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Original Article

C-Reactive Protein and D-Dimer Levels among Patients with End-Stage Renal Disease on Maintenance Hemodialysis: A Cross-Sectional Study

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Abstract
End-stage renal disease patients on maintenance hemodialysis exhibit a persistent pro-inflammatory and pro-thrombotic state that significantly increases cardiovascular morbidity and mortality. This study aimed to determine the prevalence of elevated CRP and D-dimer in hemodialysis patients in Zawia, Libya, and examine their associations with age, sex, dialysis vintage, and major comorbidities. A cross-sectional study was conducted at Zawia Kidney Hospital between March and May 2026, enrolling 91 adult maintenance hemodialysis patients. Pre-dialysis venous blood samples were collected and analyzed for serum CRP and plasma D-dimer. Kruskal-Wallis and Mann-Whitney U tests, Pearson and Spearman correlations, and chi-square tests were applied, with significance set at $p < 0.05$. Elevated D-dimer (>0.5 mg/L) was detected in 79.1% of patients, while elevated CRP (>10 mg/L) was present in only 11.0%. Neither biomarker correlated significantly with dialysis vintage. D-dimer levels varied significantly across age groups ($p = 0.041$), with the 30–45-year group recording the highest values (mean 5.61 mg/L) — exceeding even older age groups. Cardiac disease was the only comorbidity independently associated with D-dimer elevation (OR = 3.23; $p = 0.047$). D-dimer elevation is near-universal among hemodialysis patients, while CRP elevation remains infrequent. Younger patients exhibited disproportionately elevated D-dimer levels, suggesting more aggressive underlying disease. Cardiac comorbidity was the principal driver of coagulation activation. Age-stratified analysis and cardiac risk assessment are essential when interpreting coagulation biomarkers in this population.
Keywords. End-stage Renal Disease, Hemodialysis, C-reactive Protein, D-dimer, Inflammation.

Introduction

Chronic kidney disease (CKD) represents one of the most consequential non-communicable diseases of the contemporary era. According to the Global Burden of Disease Study 2023, an estimated 788 million adults worldwide were living with CKD, corresponding to an age-standardised prevalence of 14.2% — more than double the figure recorded in 1990 [1]. CKD was identified as the ninth leading cause of death globally in 2023, accounting for approximately 1.48 million deaths, and impaired kidney function was attributable to 11.5% of all cardiovascular deaths [1]. The epidemiological burden is particularly pronounced in the North Africa and Middle East region, which carries the highest age-standardised CKD prevalence worldwide at 18.0%, underscoring the disproportionate impact on populations in this geographic zone [1].

End-stage renal disease (ESRD), the terminal stage of CKD, necessitates renal replacement therapy, of which maintenance hemodialysis (HD) is the most widely utilised modality globally. The cardiovascular mortality risk in hemodialysis patients is 10- to 20-fold higher than that of the general population, and in younger dialysis patients (25–35 years), this disparity reaches an extraordinary 500-fold excess [2]. In Libya, the prevalence of dialysis-treated ESRD has been reported at approximately 624 per million population, with diabetes mellitus and hypertension constituting the predominant aetiologies, and regional variation in incidence rates reflecting the heterogeneity of healthcare provision across the country [3]. Despite these figures, locally derived data on the biochemical and haemostatic profile of Libyan hemodialysis patients remain scarce.

Patients on maintenance hemodialysis are subjected to a persistent state of systemic inflammation arising from a convergence of pathophysiological mechanisms. These include the retention and systemic circulation of uraemic toxins, oxidative stress generated by an imbalance between reactive oxygen species production and antioxidant defence, recurrent bacteraemia originating from vascular access sites, and the bioincompatibility reactions triggered by blood contact with synthetic dialysis membranes [4]. The latter mechanism involves complement activation, leukocyte priming, and cytokine release — collectively perpetuating a state of low-grade chronic inflammation that accelerates atherogenesis, promotes endothelial dysfunction, and amplifies cardiovascular risk [5].

C-reactive protein (CRP), the prototypical acute-phase reactant synthesised by hepatocytes under interleukin-6 transcriptional control, serves as the most widely employed clinical indicator of systemic inflammation in ESRD. In hemodialysis patients, CRP has demonstrated robust prognostic utility: elevated CRP levels have been independently associated with a 2.7- to 5.5-fold increase in two-year all-cause mortality and a comparable elevation in cardiovascular mortality risk [6]. Although CRP is not a direct causative factor in cardiovascular pathology, its strong predictive power derives from its reflection of underlying inflammatory processes — including vascular endothelial injury, cytokine dysregulation, and plaque instability — that drive incident cardiovascular events in this population [7].

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In parallel with inflammatory dysregulation, haemostatic disturbances are a cardinal feature of the uraemic state. D-dimer, a soluble fibrin degradation product generated by the sequential action of thrombin, factor XIIIa, and plasmin on cross-linked fibrin clots, serves as a sensitive in vivo marker of simultaneous coagulation activation and fibrinolysis [8]. In hemodialysis patients, multiple converging mechanisms promote D-dimer elevation: endothelial injury impairs the physiological anticoagulant surface, vascular access devices and the extracorporeal circuit directly activate the contact pathway of coagulation, and the chronic uraemic milieu reduces endogenous anticoagulant factors while enhancing platelet reactivity [9]. Importantly, D-dimer itself has been shown to stimulate monocyte release of interleukin-1β and interleukin-6, establishing a bidirectional feedback loop between coagulation activation and systemic inflammation [10].

The interplay between inflammation, coagulation activation, and comorbid disease burden in hemodialysis patients is further modulated by patient-specific characteristics including age, sex, and the nature of concurrent conditions. Cardiac comorbidity — encompassing ischaemic heart disease, heart failure, and valvular disease — is particularly prevalent in ESRD and may independently amplify coagulation activation through haemodynamic stasis, neurohormonal dysregulation, and endothelial injury [11]. The role of patient age introduces additional complexity: while D-dimer concentrations are known to rise with advancing age in the general population due to age-related changes in the microcirculation and coagulation system [12], the pattern in hemodialysis patients may diverge substantially, as younger patients who reach ESRD often represent a phenotype of particularly aggressive underlying renal and vascular disease [13].

Despite the established clinical relevance of CRP and D-dimer in ESRD, considerable uncertainty persists regarding their distribution across age strata, the relative contribution of specific comorbid conditions to their elevation, and the extent to which dialysis vintage independently drives these biomarker profiles. Furthermore, data characterising inflammatory and coagulation biomarkers in maintenance hemodialysis patients in Libya and the broader North African region remain sparse [14]. Addressing this evidence gap is particularly timely, given that the North Africa and Middle East region carries the highest age-standardised CKD prevalence globally [1], and that locally derived data are essential to inform appropriate risk stratification and clinical decision-making. The present study was therefore designed to characterise the prevalence of elevated CRP and D-dimer in a cohort of maintenance hemodialysis patients at a tertiary renal centre in Zawia, Libya, and to systematically evaluate their associations with dialysis vintage, patient age, sex, and major comorbidities — including hypertension, diabetes mellitus, and cardiac disease. In doing so, this work aims to provide regionally relevant evidence to inform the clinical management of inflammatory and prothrombotic risk in this high-burden patient population.

Materials And Methods

Study design and setting

This is a hospital-based cross-sectional observational study conducted at the Hemodialysis Unit of Zawia Kidney Hospital, Zawia, Libya, during May and June 2026. Zawia Kidney Hospital is a tertiary referral centre for renal replacement therapy serving the north-western region of Libya. The cross-sectional design was selected as appropriate for estimating the prevalence of biomarker elevation and characterising its associations with clinical and demographic determinants at a single time point.

Study population and eligibility criteria

The study population comprised adult patients (≥18 years of age) receiving maintenance hemodialysis therapy for a minimum of three months at Zawia Kidney Hospital. The three-month minimum was applied to ensure haemodynamic and biochemical stability following the initiation of dialysis. Patients were excluded if they had: (i) active infection or acute inflammatory illness at the time of enrolment, as confirmed by clinical assessment and the treating physician; (ii) a known diagnosis of active malignancy; (iii) a history of major surgery or hospitalisation within the 30 days preceding enrolment; or (iv) a dialysis vintage of less than three months. These exclusion criteria were applied to minimise confounding of CRP and D-dimer measurements by acute precipitants unrelated to the chronic maintenance hemodialysis state. A total of 91 patients met the eligibility criteria and were included in the final analysis.

Clinical and demographic data collection

Structured data collection was performed by trained clinical personnel using a standardised case report form. Data obtained from medical records and direct patient interview included: age (recorded in years and categorised into four groups: 18–29, 30–45, 46–59, and ≥60 years), sex, dialysis vintage (defined as the total duration of maintenance hemodialysis therapy in months from initiation to the date of enrolment), and the presence of major comorbid conditions. Comorbidities of interest were diabetes mellitus, hypertension, and cardiac disease. The comorbidity burden was assessed by recording the number and type of concurrent conditions for each patient.

Blood sampling and laboratory analysis

Pre-dialysis venous blood samples were obtained from each eligible patient immediately prior to the midweek hemodialysis session. This sampling time point was selected in accordance with standard practice to minimize dialysis-related acute fluctuations in biomarker concentrations and to obtain measurements reflective of the steady-state inter-dialytic period [15]. A trained laboratory technician under strict aseptic conditions using standard venipuncture technique

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collected all samples. Approximately five milliliters of venous blood was obtained using appropriate vacutainer tubes: serum separator tubes (gold-top) for CRP analysis and sodium citrate tubes (blue-top, 3.2% buffered) for D-dimer determination.

All blood samples were processed and transported under controlled temperature conditions to the Jama'a Altib Clinical Laboratory, Zawia, Libya, where analyses were performed. Serum CRP concentrations were measured using a human CRP enzyme-linked immunosorbent assay (ELISA) kit, performed strictly according to the manufacturer's instructions. Plasma D-dimer concentrations were determined using a latex-enhanced immunoturbidimetric assay on a Mindray BS-series automated biochemistry analyser, employing the Mindray D-dimer reagent kit, in accordance with the manufacturer's specifications. All assays were performed within the recommended time intervals from sample collection. The reference threshold for elevated CRP was defined as >10 mg/L, with additional analysis at >5 mg/L. The reference threshold for elevated D-dimer was >0.5 mg/L (the conventional clinical threshold), with secondary analysis at the more conservative threshold of >1.0 mg/L.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (version 26.0; IBM Corp., Armonk, NY, USA). Normality of continuous variables was assessed using the Kolmogorov-Smirnov test, and all primary outcome variables (CRP and D-dimer) were found to deviate significantly from normality, consistent with the characteristically skewed distributions reported for these biomarkers in ESRD populations. Continuous variables are therefore presented as median (interquartile range, IQR) alongside mean ± standard deviation (SD). Categorical variables are reported as frequencies and percentages.

Associations between continuous biomarker levels and dialysis vintage were assessed using both Pearson's product-moment correlation coefficient (to characterise the linear relationship) and Spearman's rank-order correlation coefficient (as the non-parametric complement appropriate to non-normally distributed data). Comparisons of CRP and D-dimer levels between two independent groups (male vs. female) were performed using the Mann-Whitney U test. For comparisons across four independent age groups, the Kruskal-Wallis H test was employed as the non-parametric equivalent of one-way analysis of variance; where the omnibus test reached statistical significance, post-hoc pairwise comparisons were conducted using Mann-Whitney U tests with Bonferroni correction applied to control the family-wise error rate (adjusted $\alpha = 0.0083$ for six pairwise comparisons). Associations between dichotomous biomarker variables (high vs. normal) and categorical comorbidity data were evaluated using Pearson's chi-square test or Fisher's exact test where cell counts were fewer than five, and odds ratios with 95% confidence intervals were calculated. A two-tailed p-value of <0.05 was considered statistically significant for all primary analyses.

Ethical considerations

This study was approved by Biosafety and Bioethics Committee of Libyan Medical Research Center, Zawia, Libya (approval reference: NBC:018.H.26.113). Informed consent was obtained from all participants prior to enrolment. Patient data were anonymised before analysis, and all records were stored securely in accordance with applicable institutional data protection standards. Participation was entirely voluntary, and patients were assured that their decision to participate or withdraw would not affect the standard of their clinical care.

Results

Cohort Characteristics And Prevalence Of Elevated Biomarkers

Of the 91 patients included in the final analysis, 26 (28.6%) were male and 65 (71.4%) were female. By age, the cohort was distributed across four groups: 18–29 years (n = 5, 5.5%), 30–45 years (n = 22, 24.2%), 46–59 years (n = 32, 35.2%), and ≥60 years (n = 32, 35.2%), with the two older groups each representing slightly over one-third of the sample. Elevated D-dimer (>0.5 mg/L) was detected in 72 patients (79.1%), whereas elevated CRP (>10 mg/L) was observed in only 10 patients (11.0%). Both markers were simultaneously elevated in 10 patients (11.0%). Using alternative thresholds, CRP exceeded 5 mg/L in 47.3% of patients, and D-dimer exceeded 1.0 mg/L in 50.5% (Table 1).

Table 1. Prevalence of elevated CRP and D-dimer in the hemodialysis cohort (n = 91)

Marker	Threshold	n / Total	Prevalence
D-dimer elevated	>0.5 mg/L	72 / 91	79.1%
D-dimer elevated	>1.0 mg/L	46 / 91	50.5%
CRP elevated	>10 mg/L	10 / 91	11.0%
CRP elevated	>5 mg/L	43 / 91	47.3%
Both elevated	>10 & >0.5 mg/L	10 / 91	11.0%

CRP = C-reactive protein.

Correlation With Duration of Dialysis

Neither CRP nor D-dimer demonstrated a statistically significant correlation with the duration of hemodialysis therapy. Pearson and Spearman analyses for CRP yielded $r = -0.153$ ($p = 0.147$) and $\rho = -0.066$ ($p = 0.532$), respectively. For D-dimer, the corresponding values were $r = -0.029$ ($p = 0.786$) and $\rho = +0.085$ ($p = 0.425$). The correlation between CRP and

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D-dimer was also non-significant (r = −0.024, p = 0.824; ρ = +0.191, p = 0.069). Similarly, dialysis duration did not differ significantly across age groups (Kruskal-Wallis H = 1.763, p = 0.623), with mean durations of 93.6, 84.0, 71.4, and 68.8 months for the 18–29, 30–45, 46–59, and ≥60 year groups, respectively.

Gender differences

Male patients (n = 26) had a mean CRP of 6.52 ± 5.07 mg/L and mean D-dimer of 1.81 ± 2.51 mg/L, compared with 10.06 ± 26.95 mg/L and 3.27 ± 7.75 mg/L, respectively, in female patients (n = 65). No statistically significant gender difference was identified for CRP (p = 0.177) or dialysis duration (p = 0.625). D-dimer levels approached but did not reach statistical significance (p = 0.067), with females demonstrating a higher median D-dimer (1.20 vs. 0.75 mg/L). The rate of D-dimer positivity (>0.5 mg/L) was numerically greater in females (84.6% vs. 65.4%; p = 0.080) (Table 2).

Table 2. CRP and D-dimer levels by gender.

Parameter	Male (n=26)	Female (n=65)	p-value	Significance
CRP mean ± SD (mg/L)	6.52 ± 5.07	10.06 ± 26.95	0.177	NS
D-dimer mean ± SD (mg/L)	1.81 ± 2.51	3.27 ± 7.75	0.067	Trend
D-dimer median (mg/L)	0.75	1.20	—	—
High D-dimer >0.5 mg/L	65.4%	84.6%	0.080	NS
High CRP >10 mg/L	7.7%	12.3%	0.791	NS

NS = not significant. Values expressed as mean ± SD unless stated.

CRP and D-dimer levels across age groups

CRP levels did not differ significantly across age groups (Kruskal-Wallis H = 1.660, p = 0.646), nor did the prevalence of high CRP (>10 mg/L) differ by chi-square analysis (χ^2 = 4.536, p = 0.209). Although the ≥60-year group had the highest mean CRP (11.73 mg/L), this was driven by extreme outliers rather than a consistent age-related trend (Table 3). Notably, the 30–45 age group had the highest prevalence of CRP >10 mg/L (22.7%), also attributable to outliers given the non-significant omnibus test.

Table 3. CRP levels and prevalence of high CRP across age groups.

Age Group	n (%)	Mean CRP	Median CRP	CRP >10 mg/L	CRP >5 mg/L
18–29	5 (5.5%)	4.40	5.00	0.0% (0/5)	40.0% (2/5)
30–45	22 (24.2%)	6.45	3.00	22.7% (5/22)	36.4% (8/22)
46–59	32 (35.2%)	8.87	6.35	6.2% (2/32)	53.1% (17/32)
60+	32 (35.2%)	11.73	5.40	9.4% (3/32)	50.0% (16/32)

Kruskal-Wallis H = 1.660, p = 0.646 (continuous CRP); χ^2 = 4.536, p = 0.209 (CRP >10 mg/L).

In contrast, D-dimer levels showed a statistically significant association with age group. The Kruskal-Wallis test was significant for continuous D-dimer values (H = 8.272, p = 0.041), and chi-square analysis confirmed a significant association between age group and high D-dimer (>1.0 mg/L) (χ^2 = 8.460, p = 0.037) (Table 4). The distribution was non-linear: the 30–45-year group had the highest mean D-dimer (5.61 mg/L), the highest median (1.70 mg/L), and the highest prevalence of D-dimer >1.0 mg/L (72.7%), exceeding the ≥60-year group (53.1%) and the 46–59-year group (37.5%). Post-hoc pairwise Mann-Whitney U tests with Bonferroni correction (α = 0.0083) revealed no individually significant pairwise comparisons, with the 30–45 vs. 46–59 comparison yielding p = 0.026 — the closest to significance but not surviving correction. The 30–45 group's elevated mean was substantially influenced by extreme outliers, with a maximum D-dimer of 57.3 mg/L recorded in this subgroup.

Table 4. D-dimer levels and prevalence of high D-dimer across age groups.

Age Group	Mean D-d.	Median D-d.	SD	High D-d. >0.5	High D-d. >1.0*
18–29	1.46	0.30	2.44	40.0% (2/5)	20.0% (1/5)
30–45	5.61	1.70	12.33	86.4% (19/22)	72.7% (16/22)
46–59	1.75	0.80	3.29	78.1% (25/32)	37.5% (12/32)
60+	2.28	1.20	2.91	81.2% (26/32)	53.1% (17/32)

** Kruskal-Wallis H = 8.272, p = 0.041 (continuous); χ^2 = 8.460, p = 0.037 (D-dimer >1.0 mg/L). D-d. = D-dimer (mg/L).*

Association with comorbidities

Hypertension was the most prevalent comorbidity (70.3%), followed by diabetes mellitus (40.7%) and heart disease (22.8%). No statistically significant association was identified between elevated CRP (>10 mg/L) and any comorbidity (hypertension: p = 0.740; diabetes: p = 1.000; heart disease: p = 0.862). For D-dimer, heart disease showed the strongest and only statistically significant association: 71.4% of patients with heart disease had D-dimer >1.0 mg/L versus 44.2% without (OR = 3.15, p = 0.045). At the lower threshold (>0.5 mg/L), 95.2% of cardiac patients were positive versus 74.2% of

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non-cardiac patients (OR = 6.92, p = 0.062). Hypertension and diabetes showed no significant associations with D-dimer at either threshold (Table 5).

Table 5. Association between D-dimer elevation and comorbidities.

Comorbidity	With (n, %)	Without (n, %)	OR	p-value
Heart Disease (>1.0 mg/L)	71.4% (15/21)	44.2% (31/70)	3.15	0.045*
Heart Disease (>0.5 mg/L)	95.2% (20/21)	74.2% (52/70)	6.92	0.062
Hypertension (>0.5 mg/L)	79.7% (51/64)	77.7% (21/27)	1.12	1.000
Diabetes (>1.0 mg/L)	40.5% (15/37)	57.4% (31/54)	0.51	0.138

** Statistically significant (p < 0.05). OR = odds ratio. All CRP–comorbidity associations were non-significant (p > 0.05).*

Discussion

This study investigated the prevalence of elevated CRP and D-dimer levels and their associations with dialysis duration, gender, age, and major comorbidities in a cohort of 91 patients with ESRD on maintenance hemodialysis. The dominant finding was the near-universal elevation of D-dimer (79.1% at the >0.5 mg/L threshold), in stark contrast to a modest CRP elevation rate (11.0% at the >10 mg/L threshold). A statistically significant variation in D-dimer levels across age groups was observed, with the 30–45-year group demonstrating the highest levels. Cardiac comorbidity was the only factor significantly associated with D-dimer elevation. These findings collectively illuminate the complex interplay between coagulation activation, inflammation, and patient-specific clinical characteristics in ESRD.

Prevalence of elevated D-dimer and CRP

The high prevalence of D-dimer elevation observed in this study is consistent with prior reports. Gubensek et al., in a cohort of 167 maintenance hemodialysis patients, reported that D-dimer exceeded 500 µg/L (0.5 mg/L) in 75% of cases, with a median D-dimer of 966 µg/L, and that elevated D-dimer was detected in 52% of patients who had no identifiable predisposing acute illness or chronic disease [15]. The present prevalence of 79.1% falls within the upper range of published estimates and underscores the extent to which coagulation activation is a near-universal feature of the hemodialysis state. The pathophysiological basis for this is multifactorial: chronic kidney disease is characterised by a state of hypercoagulability driven by endothelial dysfunction, reduced endogenous anticoagulant activity, enhanced platelet aggregation, and impaired fibrinolysis [9], all of which are amplified by the extracorporeal circuit of dialysis itself.

The comparatively low prevalence of elevated CRP (11.0% at >10 mg/L; 47.3% at >5 mg/L) is consistent with evidence that, while inflammatory markers are chronically elevated in ESRD relative to the general population [16], their distribution is highly skewed and episodic rather than uniformly elevated. The wide interindividual variability in CRP observed in our cohort — reflected in a maximum value of 198 mg/L alongside a majority with near-normal levels — mirrors findings that the highly skewed distribution of CRP in dialysis patients reflects patient-specific precipitants such as vascular access complications, dialysis membrane bioincompatibility, or subclinical infections, rather than a globally elevated baseline [6].

Absence of CRP correlation with dialysis duration and age

Neither CRP nor D-dimer correlated significantly with the duration of hemodialysis therapy, and CRP showed no statistically significant association with age group (p = 0.646). These findings suggest that the chronicity of dialysis per se does not drive progressive CRP elevation in this population. This is supported by prior work demonstrating that comorbidity and intercurrent clinical events — rather than dialysis vintage — are the primary determinants of CRP variation over time in hemodialysis patients [17]. In the general aging literature, mild increases in CRP have been reported with advancing age [18], yet in our hemodialysis cohort this expected age-related trend appears to be obscured by the dominant influence of uremia-specific inflammatory triggers, which operate independently of chronological age.

Significant association between D-dimer and age group: a non-linear pattern

A statistically significant variation in D-dimer levels across age groups was demonstrated (Kruskal-Wallis p = 0.041; χ^2 for D-dimer >1.0 mg/L, p = 0.037). Notably, this association followed a non-linear pattern: the 30–45-year group had the highest mean D-dimer (5.61 mg/L) and the highest prevalence of D-dimer >1.0 mg/L (72.7%), rather than the oldest group. This finding is paradoxical relative to the established general population literature, in which D-dimer concentrations increase progressively with age due to age-related changes in the microcirculation, coagulation, and fibrinolysis [19], and in which age-adjusted D-dimer thresholds have been proposed specifically to account for physiologically elevated baseline levels in the elderly [12].

Counterintuitively, among hemodialysis-specific cohorts, a similar age-related rise in D-dimer in older patients has been reported by Carracedo et al., who found that older dialysis patients had significantly higher circulating concentrations of D-dimer compared to younger counterparts, with D-dimer independently associated with age in multivariate regression (β = 0.197, p < 0.001) [20]. Gubensek et al. similarly reported that age >65 years was an independent predictor of elevated D-dimer in hemodialysis patients (OR = 2.93) [15]. The divergence of the present findings from this expected pattern — with the 30–45-year group exceeding the ≥60-year group — may be explained by several factors specific to this cohort.

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First, younger patients on maintenance hemodialysis represent a distinctly high-risk phenotype. Those who develop ESRD at a younger age disproportionately carry more aggressive underlying renal disease — such as rapidly progressive glomerulonephritis, lupus nephritis, or severe diabetic nephropathy — leading to earlier initiation of dialysis and a higher burden of vascular and inflammatory disease relative to their chronological age [13]. Second, the 30–45 age group in this cohort had a longer mean dialysis vintage (84.0 months) compared to the ≥60-year group (68.8 months), suggesting more prolonged exposure to the dialysis-related prothrombotic milieu, including repeated circuit-related coagulation activation [21]. Third, the wide standard deviation in the 30–45 group (SD = 12.33) and an extreme outlier maximum of 57.3 mg/L indicate that a small number of patients with very high D-dimer levels substantially elevated the group mean, limiting the generalisability of this subgroup finding. The absence of Bonferroni-corrected pairwise significance reinforces the need for caution in interpreting age-group differences in this relatively small sample.

Gender differences

Female patients showed numerically higher D-dimer levels (median 1.20 vs. 0.75 mg/L) and a higher rate of D-dimer positivity (84.6% vs. 65.4%; p = 0.080), with a p-value of 0.067 for continuous D-dimer approaching statistical significance. These observations are consistent with recent evidence in ESRD patients that female sex is associated with a stronger prothrombotic haemostatic profile, including higher platelet counts and D-dimer levels compared to males [22]. The broader epidemiological literature confirms that women on dialysis experience disproportionately worse cardiovascular outcomes than men, suggesting underlying sex-based differences in vascular and haemostatic biology that merit further investigation [23]. The statistical non-significance in this study may partly reflect the marked sex imbalance in the cohort (65 females vs. 26 males), which limits power for sex-stratified comparisons.

Association between D-dimer and cardiac comorbidity

Heart disease was the only comorbidity significantly associated with elevated D-dimer, with patients with cardiac disease having 3.2-fold higher odds of D-dimer >1.0 mg/L (p = 0.045) and 7.3-fold higher odds at the >0.5 mg/L threshold (p = 0.062). This association is mechanistically coherent: structural cardiac disease — including heart failure, valvular disease, and ischaemic heart disease — promotes ventricular stasis, endothelial injury, and neurohormonal activation, all of which drive sustained thrombin generation and fibrin turnover as reflected in elevated D-dimer [24]. In hemodialysis patients specifically, the cardiorenal syndrome further perpetuates coagulation activation through volume overload, redox imbalance, and persistent endothelial dysfunction [11]. The specificity of the cardiac association — in the absence of significant associations for hypertension (p = 1.000) or diabetes (p = 0.138) — underscores that it is the structural and haemodynamic sequelae of overt heart disease, rather than metabolic risk factors in isolation, that most directly amplify coagulation activation in this cohort.

Absence of CRP associations with comorbidities

No significant association was identified between elevated CRP (>1.0 mg/L) and any of the three comorbidities studied. This finding is consistent with the view that CRP elevation in hemodialysis patients reflects episodic acute-phase responses to specific precipitants — such as infections, vascular access events, or acute illness — rather than chronic elevation driven by stable comorbid conditions [16]. The relatively low overall prevalence of frank CRP elevation (11.0%) in this cohort may also have constrained statistical power to detect associations of modest effect size, and a larger study would be required to assess comorbidity-specific CRP patterns definitively.

Limitations and future directions

The sample size — while adequate for prevalence estimation — limits statistical power for subgroup analyses, particularly for age groups containing few patients (e.g., n = 5 in the 18–29 group), and for sex-stratified comparisons given the imbalanced distribution. Single time-point measurement of CRP and D-dimer does not capture the within-patient variability that characterises these markers in ESRD. Data on important confounders — including vascular access type, dialysis membrane composition, anticoagulation regimen, and nutritional status — were not incorporated. Future studies should employ a prospective design with serial biomarker sampling, a larger and sex-balanced cohort, and multivariable adjustment for the full spectrum of clinical confounders, to more precisely characterise the determinants of the inflammatory and coagulation profiles of hemodialysis patients.

Conclusion

This study confirms the near-universal prevalence of D-dimer elevation in patients with ESRD on maintenance hemodialysis. It identifies a statistically significant, non-linear association between D-dimer and age group, with the 30–45-year cohort exhibiting the highest levels — a pattern that likely reflects the aggressive disease phenotype and longer dialysis vintage characteristic of younger ESRD patients. Cardiac comorbidity was the only factor significantly associated with D-dimer elevation, underscoring the central role of structural heart disease in driving coagulation activation in this population. CRP elevation was infrequent and showed no significant associations with age, dialysis duration, or chronic comorbidities, consistent with its role as an episodic rather than a chronically elevated biomarker in ESRD. These findings reinforce the complexity of the uremic prothrombotic state and highlight the importance of cardiac status and patient age in the clinical interpretation of D-dimer in hemodialysis patients.

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