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Intradialytic Hypotension in Two Sudanese Hemodialysis Centers During the 2023 Armed Conflict: A Cross-Sectional Study

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Abstract

Background

Intradialytic hypotension (IDH) is a frequent hemodialysis complication associated with symptoms, inadequate fluid removal, and adverse cardiovascular outcomes. Evidence from Sudan is limited, particularly during the health-system disruption caused by the 2023 armed conflict. This study assessed the prevalence, associated factors, clinical manifestations, and management of IDH in two Sudanese dialysis centers.

Methodology

We conducted a hospital-based, cross-sectional study from March to August 2023 among 111 adults with end-stage kidney disease receiving hemodialysis at Soba Teaching Hospital, Khartoum (n = 30), and Port Sudan Center for Dialysis and Kidney Surgery (n = 81). Data were collected using a structured interviewer-administered questionnaire. IDH was operationally defined as a decrease in systolic blood pressure of at least 20 mmHg or a decrease in mean arterial pressure of at least 10 mmHg accompanied by symptoms during hemodialysis. Associations were examined using chi-square tests and multivariable logistic regression, with p-values <0.05 considered statistically significant.

Results

IDH was reported in 74 (66.7%) participants. Among affected patients, 55 (74.3%) experienced hypotension during the third to fourth hours of dialysis. The most frequent manifestations were sweating (66.2%), fatigue (48.6%), nausea (35.1%), vomiting (32.4%), and muscle cramps (14.9%). Hypertension (p = 0.036) and low body mass (p = 0.048) were associated with IDH in bivariable analysis. After adjustment, hypertension remained independently associated with IDH (adjusted odds ratio = 2.70, 95% confidence interval = 1.09-7.80; p = 0.04). Normal saline until recovery was the only documented management strategy.

Conclusions

IDH represented a substantial clinical burden in these dialysis centers. Standardized, individualized prevention and management protocols, including careful volume assessment, ultrafiltration optimization, and systematic monitoring of high-risk patients, are warranted, particularly in resource-constrained and conflict-affected settings.

Categories: Therapeutics, Nephrology
Keywords: end-stage kidney disease, hemodialysis, intradialytic hypotension, risk factors, sudan

Introduction

Intradialytic hypotension (IDH) is among the most frequent and clinically important complications of maintenance hemodialysis. It reflects an inability to maintain adequate arterial pressure during fluid removal and may manifest with dizziness, nausea, cramps, weakness, syncope, or the need for therapeutic intervention. Reported frequency varies substantially because studies use different blood pressure thresholds, symptom requirements, and denominators; session-based estimates using commonly applied definitions are often approximately 10%-12%, although considerably higher rates are reported in selected high-risk populations [1,2]. Importantly, IDH is not merely a transient procedural event. Recurrent episodes

are associated with impaired organ perfusion, cardiovascular events, and increased mortality, and nadir systolic blood pressure appears particularly relevant to prognosis [3,4].

The pathophysiology of IDH is multifactorial. Ultrafiltration reduces circulating volume, and hypotension develops when plasma refill and cardiovascular compensatory responses cannot maintain cardiac output and vascular tone. Susceptibility is influenced by the prescribed ultrafiltration rate, interdialytic weight gain (IDWG), target weight, dialysate composition and temperature, meal intake, antihypertensive exposure, autonomic dysfunction, cardiac disease, diabetes, anemia, age, and body size [1,5]. Because several of these determinants are modifiable, prevention depends on identifying vulnerable patients and tailoring the dialysis prescription rather than relying solely on rescue treatment after blood pressure has fallen.

Contemporary guidance emphasizes individualized blood pressure and volume management, reassessment of target weight, avoidance of excessive ultrafiltration, review of medication timing, and modification of dialysis-related factors when clinically appropriate [6]. Recent evidence also supports cooler dialysate as a practical option for selected patients: a 2025 meta-analysis of 31 studies found a lower risk of IDH with cooled versus standard-temperature dialysis, although thermal discomfort was more frequent [7]. Updated reviews similarly advocate a prevention-first, multidisciplinary approach that combines prescription optimization, nutritional counseling, and selected pharmacologic or technology-assisted strategies when recurrent IDH persists [8].

These issues are particularly important in Sudan, where the armed conflict that began in April 2023 disrupted dialysis infrastructure, supply chains, transportation, staffing, and continuity of care. Reports published after the onset of the conflict describe major strain on dialysis services, frequent treatment interruptions, clinical complications, and substantial displacement among patients requiring maintenance hemodialysis [9-12]. The present study began at Soba Teaching Hospital in Khartoum shortly before the conflict and was subsequently continued at the Port Sudan Center for Dialysis and Kidney Surgery when data collection in Khartoum became unsafe. This provides a distinctive real-world view of dialysis complications during a period of acute health-system disruption.

Despite the clinical importance of IDH, Sudan-specific evidence on its burden, associated factors, manifestations, and management remains limited. The present study therefore aimed to determine the participant-level prevalence of IDH among adults receiving hemodialysis in two Sudanese dialysis centers, identify demographic and clinical factors associated with its occurrence, describe its timing and short-term manifestations, and characterize the management approaches used in routine practice.

Materials And Methods

Study design and reporting

We conducted a hospital-based, observational, cross-sectional study between March and August 2023. The study was structured in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [13].

Study setting and conflict-related relocation

The study was initiated at Soba Teaching Hospital, a university-affiliated tertiary hospital with hemodialysis services in Khartoum, Sudan, where data were collected from March 3 to April 10, 2023. Following the outbreak of armed conflict in Khartoum in mid-April 2023, data collection at Soba Teaching Hospital was interrupted because of safety and access constraints. The study was subsequently resumed at the Port Sudan Center for Dialysis and Kidney Surgery in Red Sea State, where data were collected from June 16 to August 15, 2023. The final sample therefore included 30 participants from Soba Teaching Hospital and 81 from the Port Sudan center.

Participants and eligibility criteria

The study population comprised Sudanese adults with end-stage renal disease who attended the participating hemodialysis centers during the study period. Participants were eligible for inclusion if they were older than 18 years, had end-stage renal disease requiring hemodialysis, and provided written consent to participate in the study. Children and pregnant women were excluded because of their distinct physiological characteristics and differences in blood pressure regulation, which could potentially influence the assessment of IDH and reduce comparability with the general adult hemodialysis population. Patients who declined to participate were also excluded.

Sampling, sample size and sampling method

A non-probability convenience sampling approach was used because probability-based sampling was not feasible under the exceptional security and operational constraints prevailing during the 2023 armed conflict in Sudan. At Soba Teaching Hospital in Khartoum, access to the dialysis unit and participant recruitment were curtailed by the outbreak of conflict; consequently, all 30 eligible patients available during the recruitment period were enrolled. The Port Sudan Center for Dialysis and Kidney Surgery served

approximately 210 patients; however, recruitment was restricted to the morning dialysis shift because of operational limitations. All 81 eligible patients attending that shift during the recruitment period were included. The final sample therefore comprised 111 participants, including 30 from Soba Teaching Hospital and 81 from the Port Sudan center.

Because this unexpected disruption limited prospective recruitment, the achieved sample size was determined primarily by the accessible study population rather than by a fixed recruitment target established before data collection. Nevertheless, the adequacy of the achieved sample was assessed retrospectively. Using an anticipated IDH prevalence of 11.6%, a 95% confidence level, 5% absolute precision, and an estimated source population of 240 patients across the two centers, application of the Cochran formula followed by finite-population correction yielded a minimum required sample of approximately 96 participants. The achieved sample of 111 participants therefore exceeded this estimate. A post hoc sensitivity analysis was also performed to characterize the statistical power of the achieved sample. With 111 participants, a two-sided α level of 0.05, and a 2 × 2 chi-square test, the study had approximately 81% power to detect a moderate effect size corresponding to Cohen's w of 0.27.

Data collection instrument, procedures, and operational definitions

Data were collected through direct face-to-face interviews conducted before dialysis using a structured, closed-ended questionnaire developed by the investigators. The instrument was pretested among 10 participants before full data collection. It captured demographic characteristics, comorbid conditions, dialysis history, IDWG, potential IDH-related factors, occurrence and timing of hypotension, associated symptoms or complications, and management. The same core instrument was used at both study sites. In the study protocol, IDH was defined as a decrease in systolic blood pressure of at least 20 mmHg or a decrease in mean arterial pressure of at least 10 mmHg accompanied by symptoms during hemodialysis [1,2].

Study variables

The primary outcome was the occurrence of IDH. The principal explanatory variables were age, sex, hypertension, diabetic nephropathy/diabetes mellitus, cardiovascular disease, peripheral vascular disease, severe anemia (hemoglobin ⩽8 g/dL), smoking, heavy meal intake before dialysis, duration of dialysis treatment, mean IDWG, and low body mass.

Statistical analysis

Data were analyzed using IBM SPSS Statistics version 28.0 (IBM Corp., Armonk, NY, USA). Categorical variables were summarized as frequencies and percentages. Bivariable associations between IDH and categorical explanatory variables were assessed using the chi-square test. A multivariable logistic regression model was used to evaluate independent associations with IDH while adjusting for potential confounding. Adjusted odds ratios (AORs), 95% confidence intervals (CIs), and p-values are reported. Statistical significance was defined as p-values <0.05. Because the study was cross-sectional, all regression findings were interpreted as associations rather than causal effects.

Ethical considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval (FPEC-35-2023) was obtained from the Ethical Committee of the Faculty of Pharmacy, University of Khartoum. Additional authorization was obtained from the Scientific Research Authority of the Ministry of Health. Participants received an explanation of the study purpose and procedures and provided written informed consent before participation.

Results

Participant characteristics

A total of 111 adults receiving hemodialysis were included. Most participants were male (67/111, 60.4%), and 59 (53.2%) were aged 40-60 years. Hypertension was the most frequently recorded comorbidity (95/111, 85.6%), followed by diabetic nephropathy (8/111, 7.2%), cardiovascular disease (7/111, 6.3%), and gout (7/111, 6.3%) (Table *1*). Low body mass was recorded in 38 (34.2%) participants, smoking in 34 (30.6%), and heavy meal intake before dialysis in 23 (20.7%). Nearly half of the participants (49/111, 44.1%) had been receiving dialysis for one to five years. Mean IDWG was most commonly 3 kg (41/111, 36.9%) or 2 kg (40/111, 36.0%) (Table *1*).

Characteristic	Category	n (%)
Sex	Male	67 (60.4)
	Female	44 (39.6)
Age group, years	<40	29 (26.1)
	40–60	59 (53.2)
	>60	23 (20.7)
Past medical history*	Hypertension	95 (85.6)
	Diabetic nephropathy	8 (7.2)
	Cardiovascular disease	7 (6.3)
	Gout	7 (6.3)
	Severe anemia (Hb ≤8 g/dL)	3 (2.7)
	Peripheral vascular disease	2 (1.8)
	Asthma	1 (0.9)
	None recorded	12 (10.8)
Identified factors*	Low body mass	38 (34.2)
	Smoking	34 (30.6)
	Heavy meal before dialysis	23 (20.7)
	None recorded	32 (28.8)
Duration on dialysis	<1 year	8 (7.2)
	1–5 years	49 (44.1)
	6–10 years	36 (32.4)
	>10 years	18 (16.2)
Mean IDWG	1 kg	23 (20.7)
	2 kg	40 (36.0)
	3 kg	41 (36.9)
	4 kg	7 (6.3)

TABLE 1: Demographic, clinical, and dialysis characteristics of participants (N = 111).

*: Categories were not necessarily mutually exclusive.

Hb: hemoglobin; IDWG: interdialytic weight gain

Prevalence, timing, manifestations, and management of intradialytic hypotension

IDH occurred in 74 of 111 (66.7%) participants (Table *2*). Among participants with IDH, onset was most frequently reported during the third to fourth hours of dialysis (55/74, 74.3%), whereas 18 (24.3%) reported onset during the first to second hours and one (1.4%) within the first hour (Table *2*). Sweating was the most commonly reported short-term manifestation (49/74, 66.2%), followed by fatigue (36/74, 48.6%), nausea (26/74, 35.1%), vomiting (24/74, 32.4%), and muscle cramps (11/74, 14.9%). Itching and sleep problems were each reported by two participants (2.7%) (Table *2*). Normal saline administered until recovery was the only management approach in this study.

Variable	Category	n (%)
Occurrence of IDH (N = 111)	Yes	74 (66.7)
	No	37 (33.3)
Timing among IDH cases (n = 74)	<1 hour	1 (1.4)
	1–2 hours	18 (24.3)
	3–4 hours	55 (74.3)
Short-term manifestations (n = 74)*	Sweating	49 (66.2)
	Fatigue	36 (48.6)
	Nausea	26 (35.1)
	Vomiting	24 (32.4)
	Muscle cramps	11 (14.9)
	Itching	2 (2.7)
	Sleep problems	2 (2.7)

TABLE 2: Participant-level prevalence, timing, and manifestations of IDH.

*: Multiple manifestations could be reported by the same participant.

IDH: intradialytic hypotension

Bivariable analysis

As shown in Table 3, sex and age group were not significantly associated with IDH (p = 0.272 and p = 0.406, respectively). Hypertension was more frequent among participants with IDH than among those without IDH (90.5% vs 75.7%; p = 0.036). Low body mass was also associated with IDH in bivariable analysis (40.5% vs 21.6%; p = 0.048). Diabetic nephropathy, cardiovascular disease, peripheral vascular disease, severe anemia, smoking, heavy meal intake before dialysis, and mean IDWG were not significantly associated with IDH. Duration on dialysis showed a borderline association (p = 0.051) (Table 3).

Characteristic	Category	IDH yes (n = 74), n (%)	IDH no (n = 37), n (%)	P-value
Sex	Male	42 (56.8)	25 (67.6)	0.272
	Female	32 (43.2)	12 (32.4)	
Age group	<40 years	18 (24.3)	11 (29.7)	0.406
	40-60 years	38 (51.4)	21 (56.8)	
	>60 years	18 (24.3)	5 (13.5)	
Hypertension	Yes	67 (90.5)	28 (75.7)	0.036
	No	7 (9.5)	9 (24.3)	
Diabetic nephropathy	Yes	6 (8.1)	2 (5.4)	0.604
	No	68 (91.9)	35 (94.6)	
Cardiovascular disease	Yes	6 (8.1)	1 (2.7)	0.269
	No	68 (91.9)	36 (97.3)	
Peripheral vascular disease	Yes	2 (2.7)	0 (0.0)	0.313
	No	72 (97.3)	37 (100.0)	
Severe anemia (Hb ≤8 g/dL)	Yes	2 (2.7)	1 (2.7)	1.000
	No	72 (97.3)	36 (97.3)	
Low body mass	Yes	30 (40.5)	8 (21.6)	0.048
	No	44 (59.5)	29 (78.4)	
Smoking	Yes	22 (29.7)	12 (32.4)	0.771
	No	52 (70.3)	25 (67.6)	
Heavy meal before dialysis	Yes	18 (24.3)	5 (13.5)	0.185
	No	56 (75.7)	32 (86.5)	
Duration on dialysis	<1 year	2 (2.7)	6 (16.2)	0.051
	1–5 years	32 (43.2)	17 (45.9)	
	6–10 years	26 (35.1)	10 (27.0)	
	>10 years	14 (18.9)	4 (10.8)	
Mean IDWG	1 kg	11 (14.9)	12 (32.4)	0.193
	2 kg	28 (37.8)	12 (32.4)	
	3 kg	30 (40.5)	11 (29.7)	
	4 kg	5 (6.8)	2 (5.4)	

TABLE 3: Bivariable analysis of factors associated with IDH (N = 111).

Bivariable associations between IDH and categorical explanatory variables were assessed using the chi-square test, with statistical significance at $p < 0.05$.

Hb: hemoglobin; IDH: intradialytic hypotension; IDWG: interdialytic weight gain

Multivariable logistic regression

In the adjusted model (Table *4*), hypertension was the only variable that remained statistically significantly associated with IDH (AOR = 2.70, 95% CI = 1.09-7.80; p = 0.04). Low body mass showed an elevated point estimate but was not statistically significant after adjustment (AOR = 2.79, 95% CI = 0.69-11.32; p = 0.15) (Table *4*). Heavy meal intake before dialysis (AOR = 2.64, 95% CI = 0.76-9.12; p = 0.13) and longer dialysis

duration (AOR = 1.60, 95% CI = 0.91-2.80; p = 0.10) were also not statistically significant. No significant adjusted associations were observed for sex, age, diabetes mellitus, severe anemia, cardiovascular disease, smoking, or mean IDWG (Table 4).

Variable	AOR	95% CI	P-value
Male sex	0.60	0.19-1.89	0.38
Age, years	1.02	0.99-1.04	0.29
Hypertension	2.70	1.09-7.80	0.04*
Diabetes mellitus	1.07	0.15-7.46	0.94
Severe anemia	2.22	0.11-47.02	0.61
Cardiovascular disease	3.54	0.34-37.14	0.29
Low body mass	2.79	0.69-11.32	0.15
Smoking	1.13	0.35-3.71	0.83
Heavy meal before dialysis	2.64	0.76-9.12	0.13
Duration on dialysis, years	1.60	0.91-2.80	0.10
Mean IDWG, kg	1.41	0.83-2.38	0.20

TABLE 4: Multivariable logistic regression of factors associated with IDH.

A multivariable logistic regression model was used to evaluate independent associations with IDH while adjusting for potential confounding. *: Statistically significant at p < 0.05.

AOR: adjusted odds ratio; CI: confidence interval; IDWG: interdialytic weight gain

Discussion

This study identified a substantial burden of IDH among adults receiving hemodialysis in two Sudanese centers during a period that overlapped with the onset of armed conflict. Two-thirds of participants were classified as having IDH; most episodes were reported during the third to fourth hours of dialysis, and sweating, fatigue, nausea, and vomiting were common manifestations. Hypertension and low body mass were associated with IDH in bivariable analysis, but only hypertension remained significant after multivariable adjustment. A further clinically important finding was the narrow management pattern: normal saline until recovery was the only documented strategy. Together, these findings highlight both patient vulnerability and an opportunity to strengthen protocolized prevention and management in resource-constrained dialysis services.

The participant-level prevalence of 66.7% is higher than most session-based estimates in the international literature. A systematic review and meta-analysis reported IDH in approximately 10%-12% of hemodialysis sessions when commonly used European Best Practice Guideline or nadir systolic blood pressure definitions were applied [2]. African studies have also reported lower session-level or single-session estimates, including 11.6% of sessions in Cameroon, 12.4% in Burkina Faso, and 13.4% of patients observed during a single session in Uganda [14-16]. In contrast, a recent study from Somalia reported IDH in 55% of patients using pre- and post-dialysis blood pressure changes [17]. These differences reinforce an important methodological point: prevalence depends heavily on case definition, blood pressure sampling frequency, symptom requirements, and whether the denominator is patients or dialysis sessions. The high estimate in our study should therefore be interpreted as a participant-level burden rather than directly equated with session-level incidence.

Hypertension was the only independent factor associated with IDH in the adjusted model. Participants with hypertension had approximately 2.7-fold higher odds of IDH, although the CI was wide. The relationship between chronic hypertension and intradialytic blood pressure instability is biologically plausible but complex. Long-standing hypertension may impair vascular compliance and autoregulatory responses, while the risk of IDH also depends on pre-dialysis pressure, ultrafiltration requirements, cardiac reserve, and medication timing [1,5,6]. Recent data from Somalia showed an association between higher pre-dialysis systolic pressure and IDH, whereas a Tanzanian cohort identified systolic pressure below 140 mmHg as protective against recurrent IDH [17,18]. Our finding should therefore be viewed as a context-specific association rather than evidence that hypertension alone causes IDH.

Low body mass was associated with IDH in bivariable analysis but lost statistical significance after adjustment. This pattern is compatible with the broader literature, in which lower body weight has repeatedly emerged as a marker of susceptibility to IDH [2]. However, the lack of a numerical body mass index threshold limits interpretation of this variable. Heavy meal intake before dialysis was not statistically significant in our study, although the AOR remained above unity. This contrasts with studies from Cameroon and Burkina Faso, where feeding during or around dialysis was associated with IDH [14,15]. Mean IDWG was also not significantly associated with IDH in the present cohort, despite its established relevance to ultrafiltration demand and hemodynamic stress [1,2]. The modest sample size and categorical measurement of these exposures may have reduced statistical power.

The clinical manifestations observed in our cohort are consistent with the symptomatic burden described in prospective hemodialysis studies. Kuipers et al. documented considerable variability in IDH symptoms and nursing interventions across 3,818 sessions, while Ozen and Cepken similarly reported clinically important hypotensive episodes and nursing responses across 744 sessions [19,20]. In our study, the predominance of sweating and fatigue, followed by gastrointestinal symptoms and cramps, emphasizes that IDH can substantially impair treatment tolerance even when catastrophic complications are not documented. Recurrent symptoms may also shorten or interrupt dialysis sessions and thereby compromise achievement of volume and solute removal targets.

The management finding has direct practice implications. Normal saline is a familiar acute rescue measure, but a saline-only strategy does not address the heterogeneous mechanisms that precipitate IDH. Kidney Disease: Improving Global Outcomes (KDIGO) conference conclusions emphasize individualized assessment of volume status and target weight, dialysis prescription, comorbidities, and patient symptoms [6]. Contemporary reviews recommend prevention-focused measures such as avoiding excessive ultrafiltration, reassessing dry weight, reviewing antihypertensive timing, considering meal timing, and using cooler dialysate in selected patients [5,8]. The 2025 meta-analysis by Chander et al. found that cooled dialysate reduced the risk of IDH, although at the cost of greater thermal discomfort [7]. For Sudanese centers with limited resources, standardized low-cost protocols incorporating careful blood pressure monitoring, ultrafiltration review, target-weight reassessment, and selective dialysate cooling may be more feasible than technology-intensive solutions.

A key clinical challenge in IDH is the potential for a self-perpetuating cycle involving volume assessment, target weight determination, ultrafiltration intensity, and recurrent hemodynamic instability. Accurate estimation of dry weight remains difficult when based predominantly on clinical assessment, and underestimation of target weight or the need to remove substantial interdialytic fluid accumulation within a fixed treatment period may necessitate high ultrafiltration rates that exceed plasma-refilling capacity. When IDH develops, clinicians may need to reduce or interrupt ultrafiltration and administer intravenous fluids, potentially preventing achievement of the prescribed target weight and leaving residual volume excess that increases fluid removal requirements during subsequent sessions. Repetitive IDH is clinically important because recurrent reductions in systemic and regional perfusion may result in cumulative ischemic organ injury. Hemodialysis-induced myocardial ischemia can cause regional wall-motion abnormalities and myocardial stunning, which have been associated with progressive left ventricular dysfunction and adverse cardiovascular outcomes [21]. Cerebral perfusion is also vulnerable; continuous cerebral oxygenation monitoring has demonstrated frequent intradialytic cerebral ischemic episodes, many of which occur without overt neurological symptoms [22]. The splanchnic circulation may similarly be affected, with recurrent IDH associated with an increased risk of hospitalized mesenteric ischemia [23]. Furthermore, dialysis-associated hypotension has been associated with accelerated loss of residual kidney function, which may adversely affect volume control and increase subsequent ultrafiltration requirements [21]. These observations support a prevention-oriented approach in which the therapeutic goal extends beyond the immediate correction of symptomatic hypotension to minimizing repetitive hemodynamic stress and cumulative end-organ hypoperfusion.

The armed conflict context strengthens the clinical relevance of these findings. The study was forced to move from Khartoum to Port Sudan after fighting began, directly illustrating the disruption faced by dialysis programs. Subsequent Sudanese studies documented missed dialysis sessions, reduced treatment frequency, displacement, financial barriers, and high rates of clinical complications after the conflict began [9-12]. Because stable dialysis delivery depends on reliable staffing, electricity, consumables, medications, transportation, and repeated patient attendance, conflict-related disruption can amplify the conditions that make hemodynamic management difficult. Our data do not permit attribution of IDH to the conflict itself, but they provide an early clinical snapshot from dialysis services operating during this transition.

This study has several strengths. It provides rare primary data on IDH from Sudan, includes patients from two geographically distinct dialysis centers, captures both clinical manifestations and management patterns, and uses multivariable analysis to distinguish crude from adjusted associations. The conflict-related relocation also gives the study unusual health-system relevance. Several limitations require careful consideration. The cross-sectional design precludes causal inference. The study used non-probability convenience sampling, and recruitment at the Port Sudan center was restricted to patients attending the morning dialysis shift. In addition, data collection at Soba Teaching Hospital was interrupted by the outbreak of armed conflict, resulting in unequal recruitment across the two centers. Given the non-

probability sampling strategy and restriction of recruitment to a single shift at one center, the possibility of selection bias and limited representativeness should be considered when interpreting the findings and limited the generalizability of the findings to the wider Sudanese hemodialysis population. Furthermore, some clinical histories were self-reported, and the study did not provide a detailed blood pressure measurement schedule or a numerical threshold for low body mass. Important dialysis-specific determinants, including ultrafiltration rate, dialysate temperature, target-weight assessment, antihypertensive timing, vascular access, and laboratory measures, were not comprehensively captured. Center-level differences could not be reliably examined because only 30 participants were recruited at Soba before data collection was interrupted. These limitations may explain some null associations and should temper interpretation of the effect estimates.

The clinical implication is practical: Sudanese dialysis programs should prioritize a standardized IDH pathway that identifies high-risk patients before treatment and combines structured intradialytic monitoring with individualized prevention. Such a pathway should include review of pre-dialysis blood pressure and antihypertensive use, assessment of target weight and IDWG, avoidance of unnecessarily high ultrafiltration rates, counseling on meal and fluid practices, consideration of cooler dialysate when feasible, and protocolized rescue treatment when symptomatic hypotension occurs. Prospective multicenter studies should record repeated session-level blood pressures and ultrafiltration parameters, use standardized IDH definitions, and evaluate whether these interventions reduce treatment interruptions, symptoms, hospitalization, and mortality.

Future international research on IDH should move toward individualized risk prediction, objective volume assessment, continuous physiological monitoring, and patient-centered outcomes. Standardized pre-dialysis screening tools incorporating previous IDH episodes, pre-dialysis blood pressure, IDWG, prescribed ultrafiltration rate, cardiovascular comorbidity, and medication exposure could facilitate early identification of high-risk patients. Artificial intelligence approaches may further enhance dynamic risk prediction; deep learning models based on routinely generated dialysis machine data have demonstrated promising performance [24], while recent time-series approaches incorporating Long Short-Term Memory networks and recurrence-aware modeling may improve prediction of both initial and recurrent IDH events [25]. Integration of non-invasive biosensors with closed-loop biofeedback systems represents another important research direction, allowing continuous monitoring of physiological signals and automated adjustment of ultrafiltration or other dialysis parameters in response to evolving hemodynamic instability [26]. Objective determination of volume status and dry weight also deserves greater emphasis. Multi-frequency bioimpedance spectroscopy can quantify extracellular fluid excess and has been evaluated as a tool to guide fluid management [27], whereas point-of-care lung ultrasound can detect clinically occult pulmonary congestion and support more individualized dry-weight adjustment [28]. Future trials should also evaluate individualized timing of antihypertensive medications, dialysate temperature and composition, established pharmacological approaches such as midodrine, and emerging vasoactive therapies within physiology-guided treatment strategies. Finally, progress in this field will require internationally harmonized diagnostic criteria for IDH because substantial heterogeneity persists among definitions based on blood pressure decline, absolute nadir pressure, symptoms, and clinical interventions [29]. Future studies should complement objective hemodynamic endpoints with patient-reported outcomes, including symptom burden, post-dialysis recovery, treatment tolerance, functional status, and health-related quality of life, particularly because many objectively documented hypotensive episodes may occur without corresponding patient-reported symptoms [30].

Conclusions

IDH was common among adults receiving hemodialysis in the two studied Sudanese centers, affecting 66.7% of participants. Hypertension remained independently associated with IDH after multivariable adjustment, whereas the association with low body mass was attenuated after adjustment. Most episodes occurred late in the dialysis session and were accompanied by substantial symptom burden. The exclusive documentation of normal saline as management highlights the need to move from a predominantly reactive approach toward standardized, individualized prevention and management. Dialysis services should strengthen objective volume and ultrafiltration assessment, intradialytic monitoring, medication and meal review, and feasible prescription-based interventions. Future multicenter prospective studies should evaluate objective dry-weight assessment, predictive and biofeedback technologies, individualized pharmacological and dialysate strategies, and should adopt internationally standardized session-level definitions while incorporating cardiovascular, organ-specific, and patient-reported outcomes.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

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