40 participants, divided into control and intervention groups. The mean ages were 65.10 ± 8.66 years for the control group and 56.35 ± 13.76 years for the intervention group. Analysis of echocardiographic parameters revealed significant differences between the groups after three months, with the intervention group showing a notable increase in ejection fraction and significant reductions in NYHA functional class, SPAP, and MPAP compared to the control group.

Conclusion: Our findings showed that L-carnitine positively impacts cardiac function and echocardiographic parameters in hemodialysis patients with pulmonary hypertension. The significant improvements in ejection fraction and reductions in the NYHA functional class, SPAP, and MPAP indicate that L-carnitine may play an effective role in enhancing cardiac performance and improving symptoms in this patient population.

Trial Registration: The trial protocol was approved by the Iranian Registry of Clinical Trials (identifier: IRCT20230425057989N1; https://irct.behdasht.gov.ir/trial/69751), and ethical code from Shahrekord University of Medical Sciences (Ethical code#IR.SKUMS.REC.1400.157).

Clinical Trial

Introduction

Pulmonary hypertension in hemodialysis patients is a resting mean pulmonary artery pressure (MPAP) greater than 25 mm Hg, as measured by right heart catheterization (1-3). It is further classified into mild (25-40 mm Hg), moderate (40-60 mm Hg), and severe (>60 mm Hg) based on the level of pressure elevation (3). Pulmonary hypertension is highly prevalent in end-stage renal disease (ESRD) patients on hemodialysis, with a reported rate of 38% (ranging from 8% to 70%) in a meta-analysis study on 41 studies (4); which is an underestimated cardiovascular consequence and a significant predictor of mortality in this patient population (3).

The pathogenesis of pulmonary hypertension in hemodialysis is multifactorial and not fully elucidated. Factors that may contribute to its development include

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chronic volume overload, alterations in calcium and phosphate metabolism, metabolic derangements affecting pulmonary vasculature, and chronically increased blood flow from arteriovenous fistulas (2,3). The clinical signs of pulmonary hypertension in hemodialysis patients are often hidden by the underlying etiology, and diagnosis is frequently established only after the development of right ventricular failure (5). Today, pulmonary hypertension can be diagnosed relatively accurately in most patients using non-invasive doppler echocardiography. If this condition is diagnosed early, it can be managed to some extent by addressing the underlying causes before the onset of right ventricular failure, thereby reducing the mortality rate associated with cardiac issues in hemodialysis patients (6).

L-carnitine is a naturally occurring molecule that plays a role in fatty acid metabolism and is synthesized in the human body from the amino acids L-lysine and L-methionine, which serve as its building blocks; this endogenous molecule can be obtained through dietary sources, with red meats like beef and lamb being the richest sources for increasing carnitine intake (7). L-carnitine plays a vital role in the management of hemodialysis patients by addressing several complications associated with chronic kidney disease. It is particularly effective in treating erythropoietin-resistant anemia, as studies have shown that L-carnitine supplementation can increase plasma L-carnitine levels, enhance the response to erythropoiesis-stimulating agents, and reduce the required doses of these medications, thereby maintaining hemoglobin and hematocrit levels more effectively. Additionally, L-carnitine helps alleviate intradialytic hypotension and improves cardiac function, which are common issues in this patient population (8).

Research suggests that L-carnitine supplementation can have significant benefits for hemodialysis patients, such as reducing dialysis-related hypotension (9), improving muscle status and physical activity (10), and regulating inflammatory markers in critically ill patients (11). Specifically, L-carnitine has been shown to reduce inflammatory markers like C-reactive protein and interleukin-6 levels, improve muscle mass, decrease fat mass, and enhance exercise activity in hemodialysis patients (9,10). Therefore, incorporating oral L-carnitine supplementation in hemodialysis patients with a pulmonary hypertension treatment regimen may lead to positive changes in echocardiographic parameters and overall cardiovascular health. This study aimed to evaluate the effects of oral L-carnitine consumption on echocardiographic parameters as cardiovascular health index in hemodialysis patients with pulmonary hypertension through a clinical trial Investigation.

Objectives

This double-blind clinical trial aimed to determine whether L-carnitine can significantly improve cardiac function, as measured by echocardiographic assessments, and to assess its potential role in enhancing cardiovascular health in this high-risk patient population. The study seeks to provide evidence for the efficacy of L-carnitine as a therapeutic intervention to mitigate the cardiovascular complications associated with hemodialysis and pulmonary hypertension.

Implication for health policy/practice/research/medical education:

The implications of this study are significant for clinical practice and patient management in hemodialysis patients with pulmonary hypertension. Given the demonstrated positive effects of L-carnitine on cardiac function and hemodynamic parameters, healthcare providers may consider incorporating L-carnitine supplementation as part of a comprehensive treatment strategy to enhance cardiac performance and alleviate symptoms in this vulnerable population. Furthermore, these findings warrant further investigation into the long-term benefits and optimal dosing of L-carnitine, as well as its potential role in broader patient populations with cardiac dysfunction. Ultimately, this research could lead to improved quality of life and clinical outcomes for patients suffering from compromised cardiac function associated with chronic kidney disease and pulmonary hypertension.

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Patients and Methods

Study design and participants

This double-blind, placebo-controlled, randomized clinical trial study aimed to evaluate the effects of oral L-carnitine supplementation on echocardiographic parameters. The study population consists of hemodialysis patients diagnosed with pulmonary hypertension who were referred to dialysis centers located in Shahrekord city, Chaharmahal va Bakhtiari province, Iran, in 2022.

Inclusion and exclusion criteria

The inclusion criteria for this study comprised individuals aged over 13 years, a minimum history of six months of hemodialysis treatment, possession of a medical record at the designated dialysis center, undergoing dialysis two to three times weekly for three to four hours per session, and a physician's confirmation of the indication for oral L-carnitine supplementation. Additionally, participants were required to have no physical or mental disabilities, maintain a stable dry weight, and provide written informed consent to participate in the research. Patients experiencing adverse drug reactions or those who did not adhere to the L-carnitine administration protocol were excluded from the study.

Sample size calculation

The sample size was calculated based on the expected effect size of L-carnitine on echocardiographic parameters, with a power of 80% and a significance level of 0.05 with 20 patients in each group.

Blinding

The study was conducted as a double-blind trial; participants and investigators were blinded to the group allocation and treatment. In other words, both the participants and the researchers were unaware of who received the treatment or the placebo .

Randomization and intervention

Eligible participants will be randomly assigned (1:1) to receive either oral L-carnitine or placebo. Based on the order of selection of participants who entered the study, individuals whose selection order was odd were assigned to the intervention group, while the remaining individuals were placed in the control group. The L-carnitine group patients took one gram of L-carnitine orally, two times daily for 12 weeks; while placebo group patients took identical placebo capsules, two times daily for 12 weeks. Randomization was stratified by age and severity of pulmonary hypertension (12).

Data collection and outcomes

Demographic characteristics of the patients were collected using a demographic checklist. Initially, echocardiography was performed on the patients, and values for the ejection fraction (EF), systolic pulmonary artery pressure (SPAP), MPAP, and New York Heart Association (NYHA) functional class were measured. The intervention group received routine treatment plus 1000 mg of L-carnitine every 12 hours for 3 months, while the control group received routine treatment plus a placebo every 12 hours for the same period. After three months, echocardiography was repeated for the patients, and the echocardiographic parameters as well as the NYHA functional class scales were measured again, and compared between the two groups.

Statistical analysis

The data were analyzed utilizing SPSS version 27. For the qualitative data, the chi-square was employed to compare the results between the control and intervention groups. Quantitative data analysis by the use of the Wilcoxon rank-sum test, paired t-test, Mann-Whitney U test, and independent t-test, depending on the normality of data distribution. The Kolmogorov-Smirnov test was conducted to assess normality, and the Levene test was carried out for variance homogeneity evaluation. A *P* value of less than 0.05 was deemed statistically significant.

Results

In this clinical trial study, 146 participants were evaluated for eligibility, out of which 106 were excluded; 79 did not meet the inclusion criteria, 16 declined to participate, and 8 had other reasons for exclusion. Following this, 43 participants were randomized into two groups; 22 were allocated to the intervention group and 21 to the control group. All 22 participants received the allocated intervention in the intervention group, and none were excluded from the analysis. In the control group, 20 participants received the allocated intervention while one case did not continue due to unwillingness. Additionally, two participants in the intervention group discontinued the intervention due to non-adherence to the medication protocol. Ultimately, 20 participants from the intervention group and 20 from the control group were analyzed, with no participants lost to follow-up or excluded from analysis (Figure 1).

The demographic data of the participant individuals by intervention and control groups is presented in Table 1. The study comprised a total of 40 participants, with 20 in the control group and 20 in the intervention group. The gender distribution differed between the groups, with 65% males and 35% females in the control group, compared to 40% males and 60% females in the intervention group. However, this difference was not statistically significant. The mean age of participants was 65.10 ± 8.66 years in the control group and 56.35 ± 13.76 years in the intervention group, with a borderline significant difference.

The comparison of echocardiography parameters between the control and intervention groups before and after the intervention is summarized as follows. Before the intervention, the NYHA functional class scale did not show a significant difference between the control and intervention groups; however, after the intervention, a significant difference was observed. The ejection fraction was 48.75±8.09% in the control group and 53.25±5.68% in the intervention group before the intervention, with no significant difference noted. Post-intervention values changed to 48.00±7.67% for the control group and 54.25±5.44% for the intervention group, which was statistically significant. For SPAP, the mean difference between the control and intervention groups was statistically significant at both time points, before and after the intervention. Finally, the MPAP showed no significant

Table 1. Demographic data of the participant individuals by intervention and control groups

Variable	Group				*P* value
	Control (n = 20)		Intervention (n = 20)		
	No.	%	No.	%	
Gender					
Male	13	65	8	40	0.745*
Female	7	35	12	60	
	Mean	SD	Mean	SD	
Age (y)	65.10	8.66	56.35	13.76	0.052**

SD: Standard deviation.
*Chi-square, **Independent *t* test.

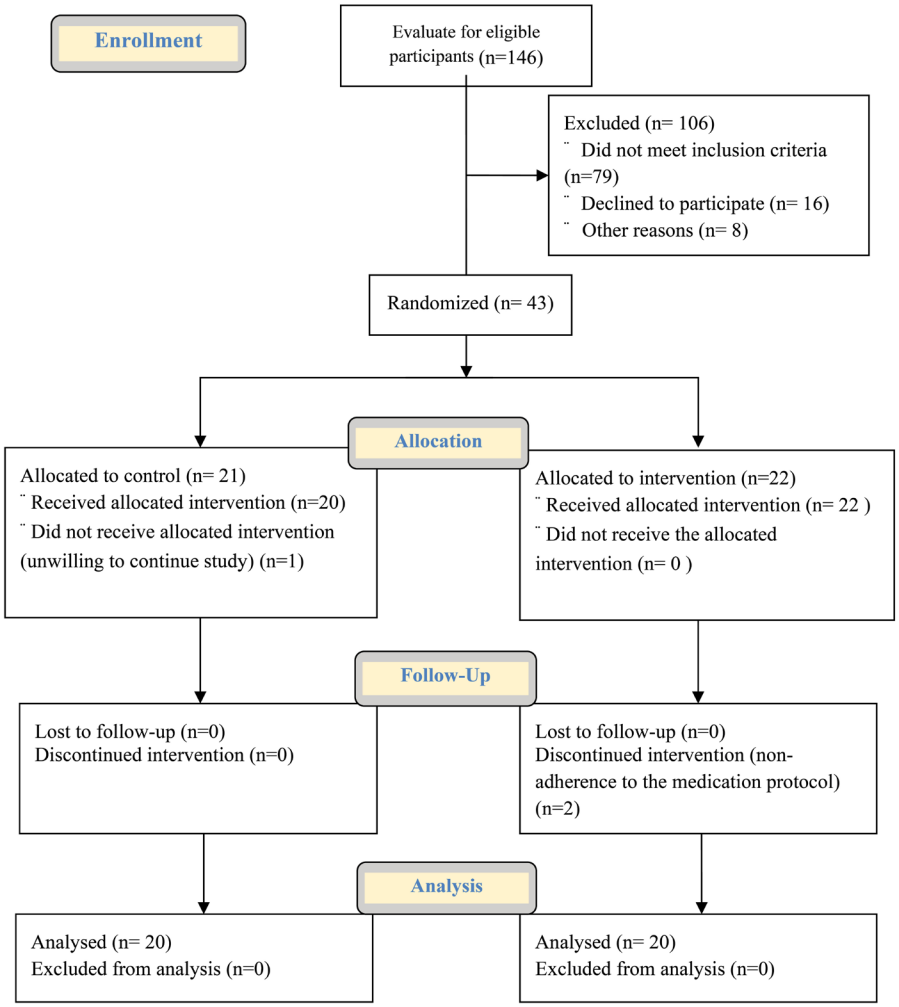

Figure 1. CONSORT Flowchart of the study.

difference between the control and intervention groups before the intervention; however, after the intervention, a significant difference was noted (Table 2).

The results of the data analysis indicated that, in the L-carnitine treatment group, echocardiographic parameters at three months post-intervention exhibited a statistically significant improvement compared to baseline measurements, specifically demonstrating an increase in ejection fraction alongside significant reductions in NYHA functional class, SPAP, and MPAP. Conversely, in the control group, there were no significant changes observed in the NYHA and ejection fraction metrics after the intervention relative to baseline; however, both SPAP and MPAP metrics showed a significant increase. These findings suggest that L-carnitine may have a beneficial effect on cardiac function and hemodynamic parameters in the treated population (Table 3).

The analysis of changes in echocardiographic

Table 2. Comparison of echocardiography parameters between the control and intervention groups at the times before and after the intervention

Variable	Before the intervention (group)		*P* value	At the end of the intervention (group)		*P* value
	Control	Intervention		Control	Intervention	
	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	
NYHA	3.5 ± 0.68	3.25 ± 0.91	0.333*	3.65 ± 0.67	2.95 ± 0.88	0.008*
EF (%)	48.75 ± 8.09	53.25 ± 5.68	0.050**	48.00 ± 7.67	54.25 ± 5.44	0.005**
SPAP (mm Hg)	36.55 ± 4.78	41.10 ± 5.31	0.007**	38.15 ± 4.80	33.65 ± 8.64	0.049**
MPAP (mm Hg)	26.45 ± 4.85	29.15 ± 3.52	0.051**	28.00 ± 5.40	24.20 ± 2.98	0.011**

SD, Standard deviation; NYHA, New York Heart Association; EF, Ejection fraction; SPAP, Systolic pulmonary artery pressure; MPAP, Mean pulmonary artery pressure.
*Independent t-test, **Mann-Whitney.

parameters from pre-intervention to three months post-L-carnitine consumption revealed significant differences between the intervention and control groups across all four parameters, including NYHA functional class, ejection fraction, SPAP, and MPAP. Specifically, the intervention group demonstrated a significantly positive increase in ejection fraction compared to the control group, while the changes in NYHA functional class, SPAP, and MPAP were negative, indicating significant reductions in these parameters within the intervention group relative to the control group (Table 4).

Discussion

This study aimed to evaluate the effects of oral L-carnitine supplementation on echocardiographic parameters in hemodialysis patients with pulmonary hypertension and provides compelling evidence regarding the potential benefits of L-carnitine in this specific patient population. The results demonstrated that the echocardiographic parameters in patients consuming L-carnitine revealed significant differences when compared to a control group, particularly in four key metrics, including NYHA functional class, ejection fraction, SPAP, and MPAP. These findings indicate a noteworthy improvement in ejection fraction among the intervention group, suggesting enhanced cardiac function, while the NYHA functional class, SPAP, and MPAP showed negative changes, reflecting a decrease in these parameters and an improvement in pulmonary hypertension.

The significant increase in ejection fraction within the intervention group is a critical finding, as ejection fraction is a key indicator of cardiac systolic function. An increase in ejection fraction suggests that L-carnitine may enhance the heart's pumping ability, which is particularly beneficial for patients with compromised cardiac function. Previous studies support this observation; a meta-analysis study by Weng et al in line with our results indicated that L-carnitine supplementation can lead to improved cardiac output and overall heart function, especially in conditions like dilated cardiomyopathy (13). In a study conducted by Kudoh et al, the effects of a daily dosage of 900 mg of L-carnitine were compared to a placebo in patients undergoing hemodialysis. The findings indicated a significant increase in ejection fraction among those who received L-carnitine, aligning with the outcomes observed in our research (14). In another study by Omori et al, the results indicated that L-carnitine can reduce cardiac fibrosis by enhancing the production of prostacyclin through the metabolism of arachidonic acid, a process that may contribute to improved left ventricular ejection fraction (15). However, in contrast with our study, a study by Topaloğlu et al on children undergoing hemodialysis, the administration of intravenous L-carnitine at a dose of 4.0-20 mg/kg three times a week over 3 months did not show a significant improvement in left ventricular systolic and diastolic function, including ejection fraction (16).

While the increase in ejection fraction is encouraging, the negative changes observed in NYHA functional

Table 3. Analysis of echocardiography parameters within the control and intervention groups by comparing post-intervention measurements to pre-intervention

Variable	Control group		*P* value	Intervention group		*P* value
	Before	After		Before	After	
	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	
NYHA	3.5 ± 0.68	3.65 ± 0.67	0.083*	3.25 ± 0.91	2.95 ± 0.88	0.010*
EF (%)	48.75 ± 8.09	48.00 ± 7.67	0.083**	53.25 ± 5.68	54.25 ± 5.44	0.042**
SPAP (mm Hg)	36.55 ± 4.78	38.15 ± 4.80	0.001**	41.10 ± 5.31	33.65 ± 8.64	<0.001**
MPAP (mm Hg)	26.45 ± 4.85	28.00 ± 5.40	0.001**	29.15 ± 3.52	24.20 ± 2.98	<0.001**

SD, Standard deviation; NYHA, New York Heart Association; EF, Ejection fraction; SPAP, Systolic pulmonary artery pressure; MPAP, Mean pulmonary artery pressure.
*Paired t-test, **Wilcoxon.

Table 4. The comparative analysis of changes in echocardiographic parameters from pre-intervention to post-intervention, between the control and intervention groups.

Variable	Control group	Intervention group	Mean difference	*P* value
	Mean ± SD	Mean ± SD	Mean	
NYHA	+ 0.15 ± 0.36	- 0.30 ± 0.47	0.45	0.002*
EF (%)	- 0.75 ± 1.83	+ 1.00 ± 2.52	1.75	0.007**
SPAP (mm Hg)	+ 1.6 ± 1.90	- 7.45 ± 7.46	9.10	<0.001**
MPAP (mm Hg)	+ 1.55 ± 1.79	- 4.95 ± 1.57	6.50	<0.001**

SD, Standard deviation; NYHA, New York Heart Association; EF, Ejection fraction; SPAP, Systolic pulmonary artery pressure; MPAP, Mean pulmonary artery pressure.
*Independent t-test, **Mann-Whitney.

class, SPAP, and MPAP warrant careful consideration. A reduction in NYHA functional class indicates that patients may experience fewer limitations in their daily activities, which is a positive outcome. However, the decrease in SPAP and MPAP suggests that L-carnitine may have a beneficial effect on pulmonary hemodynamics, reducing the strain on the heart. This is particularly relevant in patients with pulmonary hypertension, as elevated pulmonary pressures can lead to significant morbidity. In line with our results, in a study by Jing et al on patients with chronic heart failure, it was observed that receiving L-carnitine (3 grams dissolved in 100 mL saline administered intravenously twice daily for 7 days) led to a reduction of at least one NYHA class in 60.9% of the L-carnitine group compared to 44.7% of the placebo group, which was a statistically significant difference. However, these researchers did not observe a significant improvement in ejection fraction and the incidence of cardiovascular events (17). In a meta-analysis study on randomized clinical trial studies by Song et al on patients with chronic heart failure, it was observed that the administration of L-carnitine (1.5 to 6 grams per day) led to significant improvements in cardiac function, including a reduction in NYHA functional class, an increase in ejection fraction and cardiac output (18). The observed reductions in SPAP and MPAP could be indicative of improved right ventricular function and reduced pulmonary vascular resistance, which are crucial for patients with pulmonary hypertension. These changes may also reflect a decrease in the workload on the heart, potentially leading to better clinical outcomes over time.

Overall, the findings from this study suggest that L-carnitine supplementation could be a valuable therapeutic strategy for managing cardiac function in hemodialysis patients with pulmonary hypertension. The combination of improved ejection fraction and favorable changes in NYHA functional class and pulmonary pressures highlights the potential for L-carnitine to enhance the quality of life and reduce the burden of heart failure symptoms in this vulnerable population. Despite the promising results, further research is essential to fully understand the implications of L-carnitine supplementation in this context. Future studies should focus on larger cohorts and longer follow-up periods to assess the long-term effects of L-carnitine on cardiac function, exercise capacity, and overall survival in hemodialysis patients. Additionally, exploring the optimal dosing strategies and potential interactions with other treatments commonly used in this population could provide valuable insights for clinical practice.

Conclusion

The results demonstrated that oral L-carnitine supplementation can lead to significant improvements in echocardiographic parameters in hemodialysis patients with pulmonary hypertension. The increase in ejection fraction, alongside reductions in NYHA functional class, SPAP, and MPAP, underscores the potential of L-carnitine as an adjunctive therapy to improve cardiac function and patients' quality of life. However, further research is needed to validate these findings and optimize treatment strategies for this complex patient population.

Limitations of the study

Firstly, the research was conducted at a single center in Shahrekord City, which may limit the applicability of the results to other populations or geographical regions. The inclusion criteria restricted participants to those aged over 13 years, potentially excluding younger patients and limiting the age diversity of the sample. Additionally, the requirement for a minimum of six months of hemodialysis treatment may not adequately represent the varying stages of disease progression among patients. The study also lacks a comprehensive assessment of dietary intake, which could influence baseline L-carnitine levels and the efficacy of supplementation. Furthermore, the short follow-up period of three months may not capture the long-term effects of L-carnitine supplementation, and the exclusion of patients with physical or mental disabilities could introduce selection bias. Together, these limitations suggest that further research is needed to validate the findings and explore the broader implications of L-carnitine supplementation in diverse patient populations.

Authors' contribution

Conceptualization: Afiyeh Mirzaali and Zahra Habibi.
Data curation: Zahra Habibi and Afiyeh Mirzaali.
Formal analysis: Hadi Raeisi Shahraki.
Investigation: Leila Mahmoodnia and Marziyeh Nasiri.
Methodology: Hadi Raeisi Shahraki.
Project Management: Leila Mahmoodnia.
Supervision: Afiyeh Mirzaali.
Validation: Leila Mahmoodnia and Zahra Habibi.
Writing-original draft: All authors.
Writing-reviewing and editing: All authors.

Conflicts of interest

The authors declare no conflict of interest.

Ethical issues

The research was conducted in accordance with the principles of the Declaration of Helsinki, approved by the Shahrekord University of Medical Sciences, Shahrekord, Iran (the Ethical code #IR.SKUMS.REC.1400.157; https://ethics.research.ac.ir/EthicsProposalView.php?&code=IR.SKUMS.REC.1400.157). This study originated from the internal medicine residency thesis of Afiyeh Mirzaali (Thesis #5632). The study protocol was also registered as a clinical trial at the Iranian Registry of Clinical Trials (identifier: IRCT20230425057989N1; https://irct.behdasht.gov.ir/trial/69751). Written informed consent was taken from all participants before any intervention.

Besides, the authors have ultimately observed ethical issues (including plagiarism, data fabrication, and double publication).

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References

1. Alıcı G, Waberi MM, Mohamud MA, Bashir AM, Genç Ö. Pulmonary hypertension among maintenance hemodialysis patients in Somalia: a hospital-based observational study. Egypt Heart J. 2022;74:24. doi: 10.1186/s43044-022-00261-1.
2. Mukhtar KN, Mohkumuddin S, Mahmood SN. Frequency of pulmonary hypertension in hemodialysis patients. Pak J Med Sci. 2014;30:1319-22. doi: 10.12669/pjms.306.5525.
3. Nagaraju SP, Bhojaraja MV, Paramasivam G, Prabhu RA, Rangaswamy D, Rao IR, et al. Risk Factors of Pulmonary Hypertension in Patients on Hemodialysis: A Single Center Study. Int J Nephrol Renovasc Dis. 2021;14:487-94. doi: 10.2147/ijnrd.S346184.
4. Schoenberg NC, Argula RG, Klings ES, Wilson KC, Farber HW. Prevalence and Mortality of Pulmonary Hypertension in ESRD: A Systematic Review and Meta-analysis. Lung. 2020;198:535-45. doi: 10.1007/s00408-020-00355-0.
5. de Assis ACR, Boros GAB, Demarchi L, Scudeler TL, Rezende PC. Diagnostic Management and Surgical Treatment of Isolated Tricuspid Regurgitation. Case Rep Cardiol. 2021;2021:9928811. doi: 10.1155/2021/9928811.
6. Yigla M, Abassi Z, Reisner SA, Nakhoul F. Pulmonary hypertension in hemodialysis patients: an unrecognized threat. Semin Dial. 2006;19:353-7. doi: 10.1111/j.1525-139X.2006.00186.x.
7. Pekala J, Patkowska-Sokoła B, Bodkowski R, Jamroz D, Nowakowski P, Lochyński S, et al. L-carnitine--metabolic functions and meaning in humans life. Curr Drug Metab. 2011;12:667-78. doi: 10.2174/138920011796504536.
8. Ulinski T, Cirulli M, Virmani MA. The role of L-carnitine in kidney disease and related metabolic dysfunctions. Kidney Dial. 2023;3:178-91. doi: 10.3390/kidneydial3020016.
9. Chewcharat A, Chewcharat P, Liu W, Cellini J, Phipps EA, Melendez Young JA, et al. The effect of levocarnitine supplementation on dialysis-related hypotension: A systematic review, meta-analysis, and trial sequential analysis. PLoS One. 2022;17:e0271307. doi: 10.1371/journal.pone.0271307.
10. Yano J, Kaida Y, Maeda T, Hashida R, Tonan T, Nagata S, et al. l-carnitine supplementation vs cycle ergometer exercise for physical activity and muscle status in hemodialysis patients: A randomized clinical trial. Ther Apher Dial. 2021;25:304-13. doi: 10.1111/1744-9987.13576.
11. Guarnieri G. Carnitine in maintenance hemodialysis patients. J Ren Nutr. 2015;25:169-75. doi: 10.1053/j.jrn.2014.10.025.
12. El-Beshlawy A, Youssry I, El-Saidi S, El Accaoui R, Mansi Y, Makhlouf A, et al. Pulmonary hypertension in beta-thalassemia major and the role of L-carnitine therapy. Pediatr Hematol Oncol. 2008;25:734-43. doi: 10.1080/08880010802244035.
13. Weng Y, Zhang S, Huang W, Xie X, Ma Z, Fan Q. Efficacy of L-Carnitine for Dilated Cardiomyopathy: A Meta-Analysis of Randomized Controlled Trials. Biomed Res Int. 2021;2021:9491615. doi: 10.1155/2021/9491615.
14. Kudoh Y, Aoyama S, Torii T, Chen Q, Nagahara D, Sakata H, et al. Hemodynamic stabilizing effects of L-carnitine in chronic hemodialysis patients. Cardiorenal Med. 2013;3:200-7. doi: 10.1159/000355016.
15. Omori Y, Ohtani T, Sakata Y, Mano T, Takeda Y, Tamaki S, et al. L-Carnitine prevents the development of ventricular fibrosis and heart failure with preserved ejection fraction in hypertensive heart disease. J Hypertens. 2012;30:1834-44. doi: 10.1097/HJH.0b013e3283569c5a.
16. Topaloğlu R, Celiker A, Saatçi U, Kilinç K, Bakkaloğlu A, Beşbaş N, et al. Effect of carnitine supplementation on cardiac function in hemodialyzed children. Acta Paediatr Jpn. 1998;40:26-9.
17. Jing Z-C, Wu B-X, Peng J-Q, Li X-L, Pan L, Zhao S-P, et al. Effect of intravenous l-carnitine in Chinese patients with chronic heart failure. European Heart Journal Supplements. 2016;18:A27-A36. doi: 10.1093/eurheartj/suw008.
18. Song X, Qu H, Yang Z, Rong J, Cai W, Zhou H. Efficacy and Safety of L-Carnitine Treatment for Chronic Heart Failure: A Meta-Analysis of Randomized Controlled Trials. Biomed Res Int. 2017;2017:6274854. doi: 10.1155/2017/6274854.