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Authors:	Aida Ćorić[1*], Alma Mutevelić-Turković[1], Amina Valjevac[2], Amela Bećiragić[3], Fahrudin Mašnić[1], Selma Ajanović[1]
Affiliations:	[1]Clinic of Nephrology and Renal Replacement Therapy, Clinical Centre of the University of Sarajevo, Sarajevo, Bosnia and Herzegovina; [2]Department of Human Physiology, Faculty of Medicine, University of Sarajevo, Sarajevo, Bosnia and Herzegovina; [3]Medicana Hospital, Sarajevo, Bosnia and Herzegovina
Corresponding author:	Aida Ćorić, Clinic of Nephrology and Renal Replacement Therapy, Clinical Centre of the University of Sarajevo, Bolnička 25, 71000 Sarajevo, Bosnia and Herzegovina; Phone: +387 33 298 230 E-mail: idacoric@yahoo.com
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ORIGINAL ARTICLE

Clinical and inflammatory factors associated with haemoglobin control during erythropoiesis-stimulating agent therapy in haemodialysis patients: a cross-sectional study

Aida Ćorić[1*], Alma Mutevelić-Turković[1], Amina Valjevac[2], Amela Bećiragić[3], Fahrudin Mašnić[1], Selma Ajanović[1]

[1]Clinic of Nephrology and Renal Replacement Therapy, Clinical Centre of the University of Sarajevo, Sarajevo, Bosnia and Herzegovina; [2]Department of Human Physiology, Faculty of Medicine, University of Sarajevo, Sarajevo, Bosnia and Herzegovina; [3]Medicana Hospital, Sarajevo, Bosnia and Herzegovina

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Corresponding author:

Aida Ćorić

Clinic of Nephrology and Renal Replacement Therapy, Clinical Centre of the University of Sarajevo, Bolnička 25, 71000 Sarajevo, Bosnia and Herzegovina

Phone: +387 33 298 230

E-mail: idacoric@yahoo.com

ORCID ID: 0000-0002-6994-1349

ABSTRACT

Aim: To identify clinical and inflammatory factors associated with adequate haemoglobin control among patients receiving maintenance haemodialysis and erythropoiesis-stimulating agent (ESA) therapy.

Methods: This analytical cross-sectional study included 100 adults receiving maintenance haemodialysis. Among 80 patients receiving ESA therapy, adequate haemoglobin control was defined as haemoglobin ≥100 g/L and inadequate control as haemoglobin <100 g/L at the cross-sectional assessment; 20 patients not receiving ESA therapy were described separately. Clinical characteristics and laboratory measurements, including C-reactive protein (CRP), were recorded. The erythropoietin resistance index (ERI) was calculated from weekly ESA dose, body weight, and haemoglobin concentration.

Results: Eighty patients (80.0%) received ESA therapy, while 20 (20.0%) did not. Among ESA-treated patients, longer haemodialysis vintage was associated with higher odds of adequate haemoglobin control (OR = 1.02, 95% CI 1.01–1.04), whereas higher CRP was associated with lower odds (OR = 0.90, 95% CI 0.83–0.99). ERI was inversely associated with adequate control (OR = 0.004, 95% CI 0.001–0.066), although this finding is mathematically coupled to the haemoglobin-based outcome. The exploratory model was statistically significant ($\chi^2 = 45.4$; $p < 0.001$).

Conclusion: Longer haemodialysis vintage and lower CRP were associated with adequate haemoglobin control during ESA therapy. ERI findings require cautious interpretation because haemoglobin is included in the ERI denominator and was also used to define the outcome.

Keywords: anaemia; C-reactive protein; erythropoiesis-stimulating agents; haemodialysis; inflammation; treatment response

INTRODUCTION

Anaemia is a common complication of chronic kidney disease (CKD), particularly among patients receiving maintenance haemodialysis. Reduced renal erythropoietin production is central to its pathogenesis, while uraemic toxins, impaired iron availability, inflammation, and secondary hyperparathyroidism may further suppress erythropoiesis (1-3).

Erythropoiesis-stimulating agents (ESAs) reduce transfusion requirements and improve haemoglobin concentrations, but treatment response varies substantially. Excessive ESA exposure may be harmful, making the recognition of hyporesponsiveness clinically important. The erythropoietin resistance index (ERI), which relates ESA dose to body weight and haemoglobin concentration, is commonly used to quantify ESA responsiveness.

Chronic inflammation and immune dysregulation are frequent in haemodialysis (4) and may impair erythropoiesis through cytokine-mediated marrow suppression and disordered iron metabolism. C-reactive protein (CRP), hepcidin, iron indices, nutritional status, and vascular access have all been associated with ESA responsiveness (5–9).

Clinical management therefore requires simultaneous assessment of haemoglobin, iron stores, inflammation, dialysis adequacy, and other contributors to anaemia. Contemporary recommendations emphasise individualized ESA and iron therapy rather than unrestricted haemoglobin normalization (10-16). CKD-related complications and their treatment remain important determinants of morbidity in patients receiving kidney replacement therapy (17,18).

Regional evidence on haemoglobin control during ESA therapy remains limited.

The aim of this study was to identify clinical and laboratory factors associated with adequate haemoglobin control and to explore the discriminatory performance of ERI and CRP in a cohort of patients receiving maintenance haemodialysis.

MATERIAL AND METHODS

Patients and study design

This analytical cross-sectional study was conducted over a 10-month recruitment and data-collection period at the Clinic of Nephrology and Renal Replacement Therapy, Clinical Centre of the University of Sarajevo between January and October 2020. The study included 100 adults receiving maintenance haemodialysis three times weekly for 4 hours per session. Each participant underwent one cross-sectional clinical and laboratory assessment.

Patients aged 18–80 years receiving maintenance haemodialysis three times weekly who provided written informed consent were eligible. Exclusion criteria were blood-borne disease, autoimmune disease, and malignancy.

Among the 80 patients receiving ESA therapy, adequate haemoglobin control was defined as haemoglobin ≥ 100 g/L at the cross-sectional assessment (N = 40), while inadequate control was defined as haemoglobin < 100 g/L (N = 40). The 20 patients not receiving ESA therapy were retained as a separate comparison group for descriptive and exploratory three-group analyses; the primary multivariable analyses were restricted to ESA-treated patients.

Haematocrit and ferritin were analysed as laboratory characteristics and were not used to define haemoglobin control. This study-specific classification should not be interpreted as a formal longitudinal definition of ESA hyporesponsiveness.

The study was approved by the Ethics Committee of the Clinical Centre of the University of Sarajevo (No. 0302-30013, issued on 05 April 2018). All participants provided written informed consent.

Methods

Demographic and clinical variables included age, sex, cause of kidney failure, haemodialysis vintage, dialysis modality, vascular access, body mass index, secondary hyperparathyroidism, ESA preparation and dose, duration of ESA therapy, and haemoglobin-control category.

Laboratory measurements included complete blood count, serum iron, total and unsaturated iron-binding capacity, transferrin saturation, ferritin, transferrin, CRP, total protein, albumin, intact parathyroid hormone, and hepcidin. Analyses were performed at the Institute of Clinical Chemistry and Biochemistry, Clinical Centre of the University of Sarajevo.

Blood samples were collected before dialysis at the start of the midweek haemodialysis session. ESA and other prescribed medications were administered intravenously at the end of dialysis. ERI was calculated as weekly ESA dose divided by body weight and haemoglobin concentration: ESA dose (IU/week)/body weight (kg)/haemoglobin (g/dL).

Statistical analysis

Continuous variables were summarised as mean ± standard deviation (SD) or median (interquartile range), according to distribution, and categorical variables as number and percentage. Normality was assessed using the Shapiro–Wilk test and graphical inspection. Group comparisons were performed using the Kruskal–Wallis test for continuous variables and Pearson's χ^2 test for categorical variables. Associations between continuous variables were examined using Pearson, Spearman, or Kendall correlation coefficients according to variable type and distribution. Multivariable logistic regression was performed among the 80 ESA-treated patients, with adequate haemoglobin control coded as 1 and inadequate control as 0. The final model included haemodialysis vintage, ERI, and CRP. Because haemoglobin is included in the ERI denominator and was also used to define the dependent variable, analyses involving ERI were considered exploratory and the ERI coefficient was not interpreted as an independent predictive effect. Results are presented as odds ratios (ORs) with 95% confidence intervals (CIs). Exploratory receiver operating characteristic (ROC) analyses among ESA-treated patients were used to evaluate ERI and CRP for distinguishing inadequate haemoglobin control, with optimal thresholds determined using the Youden index. Tests were two-sided, and $p < 0.05$ was considered statistically significant.

RESULTS

The study included 100 patients; 58 (58.0%) were male and 42 (42.0%) were female. Mean age was 59.2 ± 12.6 years (range 20–79 years), and median haemodialysis vintage was 31.5 months.

Diabetic nephropathy was the most frequent cause of kidney failure, affecting 33 (33.0%) patients, followed by nephroangiosclerosis in 25 (25.0%), pyelonephritis in 11 (11.0%), polycystic kidney disease in 11 (11.0%), and glomerulonephritis in nine (9.0%); the cause was unknown in 11 (11.0%) patients.

Arteriovenous fistula was the vascular access in 73 (73.0%) patients and a central venous catheter in 27 (27.0%). Anaemia treatment was administered to 96 (96.0%) patients. Iron supplementation was prescribed to 90 (90.0%), all 100 patients (100.0%) received folic acid, and 80 (80.0%) received ESA therapy. Median duration of ESA therapy was 2 years (IQR 1–5 years).

Among the 80 ESA-treated patients, darbepoetin alfa was administered to 39 (48.8%) at a mean weekly dose of 29.5 ± 12.2 µg, epoetin alfa to 14 (17.5%) at 5571.4 ± 1785.2 IU/week, epoetin beta to 21 (26.3%) at 5809.5 ± 1661.9 IU/week, and continuous erythropoietin receptor activator to six (7.5%) at 119.2 ± 27.0 µg/month. Mean treatment duration with continuous erythropoietin receptor activator was 5 years.

The largest proportion of ESA-treated patients had ERI values > 0.9 (43.0%), while 25.3% had values < 0.5, 19.0% between 0.5 and 0.7, and 12.7% between 0.7 and 0.9 (Figure 1).

Haemodialysis vintage differed significantly among the three groups, with a median of 54.0 months (IQR 6.3–83.8) in patients with adequate haemoglobin control, 15.5 months (IQR 6.0–35.5) in those with inadequate control, and 37.0 months (IQR 18.3–58.8) in patients not receiving ESA therapy (Kruskal–Wallis p = 0.019), whereas age, sex, dialysis modality, and vascular access did not differ significantly (Table 1).

Among the 80 ESA-treated patients, longer haemodialysis vintage was associated with higher odds of adequate haemoglobin control (OR = 1.02, 95% CI 1.01–1.04; $p = 0.010$). Higher ERI was associated with lower odds of adequate control (OR = 0.004, 95% CI 0.001–0.066; $p = 0.001$), as was higher CRP (OR=0.90, 95% CI 0.83–0.99; $p = 0.034$). The exploratory model was statistically significant ($\chi^2 = 45.4$; $p < 0.001$), explained 44.0–58.9% of the outcome variance, and had an apparent classification accuracy of 83.3% in the analysed dataset (Table 2).

In an exploratory ROC analysis, an ERI threshold of 0.59 distinguished inadequate haemoglobin control with 93.5% sensitivity and 61.5% specificity. The area under the curve was 0.844 (95% CI 0.80–0.91; $p < 0.001$) (Figure 2A). Because haemoglobin is included in the ERI denominator, this finding should not be interpreted as an independent predictive assessment of the haemoglobin-based outcome.

In the exploratory CRP ROC analysis, a threshold of 6.35 mg/L distinguished inadequate haemoglobin control with 61.5% sensitivity and 78.5% specificity. The area under the curve was 0.66 (95% CI 0.54–0.78; $p = 0.013$) (Figure 2B).

DISCUSSION

This study identified longer haemodialysis vintage as positively associated with adequate haemoglobin control, while higher CRP was negatively associated. ERI was also inversely associated with control, although this result is affected by mathematical coupling because haemoglobin is included in the ERI denominator. The exploratory model showed apparent classification performance within this dataset, and the ERI ROC analysis showed greater discrimination than CRP; however, the ERI result is not an independent assessment of the haemoglobin-based outcome.

Secondary hyperparathyroidism is common in advanced CKD and may impair erythropoiesis through marrow effects (19). No clear association with response was observed in this cohort.

Anaemia in haemodialysis is nevertheless usually multifactorial, with contributions from erythropoietin deficiency, iron restriction, inflammation, blood loss, and shortened erythrocyte survival (20,21).

Iron status is central to ESA response, but ferritin is also an acute-phase reactant and may not reliably distinguish iron sufficiency during inflammation. Functional iron deficiency and refractory iron deficiency therefore require interpretation using multiple indices rather than ferritin alone (22-26).

The wide ERI distribution is consistent with previous evidence that inflammation is associated with reduced haemoglobin response despite higher ESA exposure (27). The inverse association between CRP and adequate response also accords with reports linking inflammatory and nutritional abnormalities to ESA resistance (28-30).

The positive association between haemodialysis vintage and adequate haemoglobin control was unexpected. It may reflect survivor selection, more stable long-term treatment, or unmeasured differences in dialysis adequacy, nutrition, iron management, and comorbidity. The cross-sectional design does not establish temporal or causal relationships.

This study is limited by its single-centre cross-sectional design, modest sample size, outcome classification based on a single haemoglobin measurement, and the absence of longitudinal dose-response assessment. The no-ESA group was conceptually distinct and was included only in descriptive and exploratory three-group comparisons; multivariable analyses were restricted to ESA-treated patients. Interpretation of ERI is limited by mathematical coupling, as haemoglobin is included in both the ERI denominator and the definition of haemoglobin control. Residual confounding by dialysis adequacy, nutrition, iron status, comorbidity, and treatment intensity is also possible.

CONCLUSION

Longer haemodialysis vintage and lower CRP were associated with adequate haemoglobin control among patients receiving ESA therapy. The ERI association should be interpreted cautiously because of mathematical coupling with the haemoglobin-based outcome. Longitudinal multicentre studies are needed to evaluate true ESA responsiveness and establish temporal relationships.

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Conflicts of interest: None to declare.

Author contributions (CRediT): Conceptualization—A.Ć. and A.M.T.; methodology—A.Ć.; software—A.V.; validation—A.Ć. and A.V.; formal analysis—A.V.; investigation—A.Ć.; resources—A.Ć.; data curation—A.Ć., A.V., and A.M.T.; writing—original draft—A.Ć.; writing—review and editing—A.Ć., A.M.T., and F.M.; visualization—A.Ć., A.M.T., F.M., S.A., and A.B.; supervision—A.Ć. and A.M.T.; project administration—A.Ć. and A.M.T. All authors have read and approved the final version of the manuscript.

Ethics statement: The study was approved by the Ethics Committee of the Clinical Centre of the University of Sarajevo (No. 0302-30013, issued on 05 April 2018). All participants provided written informed consent.

Data availability statement: The data analysed in this study are available from the corresponding author upon reasonable request.

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TABLES AND FIGURES

Table 1. Clinical characteristics according to haemoglobin control and erythropoiesis-stimulating agent treatment

Variable	Adequate control (N = 40)	Inadequate control (N = 40)	No ESA therapy (N = 20)	*p*
		Mean ± SD		
Age, years	57.9 ± 13.6	58.7 ± 12.7	62.2 ± 9.9	0.390
		n (%)		
Sex				
Male	24 (60.0)	22 (55.0)	12 (60.0)	0.880
Female	16 (40.0)	18 (45.0)	8 (40.0)	
Haemodialysis modality				
HD	24 (60.0)	32 (80.0)	11 (55.0)	0.073
HDF	16 (40.0)	8 (20.0)	9 (45.0)	
Vascular access				
AVF	29 (72.5)	31 (77.5)	13 (65.0)	0.623
CVC	11 (27.5)	9 (22.5)	7 (35.0)	
		Median (IQR)		
Haemodialysis vintage (months)	54.0 (6.3–83.8)	15.5 (6.0–35.5)	37.0 (18.3–58.8)	0.019

AVF, arteriovenous fistula; CVC, central venous catheter; ESA, erythropoiesis-stimulating agent; HD, haemodialysis; HDF, haemodiafiltration; IQR, interquartile range; SD, standard deviation

Table 2. Exploratory multivariable logistic regression of factors associated with adequate haemoglobin control during erythropoiesis-stimulating agent therapy

Model	B	SE	OR (95% CI)	*p*
Haemodialysis vintage	0.02	0.01	1.02 (1.01–1.04)	0.010
ERI	-5.5	1.4	0.004 (0.001–0.066)	0.001
CRP	-0.10	0.05	0.90 (0.83–0.99)	0.034

Dependent variable: adequate haemoglobin control.
B, regression coefficient; CI, confidence interval; CRP, C-reactive protein; ERI, erythropoietin resistance index; OR, odds ratio; SE, standard error

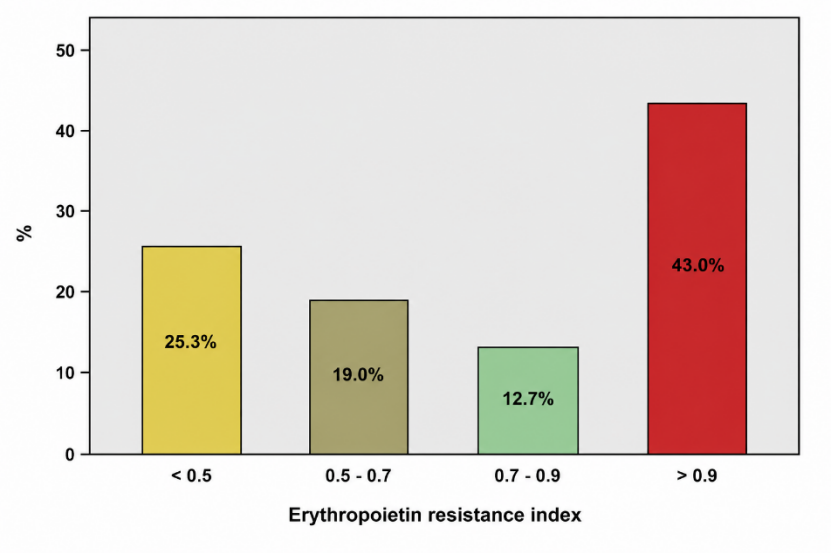

Figure 1. Distribution of the erythropoietin resistance index among patients receiving erythropoiesis-stimulating agent therapy.

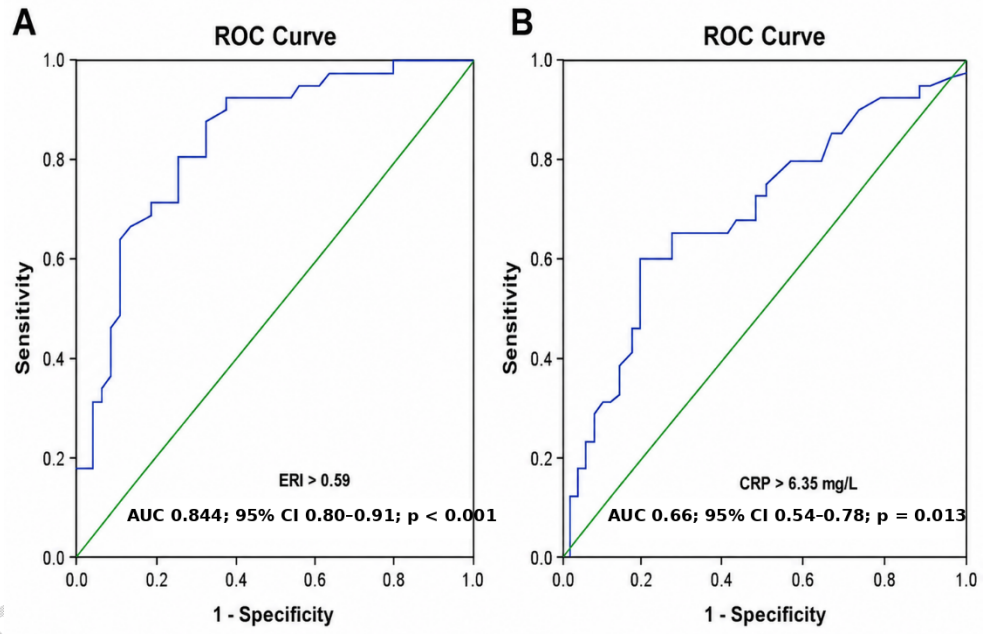

Figure 2. Exploratory receiver operating characteristic (ROC) curves of (A) the erythropoietin resistance index (ERI) and (B) C-reactive protein (CRP) for distinguishing inadequate haemoglobin control in haemodialysis patients receiving erythropoiesis-stimulating agent therapy

AUC, area under the curve; CI, confidence interval; CRP, C-reactive protein; ERI, erythropoietin resistance index; ROC, receiver operating characteristic. The ERI analysis should be interpreted cautiously because haemoglobin is included in the ERI denominator and was also used to define haemoglobin control.