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Prevalence and associated factors of intradialytic hypotension among patients with kidney failure on maintenance hemodialysis at Kiruddu National Referral Hospital, Uganda

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Abstract

Background Intradialytic hypotension (IDH), a frequent hemodialysis complication, is associated with increased morbidity, reduced quality of life, and increased mortality in patients with kidney failure. However, data on the burden and associated factors of IDH in sub-Saharan African settings, including Uganda are limited. This study determined the prevalence and associated factors of IDH among patients with kidney failure attending the dialysis unit of Kiruddu National Referral Hospital (KNRH), Uganda.

Methods A cross-sectional study enrolled adult patients (aged ≥ 18 years) with kidney failure undergoing maintenance hemodialysis through arteriovenous fistula or a central venous access catheter at KNRH from November 2024 to January 2025. Each participant was recruited and observed only once, during a single hemodialysis session. Blood pressure (BP) was measured 5 min pre-, intra- (every 30 min), and 5 min post-dialysis. IDH was defined as per European Best Practice Guidelines (EBPG: systolic blood pressure [SBP] decrease > 20 mmHg or mean arterial pressure [MAP] > 10 mmHg with symptoms requiring intervention) or nadir criteria (SBP < 90 mmHg). Sociodemographic, clinical, and dialysis-related data were collected using interviewer-administered questionnaire and from medical records review. We used multivariable logistic regression to identify associated factors.

Results We enrolled 186 participants with a median age of 46.5 (inter-quartile range [IQR] = 34–58) years; 56.9% were male. Overall, 25 developed IDH for a prevalence of 13.4% (95% CI: 9–19%). EBPG and nadir definitions identified 18 (9.67%) and 19 (10.22%) cases of IDH, respectively. Heart failure (aOR = 6.41, 95% CI: 1.29–31.77, $p = 0.023$), diabetes mellitus (aOR = 4.85, 95% CI: 1.15–20.40, $p = 0.031$), and low hemoglobin (< 6 g/dL) (aOR = 6.35, 95% CI: 1.91–21.15, $p = 0.003$) were significantly associated with IDH.

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Conclusion Intradialytic hypotension was relatively common at KNRH, affecting one in ten patients with kidney failure, and was significantly associated with underlying comorbidities, including heart failure, diabetes, and severe anemia. Early identification and management of these risk factors—through optimized volume status, improved glycemic control, and correction of severe anemia—may mitigate IDH episodes and enhance outcomes for patients with kidney failure on hemodialysis. Future longitudinal studies could assess clinical and prognostic implications of IDH in this setting.

Keywords Intradialytic hypotension, Kidney failure, Hemodialysis, Prevalence, Risk factors, Uganda

Introduction

Intradialytic hypotension (IDH) is the most common complication of hemodialysis, affecting 5–30% of patients globally, with a general prevalence of 10–12% [1, 2]. Defined by the European Best Practice Guidelines (EBPG) as a decrease in systolic blood pressure (SBP) >20 mmHg or mean arterial pressure (MAP) >10 mmHg with symptoms (e.g., nausea, dizziness) requiring intervention, or by nadir criteria as SBP < 90 mmHg, IDH contributes to cardiovascular morbidity, end-organ ischemia, and reduced quality of life [3, 4].

Risk factors include rapid ultrafiltration secondary to excessive volume depletion, advanced age (>65 years) due to reduced cardiovascular reserve and autonomic dysfunction, low pre-dialytic SBP (< 100 mmHg) which limits hemodynamic compensation. Additionally, comorbidities such as heart failure, diabetes mellitus, and anemia further increase risk by impairing myocardial contractility, autonomic function and vascular resistance respectively [5, 6].

In Sub-Saharan Africa, hemodialysis services are limited, and IDH data are scarce. Studies in Nigeria and Cameroon reported prevalence estimates of 8.6% and 11.6%, respectively [7, 8]. In Uganda, no studies have yet quantified the burden or determinants of IDH [9]. IDH increases morbidity, prolongs hospitalizations, and imposes financial burdens, with IDH-prone patients facing higher mortality odds [10, 11]. The lack of local data hinders tailored interventions in low-resource settings, such as Uganda. This study aimed to determine the prevalence and associated factors of IDH among patients with kidney failure on maintenance HD at KNRH, providing baseline data to inform clinical practice and health policy.

Methods

Study design and setting

This was a cross-sectional study conducted at the dialysis unit of KNRH in Kampala, Uganda, from November 2024 to January 2025. The dialysis unit of KNRH dialyzes approximately 300 patients with kidney failure annually.

The dialysis unit has one nephrologist, about 16 dialysis nurses, operating at a capacity of 30 hemodialysis machines and can provide up to 100 dialysis sessions in a 24-hour period. The unit operates seven days a week, beginning Sunday at 19:00 and concluding on a Saturday

at 17:00. On average, 100 maintenance hemodialysis patients are dialyzed on Monday, 80 on Tuesday, and 60 on Wednesday. Patients are dialyzed twice in a week i.e. those that are dialyzed on Monday are dialyzed again on Thursday; Tuesday patients on Friday; and Wednesday patients on Saturday and Sunday.

Study population, sample size, and sampling

We enrolled all adult patients (aged ≥ 18 years) with kidney failure who received maintenance hemodialysis at KNRH during the study period ($N=186$), irrespective of the vascular access (arteriovenous fistula or central venous catheter). Only patients who provided written informed consent were included in the study. A consecutive sampling method was used, recruiting eligible patients. During the study period, each participant was recruited once and monitored for four hours during a single hemodialysis session, with data collected from the first session of the week for that participant. While the planned duration of each session was four hours, some sessions were shortened due to significant intradialytic hypotension or acute rises in blood pressure requiring urgent interventions.

Data collection and study variables

Blood pressure (SBP, diastolic blood pressure [DBP]) was measured 5 min pre-dialysis, every 30 min intra-dialysis, and 5 min post-dialysis using a calibrated Mindray VS-600 automated Oscillo-metric sphygmomanometer.

IDH was defined using EBPG (SBP decrease >20 mmHg or MAP >10 mmHg with symptoms [e.g., nausea, dizziness] and intervention [e.g., saline administration]) or nadir (SBP < 90 mmHg) criteria [3].

Sociodemographic (age, sex, BMI), clinical (comorbidities, hemoglobin, electrolytes), and dialysis-related (session duration, ultrafiltration rate) data were collected via structured questionnaires and medical records. Blood samples were analyzed for hemoglobin, albumin, and electrolytes.

Data management and analysis

Data were entered into Qualtrics data entry tool and analyzed using Stata version 17 (StataCorp, College Station, Texas, USA). Descriptive statistics (medians,

proportions) summarized participant characteristics, with normality assessed via the Shapiro-Wilk test.

IDH prevalence was calculated as the proportion with at least one IDH episode. We used binary logistic

Table 1 Characteristics of study participants, by intradialytic hypotension status ($N = 186$)

Variable	Overall ($N = 186$) n (%)	IDH present ($n = 25$) n (%)	IDH absent ($n = 161$) n (%)	p - value
Sex				0.588
Male	106 (56.9)	13 (52.0)	93 (57.8)	
Female	80 (43.1)	12 (48.0)	68 (42.2)	
Age				0.008
< 65 years	164 (88.2)	18 (72.0)	146 (90.7)	
≥ 65 years	22 (11.8)	7 (28.0)	15 (9.3)	
BMI				0.079
Low	37 (16.7)	8 (32.0)	23 (15.8)	
Normal	95 (51.1)	12 (48.0)	83 (51.6)	
High	60 (32.2)	5 (20.0)	55 (32.6)	
Diabetes				< 0.001
No	161 (86.6)	15 (60.0)	146 (90.7)	
Yes	25 (13.4)	10 (40.0)	15 (9.3)	
Anemia				< 0.001
No	140 (75.3)	5 (20.0)	135 (83.9)	
Yes	46 (24.7)	20 (80.0)	26 (16.1)	
Heart failure				< 0.001
No	171 (91.9)	18 (72.0)	153 (95.0)	
Yes	15 (8.1)	7 (28.0)	8 (5.0)	
Hypertension				< 0.001
No	54 (29.0)	20 (80.0)	34 (21.1)	
Yes	132 (71.0)	5 (20.0)	127 (78.9)	
Duration on Dialysis				0.814
< 6 months	71 (38.2)	10 (40.0)	61 (37.9)	
≥ 6 months	115 (61.8)	15 (60.0)	100 (62.1)	
Time on dialysis				0.197
< 120 min	3 (1.6)	1 (4)	2 (1.2)	
> 120 min	183 (98.4)	24 (96)	159 (98.8)	
Pre-dialytic SBP				0.011
< 100 mmHg	1 (0.5)	1 (4.0)	0 (0.0)	
≥ 100 mmHg	185 (99.5)	24 (96.0)	161 (100.0)	
Pre-dialytic Hemoglobin				< 0.001
< 6 g/dL	58 (31.2)	17 (68.0)	41 (25.5)	
≥ 6 g/dL	128 (68.8)	8 (32.0)	120 (74.5)	
Pre-dialytic K				0.4
Low	5(2.7)	1(4)	5(3)	
Normal	117(62.9)	13(52)	111(69)	0.093
High	64(34.4)	11(44)	45(28)	
Pre-dialytic Albumin				
Low	139 (74.9)	25 (100.0)	114 (70.8)	
Normal/High	47 (25.1)	0 (0.0)	47 (29.2)	

BMI: Body mass index; SBP: Systolic blood pressure; IDH: Intradialytic hypotension

regression to identify factors associated with IDH. Variables with p value < 0.2 at bivariate logistic regression were included in multivariable analysis to identify independent factors associated with IDH, reporting adjusted odds ratios (aOR) with 95% confidence intervals (CI), and significance was set at $p < 0.05$.

Results

Characteristics of study participants

We enrolled 186 participants (median age: 46.5 years, IQR: 34–58; 56.9% male). Most had a normal BMI (51.1%), hypertension (71.0%), and low pre-dialytic albumin (74.9%). Diabetes, heart failure, and severe anemia (Hemoglobin < 6 g/dl) were present in 13.4%, 8.1%, and 24.7%, respectively. Median dialysis duration was 7 months (IQR: 3–18), and 98.4% of the participants dialyzed for more than 120 min during the period of the study.

Compared to those without IDH, participants with IDH were more likely to be aged ≥ 65 years (28.0% vs. 9.3%, $p = 0.007$), have diabetes (40.0% vs. 9.3%, $p < 0.001$), anemia (80.0% vs. 16.1%, $p < 0.001$), heart failure (28.0% vs. 5.0%, $p < 0.001$), and low hemoglobin < 6 g/dL (68.0% vs. 25.5%, $p < 0.001$). They also had lower pre-dialytic systolic BP (< 100 mmHg in 4.0% vs. 0.0%, $p = 0.011$) and universally low albumin (100.0% vs. 70.8%, $p = 0.008$). Hypertension was less common in the IDH group (20.0% vs. 78.9%, $p < 0.001$). No significant differences were observed in sex, BMI, dialysis duration, or pre-dialytic potassium (Table 1).

Prevalence of intradialytic hypotension

Of 186 participants, 25 developed IDH, yielding a prevalence of 13.4% (95% CI: 9–19%). EBPG and nadir definitions identified 18 (9.67%, 95% CI: 5–15%) and 19 (10.22%, 95% CI: 5–15%) IDH cases, respectively.

Factors associated with intradialytic hypotension

Heart failure (aOR = 6.41, 95% CI: 1.29–31.77, $p = 0.023$), diabetes mellitus (aOR = 4.85, 95% CI: 1.15–20.40, $p = 0.031$), and low hemoglobin (< 6 g/dL, aOR = 6.35, 95% CI: 1.91–21.15, $p = 0.003$) were significantly associated with IDH. Age ≥ 65 years (aOR = 3.54, 95% CI: 0.86–14.56, $p = 0.080$) and high pre-dialytic potassium (aOR = 3.07, 95% CI: 0.88–10.65, $p = 0.076$) showed borderline associations (Table 2).

Discussion

In this study at a national referral hospital in Uganda, IDH occurred in one in ten patients with kidney failure, and was significantly associated with underlying comorbidities, particularly heart failure, diabetes, and severe anemia with hemoglobin < 6 g/dl. Overall, these findings underscore the multifactorial nature of IDH in

Table 2 Factors associated with intradialytic hypotension among patients with kidney failure attending Kiruddu National referral Hospital, Uganda, November 2024–January 2025

Variable	cOR (95% CI)	p-value	aOR (95% CI)	p-value
Age				
< 65 years	Ref	-	Ref	-
≥ 65 years	3.80 (1.41–10.38)	0.008	3.54 (0.86–14.56)	0.080
Diabetes				
No	Ref	-	Ref	-
Yes	6.40 (2.49–16.43)	< 0.001	4.85 (1.15–20.40)	0.031
Heart failure				
No	Ref	-	Ref	-
Yes	7.30 (2.45–21.80)	< 0.001	6.41 (1.29–31.77)	0.023
Pre-dialytic Hemoglobin				
≥ 6 g/dL	Ref	-	Ref	-
< 6 g/dL	7.34 (2.98–18.04)	< 0.001	6.35 (1.91–21.15)	0.003
Pre-dialytic K⁺				
Normal	Ref	-	Ref	-
High	2.09 (0.88–4.93)	0.093	3.07 (0.88–10.65)	0.076
History of IDH				
No	Ref	-	Ref	-
Yes	10.41 (4.15–26.11)	< 0.001	1.09 (0.27–4.39)	0.893
BMI				
Normal	Ref	-	Ref	-
Low	2.42 (0.90–6.47)	0.079	2.59 (0.60–11.23)	0.201
High	0.67 (0.23–1.91)	0.445	0.95 (0.23–3.87)	0.949
Hypertension				
No	Ref	-	Ref	-
Yes	0.073 (0.03–0.20)	< 0.001	0.86 (0.03–18.80)	0.935
Antihypertensives				
No	Ref	-	Ref	-
Yes	0.06 (0.02–0.16)	< 0.001	0.15 (0.05–4.31)	0.269

cOR: Crude odds ratio; aOR: Adjusted odds ratio; CI: Confidence interval; IDH: Intradialytic hypotension; BMI: Body mass index; Ref: reference category

resource-limited settings, where patients often present with advanced cardiovascular and hematologic derangements.

The prevalence of IDH among patients with kidney failure receiving maintenance hemodialysis in this study was 13.4%. This relatively moderate prevalence may be partly explained by the twice-weekly dialysis schedule, which is below the internationally recommended thrice-weekly regimen, potentially contributing to fluid and hemodynamic imbalances. Nonetheless, our findings

are consistent with global estimates, which report IDH prevalence ranging from 5% to 30% [1, 2]. Furthermore, the prevalence is consistent with findings from a 2019 meta-analysis, which reported ranges between 10 and 12% using both the European Best Practice Guidelines (EBPG) and nadir definitions [2]. Similar prevalence estimates were also reported in studies from the Netherlands (8.5%) and Nigeria (8.6%) using the EBPG definition [7, 12]. A higher prevalence of 30.7% observed in a study in Portugal, may be due to the inclusion of multiple IDH episodes within individual dialysis sessions, suggesting that methodological differences may influence prevalence outcomes [12].

In the current study, participants with heart failure had significantly higher odds of experiencing IDH. This finding aligns with existing literature that implicates poor myocardial reserve in the inability to tolerate ultrafiltration-induced hypovolemia during dialysis [5, 13]. The inability of a failing heart to adequately respond to fluid shifts leads to impaired cardiac output, precipitating hypotensive events. To mitigate this risk, clinicians could individualize ultrafiltration rates, and optimize heart failure management in patients on hemodialysis (e.g. adjusting diuretic doses, optimal afterload reduction) [14].

Diabetes mellitus was also significantly associated with IDH, with diabetic patients nearly five times more likely to develop IDH. Diabetes is a major risk factor due to its association with autonomic neuropathy and ischemic heart disease [15–17]. These conditions impair the cardiovascular system's adaptive mechanisms during ultrafiltration. Chronic hyperglycemia in diabetic patients leads to the formation of advanced glycation end-products (AGEs), vascular stiffness, and atherosclerosis, all of which compromise vascular reactivity and myocardial function [18, 19]. This results in reduced baroreflex sensitivity and diminished vasoconstrictive response to hypovolemia, predisposing diabetic patients to frequent IDH episodes. Moreover, high prevalence of autonomic dysfunction among individuals with diabetes has been previously documented in our setting [20]. On the basis of these findings, there is a need to optimize glycemic control and assess autonomic function regularly among diabetic patients with kidney failure to mitigate IDH risks during the hemodialysis session.

Patients with severe anemia had significantly higher odds of experiencing IDH in the current study. Low hemoglobin reduces oxygen delivery, increases cardiac workload, and exacerbates myocardial ischemia during fluid removal [21–23]. Severe anemia triggers compensatory mechanisms such as increased sympathetic drive and higher cardiac output, which eventually strain the cardiovascular system. During dialysis, the reduced intravascular volume can overwhelm this already stressed system, resulting in hemodynamic instability. While some

studies did not find a significant association between anemia and IDH, this may be due to methodological limitations such as retrospective design and incomplete data [7]. To mitigate this risk, clinicians could optimize timely correction of severe anemia based on the KDIGO guidelines on management of severe anemia in patients with kidney failure [24]. Several limitations should be considered when interpreting our findings. First, conducting the study at a single tertiary center may limit generalizability to other Ugandan or sub-Saharan African hemodialysis populations, where resource availability and patient characteristics may differ. Second, the sample size—while powered to estimate prevalence—may be underpowered to detect associations with less common clinical variables (E.g., pre-dialytic hyperkalemia). Hence, the assessment of the associated factors in this study was only exploratory in nature. Third, blood pressure measurements were taken at 30-minute intervals; more frequent monitoring might have identified transient hypotensive episodes. Finally, unmeasured confounding factors (e.g., residual renal function, intradialytic medication use, and inter-dialytic weight changes) could influence IDH risk but were not fully explored in this analysis. Despite these limitations, our study represents the first systematic assessment of IDH prevalence and associated factors in the East African region, to the best of our knowledge. The findings provide a foundational framework for tailored interventions aimed at reducing IDH and improving hemodialysis outcomes in similar resource-limited settings in sub-Saharan Africa.

Conclusion

Intradialytic hypotension was relatively common at KNRH, affecting one in ten patients with kidney failure, and was significantly associated with underlying comorbidities, including heart failure, diabetes, and low hemoglobin < 6 g/dl. Early identification and management of these risk factors—through optimized volume status, tailored ultrafiltration rates, improved glycemic control, and timely correction of severe anemia—may mitigate IDH episodes and enhance overall outcomes for patients on hemodialysis. Future longitudinal studies could assess clinical and prognostic implications of IDH in this resource-constrained setting.

Abbreviations

aOR	Adjusted Odds Ratio
CI	Confidence Interval
EBPG	European Best Practice Guidelines
IDH	Intradialytic Hypotension
KNRH	Kiruddu National Referral Hospital
MAP	Mean Arterial Pressure
SBP	Systolic Blood Pressure

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Author contributions

DN, RM, DK conceptualized and designed the study. DN, BO, DM, CL collected data. DN, RM, DA, MS analyzed data. DN, RM, DK, RN, ROO, ADC drafted the manuscript. All authors approved the final manuscript.

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Data availability

Data are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the Mbarara University of Science and Technology Research Ethics Committee (MUST-2024-1566). Written informed consent was obtained. Participants with IDH were referred for clinical management. All procedures were conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

- Akhmouch I, Bahadi A, Zajjari Y, Bouzerda A, Asserraji M, Alayoud A, et al. Characteristics of intradialytic hypotension: experience of Agadir center-Morocco. *Saudi J kidney dis transplant an off publ Saudi cent organ transplantation*. Saudi Arab. 2010;21(4):756–61.
- Kuipers J, Verboom LM, Ipema KJR, Paans W, Krijnen WP, Gaillard CAJM, et al. The prevalence of intradialytic hypotension in patients on conventional hemodialysis: A systematic review with Meta-Analysis. *Am J Nephrol*. 2019;49(6):497–506.
- Kooman J, Basci A, Pizzarelli F, Canaud B, Haage P, Fouque D, et al. EBPG guideline on haemodynamic instability. *Nephrol Dial Transpl*. 2007;22(SUPPL2):22–44.
- Mc Causland FR, Waikar SS. Association of predialysis calculated plasma osmolality with intradialytic blood pressure decline. *Am J Kidney Dis [Internet]*. 2015;66(3):499–506. Available from: <https://doi.org/10.1053/j.ajkd.2015.3.028>.
- Gul A, Miskulin D, Harford A, Zager P. Intradialytic hypotension. *Curr Opin Nephrol Hypertens*. 2016;25(6):545–50.
- Okpa HO, Effa EE, Oparah SK, Chikezie JA, Bisong EM, Mbu PN, et al. Intradialysis blood pressure changes among chronic kidney disease patients on maintenance haemodialysis in a tertiary hospital south - south nigeria: A 2 year retrospective study. *Pan Afr Med J*. 2019;33:1–11.
- Okoye OC, Slater HE, Rajora N. Prevalence and risk factors of intra-dialytic hypotension: A 5 year retrospective report from a single Nigerian centre. *Pan Afr Med J*. 2017;28:1–7.
- Halle MP, Hilaire D, Francois KF, Denis T, Hermine F, Gloria AE. Intradialytic hypotension and associated factors among patients on maintenance hemodialysis: A single-center study in cameroon. *Saudi J kidney dis transplant an off publ Saudi cent organ transplantation*. Saudi Arab. 2020;31(1):215–23.
- Kalyesubula R, Brewster U, Kansime G. Global dialysis perspective: Uganda. 2022;3:933–6.

10. Flythe JE, Xue H, Lynch KE, Curhan GC, Brunelli SM. Association of mortality risk with various definitions of intradialytic hypotension. *J Am Soc Nephrol*. 2015;26(3):724–34.
11. Shoji T, Tsubakihara Y, Fujii M, Imai E. Hemodialysis-associated hypotension as an independent risk factor for two-year mortality in Hemodialysis patients. *Kidney Int*. 2004;66(3):1212–20.
12. Rocha A, Sousa C, Teles P, Coelho A, Xavier E. Effect of Dialysis day on intradialytic hypotension risk. *Kidney Blood Press Res*. 2016;41(2):168–74.
13. Sars B, Van Der Sande FM, Kooman JP. Intradialytic hypotension: mechanisms and outcome. *Blood Purif*. 2020;49(1–2):158–67.
14. Abohtyra R, Chait Y, Germain MJ, Hollot CV, Horowitz J. Individualization of ultrafiltration in Hemodialysis. *IEEE Trans Biomed Eng*. 2019;66(8):2174–81.
15. Davenport A. Intradialytic complications during Hemodialysis. *Hemodial Int*. 2006;10(2):162–7.
16. Vinik AI, Ziegler D. Diabetic cardiovascular autonomic neuropathy. *Circulation*. 2007;115(3):387–97.
17. Calvo C, Maule S, Mecca F, Quadri R, Martina G, Cavallo Perin P. The influence of autonomic neuropathy on hypotension during Hemodialysis. *Clin Auton Res*. 2002;12(2):84–7.
18. Prasad A, Bekker P, Tsimikas S. Advanced glycation end products and diabetic cardiovascular disease. *Cardiol Rev*. 2012;20(4):177–83.
19. Yamagishi SI, Nakamura N, Suematsu M, Kaseda K, Matsui T. Advanced glycation end products: A molecular target for vascular complications in diabetes. *Mol Med*. 2015;21:S32–40.
20. Migisha R, Agaba DC, Katamba G, Kwaga T, Tumwesigye R, Miranda SL, et al. Prevalence and correlates of cardiovascular autonomic neuropathy among patients with diabetes in Uganda: A hospital-based cross-sectional study. *Glob Heart*. 2020;15(1):1–14.
21. Burton JO, Jefferies HJ, Selby NM, McIntyre CW. Hemodialysis-induced cardiac injury: determinants and associated outcomes. *Clin J Am Soc Nephrol*. 2009;4(5):914–20.
22. Brannon ES, Merrill AJ, Warren JV, Stead EA. The cardiac output in patients with chronic anemia as measured by the technique of right atrial catheterization 1. *J Clin Invest*. 1945;24(3):332–6.
23. Umehara T, Oka H, Nakahara A, Shiraiishi T, Sato T, Matsuno H, et al. Sympathetic nervous activity and hemoglobin levels in de Novo parkinson's disease. *Clin Auton Res*. 2020;30(3):273–8.
24. McMurray JJV, Parfrey PS, Adamson JW, Aljama P, Berns JS, Bohlius J, et al. Kidney disease: improving global outcomes (KDIGO) anemia work group. KDIGO clinical practice guideline for anemia in chronic kidney disease. *Kidney Int Suppl*. 2012;2(4):279–335.

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