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Comparison of inferior vena cava indices as markers of volume status in hemodialysis patients and healthy individuals; a case–control study

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ABSTRACT

Introduction: Volume status assessment is critical in hemodialysis (HD) patients because fluid overload is closely related to cardiovascular complications and mortality. Inferior vena cava (IVC) diameter and collapsibility measured by ultrasound provide simple noninvasive estimates of intravascular volume, but comparative data versus healthy individuals are limited.
Objectives: This study therefore compares IVC indices between HD patients and healthy controls to evaluate their usefulness as markers of volume status in clinical practice.
Materials and Methods: This case–control study included 53 maintenance HD patients and 48 age- and sex-matched healthy controls recruited at Qazvin Velayat hospital between December 2024 and September 2025. Demographic and anthropometric data were recorded, and all participants underwent multi-frequency bioimpedance analysis and standardized ultrasonographic assessment of IVC diameters (maximum and minimum) and collapsibility index (categorical < 50% versus > 50%). Statistical comparisons between HD and control groups, as well as regression analyses of the association between HD status and IVC indices, were performed using SPSS version 27.
Results: Among the evaluated markers of volume status, HD status was associated with larger IVC diameters and reduced collapsibility compared with healthy individuals. In linear regression models, HD was associated with an increase of 4.02 mm in maximum IVC diameter (95% confidence interval [CI]: 2.76–5.27) and 4.29 mm in minimum diameter (95% CI: 2.86–5.71). In addition, in logistic regression analysis, HD patients had higher odds of having a collapsibility index below 50%, with an odds ratio of 3.07 (95% CI: 1.24–7.62), indicating a substantially greater likelihood of reduced vena cava collapsibility in this group.
Conclusion: These results indicate that HD patients have a pattern of larger IVC diameters and reduced collapsibility compared with healthy individuals, supporting IVC ultrasound indices as practical noninvasive markers of volume overload in this population.

Original

Implication for health policy/practice/research/medical education:
The results demonstrated that hemodialysis status emerged as a predictor of altered inferior vena cava (IVC) geometry and dynamics compared with healthy individuals, being significantly associated with larger maximum and minimum IVC diameters as well as a lower collapsibility index, which together reflect a relatively higher intravascular volume state and diminished respiratory variation in venous return among patients receiving hemodialysis.
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Introduction

Hemodialysis (HD) is the predominant form of renal replacement therapy (RRT) for patients with end-stage kidney disease (ESKD), a condition associated with substantial morbidity, reduced quality of life, and heavy utilization of healthcare resources (1,2). The global prevalence of treated ESKD has risen steadily over the past two decades, driven by increasing rates of diabetes mellitus, hypertension, and an ageing population, with HD accounting for the majority of RRT modalities in most countries (3). Cardiovascular disease (CVD) represents the leading cause of death in HD patients, with CVD-related mortality estimated to be approximately 20 times higher than in the general population, partly attributable to chronic volume overload, uremic cardiomyopathy, and persistent hypertension (4-6). Accurate management of volume status, particularly the determination of the patient's dry weight, remains one of the most critical yet challenging aspects of HD care, as both fluid overload and volume depletion are independently associated with increased all-cause and cardiovascular mortality (5-8). Clinical assessment of dry weight based on blood pressure, edema, and symptoms has well-recognized limitations and is subject to considerable inter-observer variability, underscoring the need for more objective, non-invasive methods (8-10).

The inferior vena cava (IVC) is a highly compliant vessel that carries approximately more than half of systemic venous return to the right atrium, making its diameter and respiratory variations sensitive surrogates of central venous pressure (CVP) and intravascular volume (10,11). Point-of-care ultrasonographic measurement of IVC diameter, including the collapsibility index during spontaneous respiration and the distensibility index during mechanical ventilation, has been widely studied as a non-invasive, bedside method for assessing volume status in emergency and critical care settings (12). Despite these promising findings, important limitations exist, including intra- and inter-observer variability, the influence of cardiac function, respiratory effort, and intra-abdominal pressure on IVC measurements.

In HD patients, the IVC diameter and its collapsibility index have been explored as tools for guiding ultrafiltration and adjusting dry weight prescriptions, given their ability to reflect acute changes in intravascular volume during dialysis sessions (13,14). Comparison of IVC indices in HD patients has demonstrated that pre-dialysis HD patients typically exhibit significantly lower collapsibility indices due to volume overload compared to post-dialysis patients (14). Nevertheless, establishing standardized reference values for IVC indices across different patient populations and comparing these parameters between HD patients and healthy individuals in a controlled design remains an important unresolved question that warrants further investigation.

Objectives

The primary objective of this study was to compare IVC diameter and collapsibility indices between HD patients and healthy individuals to evaluate their utility as noninvasive markers of volume status in the HD population. A secondary objective was to examine the association between HD status and these IVC indices using regression models.

Materials and Methods

Study design and participants

The study was designed as a case–control investigation conducted at Qazvin Velayat hospital, an academic center affiliated with Qazvin university of medical sciences, from December 2024 to September 2025. Participants included 53 patients receiving maintenance HD and 48 age- and sex-matched healthy individuals without known kidney disease, who served as the control group.

Inclusion and exclusion criteria

For this case–control study, inclusion criteria for the HD group were adults receiving maintenance HD at Qazvin Velayat hospital for a stable period, with regular thrice-weekly sessions for at least three months and the ability to provide informed consent. Healthy controls were age- and sex-matched adults without known kidney disease, cardiovascular instability, or other conditions affecting volume status, recruited from the hospital community, with providing informed written consent. Exclusion criteria for both groups included unwillingness to continue participation at any stage of the study, incomplete collection of demographic or clinical data, and failure to obtain adequate IVC sonographic measurements.

Group classification

Group classification was based on HD status, with participants allocated to either the HD group or the healthy control group according to their clinical condition. The HD group comprised patients receiving maintenance HD (n = 53), whereas the control group included individuals without known kidney disease or need for dialysis (n = 48), who served as a reference for comparison of IVC indices and bioimpedance parameters.

Data collection

Data were collected prospectively using a structured case–control protocol. For all participants, demographic and anthropometric information, including age, sex, and body mass index (BMI), was recorded at enrollment, and body composition and hydration status were evaluated using multifrequency bioimpedance analysis to estimate total body water and the lean and fat compartments. In HD patients, assessments were scheduled immediately before the midweek dialysis session to reflect typical peak interdialytic volume status. Transthoracic ultrasonography was then used to assess IVC dimensions. With the subject in the supine position, the IVC was imaged in a subcostal long-axis view just distal to its junction with the right atrium, and the maximal diameter during quiet end-expiration and minimal diameter during inspiration were measured to calculate the collapsibility index as the relative change in diameter between expiration and inspiration. For part of the analysis, IVC collapsibility was also treated as a categorical variable, distinguishing high from low collapsibility according to published cut-offs commonly used to approximate lower versus higher CVP states.

Outcome measurement

Outcome measurement in this study focused on ultrasonographic indices of the IVC, including maximum and minimum diameters and the collapsibility index, which were obtained using a standardized ultrasound protocol in both HD patients and healthy controls and subsequently compared between the two groups.

Statistical analysis

Statistical analyses were conducted using SPSS software, version 27 (IBM Corp., Armonk, NY, USA). The Kolmogorov–Smirnov test was applied to assess the normality of continuous variables, and because parametric and nonparametric methods produced similar results, parametric tests were preferentially used for their greater statistical efficiency. Between-group comparisons of continuous variables were performed with the independent t-test, while categorical variables were analyzed using the chi-square test. To examine the association between HD status and IVC diameters, linear regression models were fitted, and the relationship between HD status and collapsibility index categories was evaluated using binary logistic regression.

Results

The results indicated that the gender distribution was comparable between HD patients and healthy individuals, with similar proportions of men and women in both groups, suggesting no meaningful sex-based imbalance between cases and controls. Age and body mass index were also closely matched, suggesting that the two groups were similar in terms of general demographic and anthropometric characteristics. Likewise, indices derived from bioimpedance analysis, including total body water, lean body mass, body fat mass, and impedance, showed no notable differences between HD patients and healthy controls, indicating that overall body composition and electrical properties were largely comparable across the study groups (Table 1).

Compared with healthy individuals, HD patients more frequently exhibited a lower collapsibility index, indicating a relative predominance of reduced respiratory variability in IVC diameter in this group. In addition, both the maximum and minimum diameters of the IVC were larger in HD patients than in healthy controls, suggesting a higher intravascular volume status among patients undergoing HD (Table 2).

The regression analysis indicated that, compared with healthy individuals, being on HD is independently associated with larger maximum and minimum IVC

Table 1. Comparison of demographic characteristics and bioimpedance indices among HD patients and healthy individuals

Variable		Healthy controls (n = 48)	HD patients (n = 53)	*P* value
Qualitative variables, N (%)				
Gender	Male (n = 70)	34 (48.6)	36 (51.4)	0.752*
	Female (n = 31)	14 (45.2)	17 (54.8)	
Quantitative variables (Mean ± SD)				
Age (years)		63.17 ± 11.91	64.04 ± 11.83	0.713**
BMI (kg/m^2)		25.89 ± 5.95	26.44 ± 3.61	0.574**
Total body water (L)		37.94 ± 7.58	39.16 ± 6.99	0.403**
Lean body mass (kg)		54.84 ± 8.32	53.68 ± 9.89	0.531**
Mass of body fat (kg)		15.63 ± 5.62	16.23 ± 7.42	0.653**
Impedance (Ω)		359.45 ± 49.70	368.96 ± 79.58	0.479**

HD: hemodialysis; SD: Standard deviation. *Chi-square, **Independent T-test.

Table 2. Comparison of IVC diameter and collapsibility indices among HD patients and healthy individuals

Variable		Healthy controls (n = 48)	HD patients (n = 53)	*P* value
Qualitative variables, N (%)				
Collapsibility index	>50% (n = 70)	39 (55.7)	31 (44.3)	0.013*
	<50% (n = 31)	9 (29)	22 (71)	
Quantitative variables (Mean ± SD)				
IVC Max diameter (mm)		15.19 ± 2.16	19.21 ± 3.87	<0.001**
IVC Min diameter (mm)		6.22 ± 1.57	10.54 ± 4.73	<0.001**

HD: hemodialysis; IVC: Inferior vena cava; SD: Standard deviation. *Chi-square, **Independent T-test.

Table 3. The association between being on HD with IVC diameter and collapsibility indices

HD compared to healthy individuals			
IVC diameter indices			
	B	**95% CI**	***P* value***
IVC Max diameter (mm)	4.02	2.76 – 5.27	<0.001
IVC Min diameter (mm)	4.29	2.86 – 5.71	<0.001
Collapsibility indices			
	OR	**95% CI**	***P* value****
Collapsibility >50%		Ref (1)	
Collapsibility <50%	3.07	1.24 – 7.62	0.015

IVC: Inferior vena cava; OR: Odds ratio; B: Unstandardized coefficients; CI: Confidence interval. *Linear regression, **Binary logistic regression.

diameters. Furthermore, HD status is associated with a higher likelihood of having a lower collapsibility index, indicating that patients undergoing HD are more prone to reduced IVC collapsibility than healthy controls (Table 3).

Discussion

The results demonstrated that maintenance HD patients exhibit significantly larger IVC diameters and markedly reduced collapsibility compared with healthy controls. The HD status was associated with a 4.02 mm increase in maximum IVC diameter and a 4.29 mm increase in minimum IVC diameter. Furthermore, results revealed that HD patients carried an approximately 3-fold greater odds of exhibiting a collapsibility index below 50%, a threshold widely recognized as indicative of elevated right atrial pressure and reduced venous compliance. These findings collectively support the clinical utility of ultrasonographic IVC assessment as a practical, non-invasive marker of volume overload in the HD population. The observation of enlarged IVC diameters in HD patients is consistent with the well-established pathophysiology of fluid accumulation in ESKD; patients with ESKD undergoing maintenance HD are unable to maintain sodium and water homeostasis independently, leading to progressive extracellular volume expansion between dialysis sessions (7). Since the IVC is a highly compliant, valveless retroperitoneal vessel responsible for a substantial proportion of systemic venous return, changes in circulating volume are directly reflected in IVC caliber; thus, an enlarged IVC diameter therefore serves as a surrogate for elevated CVP and intravascular volume overload (8). The current findings align with those of Brennan et al, who reported that a dilated IVC (diameter > 2.1 cm) was identified in approximately 50% of HD outpatients and was associated with higher left ventricular mass index and lower left ventricular ejection fraction, reflecting the cumulative cardiac consequences of chronic volume excess (15). Similarly, the early foundational work by Cheriex et al established that IVC echography is a simple and reliable tool for estimating dry weight in HD patients, with IVC diameter and collapsibility providing clinically meaningful information about intravascular volume (16).

Previous investigations have further documented that a dilated IVC at pre-dialysis measurement is a common and clinically significant finding, rather than an incidental observation. In a previous study, Katzarski et al demonstrated in a critical evaluation of 35 HD patients that IVC diameter was larger in hypertensive compared with normotensive patients and decreased in parallel with blood volume during ultrafiltration, confirming that IVC dimensions respond dynamically to intravascular fluid changes in this population (17). Meanwhile, Mandelbaum and Ritz examined 86 healthy controls and reported wide normal variation in IVC diameters, establishing that an IVC diameter above the 95th percentile of normal correlated with an elevated CVP (> 12 cmH_2O) in overhydrated HD patients, underscoring the diagnostic relevance of defining reference values through healthy comparators, a methodological strength shared by the present study (10). The use of a well-matched healthy control group in the current investigation is particularly important, as it provides a direct empirical reference for the magnitude of IVC enlargement attributable to the HD-associated volume burden, rather than relying on assumed population norms.

Beyond absolute IVC diameter, the collapsibility index, defined as the proportional reduction in IVC diameter during inspiration, is a key dynamic parameter reflecting right atrial pressure and preload status (18). A collapsibility index below 50% is broadly consistent with elevated right atrial pressure and reduced venous compliance, as endorsed by current American Society of Echocardiography and European Association of Cardiovascular Imaging guidelines, which associate an IVC diameter > 2.1 cm combined with < 50% inspiratory collapse with a right atrial pressure of 10–20 mm Hg (8,19). The present study found that HD patients were approximately three times more likely to exhibit a collapsibility index below 50%, strongly supporting the presence of chronic intravascular volume expansion in this group relative to healthy individuals. This finding is consistent with prior literature specifically examining IVC collapsibility in HD cohorts. Al-Saray et al, in a study of Iraqi maintenance HD patients, reported that 93% of subjects had IVC collapsibility below 50%, with the IVC-collapsibility index identified as the most prevalent sign of excess volume, more sensitive than isolated IVC diameter measurement or clinical examination alone; although this study lacked a healthy comparison group, its findings converge with the current data in identifying reduced collapsibility as a near-universal feature of volume overload in this population (20). Similarly, Kaptein et al have reported that reduced IVC collapsibility independently guides fluid removal in critically ill patients on continuous ultrafiltration, with collapsibility below 20% serving as an optimal cutoff for predicting net ultrafiltration achievement during HD (21). The higher OR of 3.07 observed in the present study suggests that, even when using the broader threshold of below 50%, HD patients are significantly distinguishable from healthy individuals.

The collapsibility index is influenced not only by volume status but also by cardiac function, intrathoracic pressure, respiratory effort, and intra-abdominal pressure (8). Nevertheless, in a controlled setting with spontaneously breathing participants undergoing standardised ultrasonographic assessment, as employed in the current study, the IVC-collapsibility index retains meaningful discriminatory power. Brennan et al reported that, among outpatient HD patients assessed with hand-carried ultrasound, IVC collapsibility correlated with dry weight targets and practice variation in volume management, further establishing its relevance in routine dialysis care (15).

The clinical importance of accurate volume status assessment in HD patients cannot be overstated. Fluid overload is a major driver of hypertension, left ventricular hypertrophy, heart failure, pulmonary congestion, and both cardiovascular and all-cause mortality in this population (7,22). Large observational studies have confirmed that chronic fluid overload, as measured by bioimpedance spectroscopy, is independently associated with nearly double the risk of death; Wu et al, in a cohort of 241 maintenance HD patients, demonstrated that a dilated IVC (≥ 1.5 cm) was associated with significantly higher rates of all-cause mortality, cardiovascular mortality, and major adverse cardiovascular events (MACE), with adjusted hazard ratios of 2.88 and 3.42 for mortality and MACE, respectively (23). These findings contextualize the clinical importance of the IVC enlargement documented in the present study and highlight the potential prognostic value of routinely monitoring IVC indices in dialysis patients.

While bioimpedance spectroscopy and lung ultrasound have been increasingly validated as volume monitoring tools in the HD setting, IVC ultrasonography offers the advantage of providing direct structural and dynamic information about venous filling that complements these methods. In the context of point-of-care ultrasound, IVC assessment can be performed rapidly at the bedside with minimal training, providing real-time information to guide clinical decision-making regarding ultrafiltration targets (24). Patel et al, in a comprehensive review of modern fluid management tools in dialysis, emphasized that combining echocardiographic IVC assessment with other methods such as lung ultrasound and bioimpedance analysis allows for a more individualized and comprehensive approach to volume management than any single modality alone (25).

A notable strength of the present study is the use of a healthy age- and sex-matched control group, which provides a direct empirical comparison rarely reported in previous IVC studies in HD (14,23,26). Much of the existing literature has examined pre-to-post dialysis changes in IVC parameters within HD cohorts without a healthy comparator (14) or has assessed associations with clinical outcomes without defining normative reference values (23,26). By including 48 healthy individuals as controls undergoing identical ultrasonographic assessment, the present study quantifies the absolute magnitude of IVC enlargement and collapsibility impairment attributable to HD-associated volume excess in a rigorously controlled framework. This design strengthens the inferential validity of the regression-based estimates and supports the robustness of the associations identified.

In summary, the findings of this case–control study demonstrate that maintenance HD patients exhibit significantly larger IVC diameters and substantially reduced collapsibility compared with healthy controls, reflecting the chronic intravascular volume burden characteristic of ESKD. Linear regression models identified HD status as a predictor of both maximum and minimum IVC diameter enlargement, while logistic regression confirmed a threefold-elevated odds of IVC collapsibility below 50%, a threshold indicative of elevated right atrial pressure, in the HD group. These results are consistent with the existing body of literature documenting the prevalence and clinical significance of IVC dilation and reduced collapsibility in this population. The data support the incorporation of bedside IVC ultrasound assessment as a practical, non-invasive adjunct to clinical evaluation and established volume monitoring methods in the routine management of HD patients. Future prospective studies with longitudinal IVC measurements, larger sample sizes, and multi-centre designs are warranted to further validate these findings and to establish standardised IVC-based thresholds for guiding dry weight adjustment and ultrafiltration prescriptions in this high-risk population.

Conclusion

These findings indicate that HD status is strongly associated with a characteristic pattern of IVC enlargement and reduced collapsibility, consistent with a higher intravascular volume load compared with healthy individuals. This suggests that IVC diameter and collapsibility indices can serve as useful noninvasive markers for distinguishing the volume status of HD patients from that of healthy controls and may complement bioimpedance measures in the clinical assessment of fluid status in this population.

Limitations of the study

First, IVC ultrasonography is subject to inter-observer and intra-observer variability, influenced by operator experience, patient body habitus, intestinal gas, and the precise anatomical site of measurement. Second, the IVC-collapsibility index may be confounded by concurrent cardiac dysfunction, including right ventricular failure, tricuspid regurgitation, or diastolic dysfunction, which are prevalent comorbidities in HD patients and may independently reduce IVC collapsibility regardless of volume status. Third, the study did not assess longitudinal changes in IVC parameters before and after HD sessions, which would have provided additional evidence for the responsiveness of these indices to acute volume change. Finally, although both groups were age- and sex-matched, other potential confounders such as comorbidities, medications, residual renal function, and precise fluid intake were not fully controlled, which may have influenced hydration-related measurements.

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Authors' contribution

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Writing–original draft: All authors.
Writing–review and editing: All authors.

Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of generative artificial intelligence (AI) and AI-assisted technologies in the writing process

While preparing this work, the authors utilized AI (Perplexity and Grammarly) to refine grammar points and language style. Subsequently, they thoroughly reviewed and edited the content as necessary, assuming full responsibility for the publication's content.

Ethical issues

The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants or their legally authorized representatives. The study was carried out at Velayat Hospital in Qazvin and was approved by the Ethics Committee of Qazvin University of Medical Sciences, Iran (ethical code: IR.QUMS.REC.1403.335; https://ethics.research.ac.ir/form/yqqodusnrcmkdhnq.pdf), registered on November 27, 2024. Besides, the authors have ultimately observed ethical issues (including plagiarism, data fabrication, and double publication).

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