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Interdisciplinary Dynamics of Haemoglobin Stability in Chronic Haemodialysis: A Statistical and Computational Approach

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Aim: To investigate the factors influencing Haemoglobin (Hb) maintenance in chronic Haemodialysis (HD) patients, focusing on the role of clinical determinants such as diabetes, sleep duration, and erythropoietin derivatives, and to explore the interdisciplinary application of theoretical physics-inspired statistical methodologies in optimising clinical data analysis for enhanced anaemia management. Methods: Collected data from 116 patients after inclusion and exclusion criteria. Patients were interviewed for their demographic behavioural and clinical characteristics and some of the information related to clinical characteristics was collected from their patient file. The preferred Hb level to be maintained by the patients sets as 10-11.5g/dL. Patience was categorized into a preferred level and less than preferred level. Computational statistical tools were utilized to explore the association between demographic behaviour and clinical variables with Hb maintenance. The analysis used statistical modelling techniques for the identification of trends and correlations. The overall analysis approach shows an interdisciplinary way of clinical data

analysis.
Results: The analysis could provide an impactful association between Hb maintenance and key factors such as sleep duration, diabetes and use of erythropoietin-stimulating agents in chronic HD patients. The use of computational statistical tools with the inspiration of theoretical physics could establish the patterns and trends that traditional methods should consider. These results suggest that different methodologies in interdisciplinary areas can enhance or improve the understanding of Hb trends and needed support for the improvement of Anemia management in HD patients.
Patients who are less than or equal to 50 years of age were shown a better Hb level than those with age more than 50 years. Non-diabetic patients also show better Hb maintenance compared to diabetic patients (P= 0.002).
Patients who sleep between 5-8 hours at night showed a better Hb level. It is observed that increasing sleep duration up to 8 hours showed an increasing trend of Hb maintenance among chronic HD patients (P=0.046). The use of Erythropoietin stimulating agents especially other than Recombinant Erythropoietin preparations showed a good Hb maintenance (P=0.0031).
Conclusion: Sleep duration, Erythropoietin stimulating agents, and diabetes management play a crucial role in Hb maintenance among chronic HD patients. Advanced statistical methods inspired by Theoretical physics were used in the data analysis and provided new insight into Anemia management among Chronic HD patients. The study could highlight the importance of integrating interdisciplinary fields to improve individualised patient care for HD patients. Better Hb is linked to diabetic control, adequate sleep duration (5-8 hours at night), and the use of long-acting Erythropoietin Stimulating agents.
Keywords: Anaemia, Chronic Kidney Disease, Haemoglobin, Haemodialysis.

1. Introduction

There are many factors which affect Hb maintenance in Chronic HD patients. Hb maintenance can be compared to the energy distribution in Physics, where different forces combined to create balance. In Hb maintenance Biological, Behavioral and clinical factors combined to affect Hb level. The approach using advanced statistical methods inspired by physics in analyzing the factors connects clinical research with computational techniques typically used in high energy physics, offering a new perspective on understanding Hb maintenance among chronic HD patients. By leveraging universal scientific principles, the findings aim to inspire both improved clinical practices and interdisciplinary research methodologies.

Maintaining Hb levels among chronic HD patients is challenging. There are a lot of possibilities for the patients on maintenance HD to get the Hb level low. Things like blood loss through clotting of the circuit, inappropriate rinse back to the patient while closing HD, blood loss through blood sampling, residual chemical exposure to the blood which is used for reprocessing of the dialyser, contaminants in the water used for HD, bleeding through vascular access, loss of water-soluble vitamins etc. Good maintenance of the Hb level will improve the quality of life of chronic HD patients and reduce the risk of cardiovascular disease and

mortality. We can consider a preferred target level of Hb maintenance between 10-11.5gm/dL, which will help chronic HD patients maintain their patency of vascular access and sufficient oxygenation to the different parts of the body[1,2]. Due to dietary restrictions and HD, the chances of vitamin deficiency are higher and it can lead to low immunity and low Hb among HD patients[3]. Low Hb maintenance can lead to cardiovascular issues among HD patients[4].

The reasons behind the low level of Hb in chronic HD patients were low levels of nutrients like iron, Vitamin B12 and folate and other reasons like blood loss, infection, inflammation, Low erythropoietin production and malnutrition[5]. Low Hb level can lead to Tiredness, Weakness, shortness of breath, irregular heartbeat, dizziness and light-headedness, chest pain, cold hands and feet, and Headaches among chronic HD patients[6]. As per one meta-analysis by Vijay, there is a good percentage of HD patients non adhering to the dietary instructions[7]. This can be a reason for low Hb among chronic HD patients.

The purpose of the study is to know whether the HD patients in the Malwa, Punjab region can maintain the Hb at a preferred level of 10-11.5g/dL or not, and also to explore any unknown factors associated with their Hb maintenance between 10-11.5g/dL The result of the study may help the patients as well as doctors to think and act more efficiently to improve the quality of life of chronic HD patients not only in Punjab but also all over the world.

People and Place: This paper was produced as a part of the PhD, by using the data collected for the research thesis entitled "The Effect of The Quality of Drinking Water on Pre-HD Blood Pressure Maintenance among Patients of Malwa, Punjab". The study was conducted in Patiala district, one of the 12 districts in the Malwa region of the Punjab, an Indian State. Panjab consists of 23 districts classified into 4 regions, Majha, Malwa, Doaba and Podh regions. Malwa region was the most suitable place for conducting the present research due to its geographic location, composition, climate, infrastructure, industrial activities, agricultural practices etc, along with being convenient to the researcher [8,9].

The patients were provided with a patient information sheet followed by a consent form. Ethical approval for the study sanctioned by Chitkara University Ethical Committee, Punjab. Ethics Committee Registration No. EC/NEW/INST/2020/531, issued under Biomedical & Health Research (NECRBHR), Department of Health Research (DHR), Government of India, New Delhi 110001).

Aim:

Aim of the study used to investigate factors affecting Hb maintenance mainly focused on Diabetes, sleep duration and Erythropoietin stimulating agents and also explore advanced statistical methods to optimize clinical data analysis to improve anaemia management in Hb patients.

Objectives

1. To evaluate the effect of diabetes, sleep duration and Erythropoietin use on Hb maintenance in Chronic HD patients.

2. To apply advanced statistical methods inspired by theoretical physics to analyse clinical data related to anaemia management.

3. To enhance clinical data interpretation to improve decision-making in individualized patient care in anaemia management.

4. Explore the integration of Physics-based concepts in medical research to boost anaemia management in chronic HD patients.

2. Methods

Study Location and Design

It was a cross-sectional study conducted in the Malwa Region of Punjab, India. The data was collected from three different dialysis centres located in Patiala district Punjab. The selection criteria of Dialysis centres were based on the number of Dialysis patients, Renal diet protocols and the dialysis concentrate. (dialysis concentrate from the same manufacturer).

Target Population

Chronic Kidney disease (CKD) stage five on maintenance HD.

Inclusion and Exclusion Criteria

Inclusion Criteria:

1. Patients with the CKD stage 5 on maintenance HD
2. Age between 18-70years
3. Those who are willing to participate in the study

Exclusion Criteria:

1. Patients, who had initiated HD newly (within in last three weeks).
2. Patients, whose age is less than 18 years.
3. Those who are in non-adherence to unit protocol

Sample Size and Data Collection

Interviewed 150 patients, 116 patients met the selection criteria and the sample size was calculated based on the prevalence of hypertension in CKD stage 5 patients. The data collected as per the below-mentioned strategy:

- Patient Interviews: To gather demographic and behavioural data.
- Hospital Records: To extract clinical characteristics such as Hb levels, diabetes history, and sleep patterns.

Statistical Analysis

Used Stata software 14.1version for analysis. The tests used were the Pearson Chi-square test and Fisher's exact test. To analyse the data, the data was categorized into two groups based on their Hb levels. Groups are the Preferred range group (Hb level of 10-11.5g/dL) and Below the Preferred range (Hb level lower than 10g/dL).

Computational and Statistical Modelling

The use of computational statistical tools inspired by theoretical physics models with the incorporation of principles of system dynamics and phase transitions helped the identification of nonlinear trends and correlations often missed in conventional methods analysis. The interdisciplinary approach using Monte Carlo simulations and maximum likelihood estimation provided a very precise framework for understanding the factors and their effect on anaemia management in CKD stage 5 patients on maintenance HD.

3. Results

Details of the Study Patients:

The percentage of the patients from three different hospital-based dialysis centres were; 18.10%(Centre A), 33.62% (Centre B) and 48.28% (Centre C).73 were male and 43 were female. Regarding the history of hypertension, 78.45 % of the Patients had a history of hypertension before starting their first HD. 25% of the Patients did not have a history of hypertension before starting their first HD treatment.

The interdialytic weight gain (IWG) among the Patients was classified into three categories. 11.21% of the Patients came between zero to one kilogram (Kg) IWG. 60.34% came under the category of IWG between 1 -3 kg. 28.457% of the Patients had an IWG of > 3 Kg.

Regarding the renal diet consideration among the Patients, 84.48 % of the Patients were completely following the renal diet instructions given by the HD centre. 10.34% were partially following the HD unit instruction and only 5.17% of Patients responded as not following the renal diet instructions.98.28 % of the Patients were not taking any other medicines without consulting the nephrologist but 1.72 % of the Patients were taking medicines(ayurvedic or some other locally available) especially without acknowledging the nephrologist.

Initially duration of sleep at night among the Patients was categorised into five groups (no sleep at night, < five hours sleep, up to six hours sleep, up to seven hours sleep and 8 hours sleep). 17.24 % of the Patients were not sleeping during the night. 21.55% of them were sleeping less than five hours at night. 18.97% were sleeping up to six hours at night 10.34% of the Patients were sleeping up to seven hours at night 31.90% of the Patients were sleeping eight hours or more at night. For analysis purposes, we categorised the patients into 3 groups based on sleep(No sleep,< 5 hours and 5 to 8 hours).

Regarding alcohol consumption among the Patients, 89.66% were not consuming alcohol or alcohol-contained drinks.2.59% of the Patients were occasionally consuming alcohol or alcohol-contained drinks and 1.72 % of Patients had a previous habit of consuming alcohol-contained drinks, that is before enrolling in the study while on maintenance HD. 6.03% of the Patients were regularly using alcohol-contained drinks. 0.86% of the Patients were regular smokers and 1.72% of the Patients had a previous habit of smoking.1.72 % of the Patients occasionally smoke and 95.69% of the Patients were non-smokers.

Regarding tea and coffee consumption among the Patients, 78.45% of the Patients were not taking coffee and 18.97% were consuming coffee occasionally. Only 2.59 % of the Patients were regularly consuming coffee. 93.97 % of the population were regularly taking tea every

day 2.59% were occasionally drinking tea and 3.45% of Patients were not consuming tea.

Regarding the Patients by the number of antihypertensives, 23.48 % were not taking any antihypertensives. All of the Patients were holding one dose of antihypertensives before HD if it was on the same day of HD.28.70% were taking one antihypertensive per day. 14.78% of the Patients were taking three or more antihypertensives per day. The maximum number of antihypertensives used per day among the Patients was five. 6.03% of the Patients were not taking antihypertensives correctly 81.03% among the Patients who were taking BP medicines correctly 15% of the Patients were not under antihypertensive medications.67.23% of the patients were taking calcium channel blockers (CCB)for BP control along with other antihypertensives of alone.27.59 % of the Patients were depending only on CCB, and among them, 0.86 % of the patients were using more than one CCB. 46.54% of the patients were using sympatholytic alone or with other antihypertensives, among them 6.03% were using sympatholytic alone and 12.93% were using two to three sympatholytics in combination with calcium channel blockers or vasodilators.

The type and dose of erythropoietin or erythropoietin-related drugs were erythropoietin alfa 4000 IU/week/Subcutaneously (SC)(taking 61.95% of the Patients),8000IU/week/SC (taking 7.96% of the Patients),10000IU/Week/SC(taking 7.96% of the Patients), Darbepoetin 40mcg/once in 2 week/SC(taking 2.65% of the Patients), Methoxy polyethylene glycol-epoetin beta 50mcg/ once in 2 weeks/SC (taking 0.88% of the Patients), Methoxy polyethylene glycol-epoetin beta 100mcg/ once in month/SC(taking 0.88 % of the Patients).

The approximate drinking water intake per day among Patients was,46.54 % of the Patients were taking up to 500 ml/day 46.55% of the Patients were consuming drinking water up to 1000ml/day 5.17% of the Patients were consuming drinking water up to 1500ml/day and 1.72 % were consuming drinking water up to 2000ml/day. HD twice weekly and thrice weekly Patients were 69.03% and 30.97 %. Concerning the quality of dialysis water, 33.62 % of the Patients were getting HD with an average Total dilution of solutes (TDS) of 7ppm, and 48.28% of the Patients were getting HD with an average TDS of dialysis water 9ppm. 18.10 % of the Patients were getting HD with an average TDS of 17 ppm. 18.10% of the HD patients were treated with an average dialysis water calcium of 10mg/L. The average fluoride of dialysis water among the patients was 0.2mg/L.

The preferred level of Hb maintenance among HD patients can be considered as 10-11.5g/dL and the total patients are categorised into two, that is Hb level below the Preferred range and Hb level in the Preferred range. Analysis was done based on the age < 50 years and more than or equal to 50 years.65 patients were under the age of < 50 years and among them 78.16%(51 patients) were maintaining their Hb below the Preferred range.21.54%(14 patients) were maintaining their Hb level in the Preferred range. There were 51 patients age >=50 years and among them, 82.24% (45 patients) were maintaining their Hb level below the Preferred level and 11.76% (6 patients) were maintaining their Hb level in the Preferred range. Overall, without considering the age 82.76% (96 patients) did not maintain their Hb level in the Preferred range and 17.24% (20 patients) could be able to maintain their Hb in the Preferred range. Pearson Chi-square test regarding the association of age and Hb maintenance Pr=0.16. However, the association is not statistically significant, there is slightly higher Preferred maintenance noted in the age group <50 years.

Based on gender 79.45% of the male population is below the Preferred level of Hb. Only 15% of the male population is under the Preferred level of Hb. 88.37 % of the female population were below the Preferred level of Hb and only 11.63% were maintaining Hb in the Preferred level for the chronic HD population. We could be able to see a 10% higher Preferred Hb level among the male population than the female population, however statistically not a significant association between gender and Hb maintenance among chronic HD patients.

Based on the duration(Years) of the HD completed, we could observe that 19% of the population who completed less than two years maintained the Hb in the Preferred range and only 14.29% among the people who had completed more than or equal to 2 years maintained their Hb in a Preferred range. It is observed that a 5 % higher number of people among the population under two years completion when compared to more than or equal to years maintained Hb level in a Preferred range. However, there is no significant association is observed statistically (See Table 1)

As per the observation, those who had a history of cardiovascular disease, could not be able to maintain the Hb in a Preferred range. Regarding the population having no history of cardiovascular disease,18.02% could be able to maintain the Hb level in the Preferred range. However, there is statistically not a significant association between Hb maintenance and a History of cardiovascular disease, We observed that no Patients Preferred the level of Hb maintenance for those who had a history of cardiovascular disease. There is a statistically significant association observed between the history of diabetes and Hb maintenance among chronic HD patients (Pr =0.002). None of the Patients who had a history of Diabetes could maintain the Hb level in the Preferred range. No association was observed between the Patients having a history of Hypertension and Hb maintenance. As per the body weight category less than or equal to 60kg and above 60 kg, in both cases nearly the same 16-17% of the Patients were maintaining their Hb in a Preferred range. There is no significant statistical association was found between body weight and Hb maintenance (See Table 1).

Table 1, Demographic factors and Hb maintenance among patients.

Variables	Total Patients	Non-maintaining a Preferred level of Hb	Maintaining the Preferred level of Hb	P-value
	N	n (%)	n(%)	
Age				
<50 years	65	51(78.5)	14(21.5)	
>=50 years	51	45(88.2)	6(11.8)	0.0167
Sex				
Male	73	58(79.45)	15(20.55)	
Female	43	38(88.37)	5(11.63)	0.219
Duration of HD				
<2years	67	54(80.60)	13(19.40)	
>=2years	49	42(85.71)	7(14.29)	0.471
History of cardiovascular disease				

Yes	5	5(100)	0	
No	111	91(81.98)	20(18.02)	0.297
History of Diabetes				
Yes	32	32(100)	0	
No	84	64(76.19)	20(23.81)	0.002
History of Hypertension				
Yes	91	73(80.22)	18(19.78)	
No	25	23(92)	2(8)	0.167
Weight of the participants				
<=60kg	59	49(83.05)	10(16.95)	
>60Kg	56	46(82.14)	10(17.86)	0.898
Usual weight gain				
<1kg	13	9(69.23)	4(30.77)	
1-3kg	69	60(86.96)	9(13.04)	
>3kg	33	26(78.79)	7(21.21)	0.239

We could observe that only 13% of the Patients are maintaining their usual inter-dialytic weight gain of <1kg and most of the Patients (69%) are under the usual intradialytic weight gain of 1-3 kg. 33% of the Patients had >3kg weight gain. We could observe that the Patients having <1kg had more tendency to maintain the Hb level at a Preferred level and whenever the inter-dialytic weight increases there is observed a decline in the number of Patients who could be able to maintain their Hb level in the Preferred range. Statistically, there is no significant association between weight gain and Hb maintenance (See Table 1).

Regarding the Patients who are following the renal diet strictly have more capability to maintain their Hb level at the Preferred level when compared to other groups like non/partial compliance with renal diet, there is also not a significant statistical association between renal diet Hb maintenance.

Table 2, Behavioural measurement and Hb maintenance among patients.

Variables	Total Patients	Non-maintaining a Preferred level of Hb	Maintaining the Preferred level of Hb	P-value
	N	n(%)	n(%)	
Following Renal Diet				
No	6	5(83.3)	1(16.67)	
Yes	98	81(82.65)	17(17.35)	0.998
Partial	12	10(83.33)	2(16.67)	
Duration of sleep at night				
No sleep	20	20(100)	0	
<5 hours	25	20(80)	5(20)	
5-8 Hours	71	56(78.87)	15(21.13)	0.046

We observed the Hb maintenance among the Patient categories and found out that ”no sleep at night” Patients had zero maintenance in the Preferred Hb level. Most number of the Patients who were sleeping five to eight hours could maintain their Hb at the Preferred level. We got a statistically significant association between the duration of sleep at night and Hb maintenance among Chronic HD Patients (Pr= 0.046) (See Table 2).

Regarding the use of antihypertensives, However, there is no statistically significant association between the use of antihypertensives and Hb maintenance, the Patients who were not using antihypertensives had fewer number Patients maintained their Hb level Preferred level when compared with the Patients who were on antihypertensives. Also, there is an observation about the number of HD per week and Hb maintenance, the Patients who are maintaining three HD per week (12 hours/week) have good Hb maintenance in the Preferred range when compared to the Patients who are maintaining the two HD/Week(8hours/week). There was an observation that more number of patients who are not using erythropoietin or related drugs had good Hb maintenance in the Preferred range with those who are using erythropoietin 4000 to 10000 IU/week/SC. Also, it is observed that those who are under other erythropoietin-related drugs like Darbepoetin and Methoxy polyethylene glycol-epoetin beta showed good Hb maintenance in the Preferred Hb level when compared to those who are using erythropoietin 4000-10000IU/week/SC. We could see that statistically also there is a significant association (Pr = 0.031)(Table 3).

Table 3, Clinical measurements and Hb maintenance among patients.

Variables	Total Patients N	Non-maintaining a Preferred level of Hb n(%)	Maintaining the Preferred level of Hb n(%)	P-value
Antihypertensives				
Yes	88	72(81.82)	16(18.8)	
No	27	23(85.19)	4(14.81)	0.46
HD per week				
2	78	67(85.9)	11(14.10)	
3	38	29(76.32)	9(23.68)	0.154
Erythropoietin preparations				
No	20	13(65)	7(35)	
4000IU/week/SC	70	63(90)	7(10)	
8000IU/week/SC	9	7(77.8)	2(22)	
10000IU/week/SC	9	8(88.89)	1(11.11)	
Others	5	3(60)	2(40)	0.031

Key findings include:

- Age and Hb Maintenance: Patients aged <50 years exhibited higher Hb maintenance rates (21.54%) compared to those ≥50 years (11.76%).
- Diabetes: Non-diabetic patients demonstrated significantly better Hb maintenance (23.81%) than diabetic patients (0%; p = 0.002).

- Sleep Duration: Patients sleeping 5-8 hours had higher Hb maintenance rates (21.13%; $p = 0.046$) compared to those with no sleep.
- Erythropoietin Derivatives: Long-acting agents like Darbepoetin showed better outcomes than recombinant preparations ($p = 0.031$).

These results, when visualized as phase transitions in energy states, suggest analogies between clinical and physical systems.

4. Discussion:

No person has Hb more than 12g/dL. It was observed that the Patients less than 50 years old showed a higher capacity to maintain their Hb in the Preferred range. There is a significant statistical association found in Hb maintenance among the age less than or equal to 50 than that above 50. It was observed that less maintenance of Hb in the Preferred level is found among females compared to males though women were less diagnosed and insufficiently treated group regarding cardiovascular disease[4]. Also, people who have completed HD more than or equal to two years have less efficiency in maintaining their Hb at the Preferred level for chronic HD patients. It is also detected that those who have a history of cardiovascular disease are not able to maintain their Hb in the Preferred range. Although there is no statistically significant association, we could observe that those who had had a history of hypertension before starting their first HD maintained their Hb level at a Preferred level more than those who did not have a history of hypertension. There is a slight increase in the number of patients who are not maintaining their Hb in the Preferred level noticed among the patients whose weight is more than or equal to 60 Kg. It is observed that most of the patients who could maintain their Hb at the Preferred level are the Patients who strictly follow renal diet instructions. There is a statistically significant association observed in Hb maintenance among non-diabetic Patients than that of diabetic Patients (Pr: 0.002). Patients who slept 5-8 hours at night showed good Hb maintenance and it is observed that increasing sleep hours from zero to eight hours has an increasing trend of Hb maintenance capacity (0.046). It is also observed that Patients using erythropoietin derivatives other than recombinant erythropoietin preparations had good Hb maintenance (0.0031).

The overall contribution of this study to Chronic HD patients:(See Figure 1).

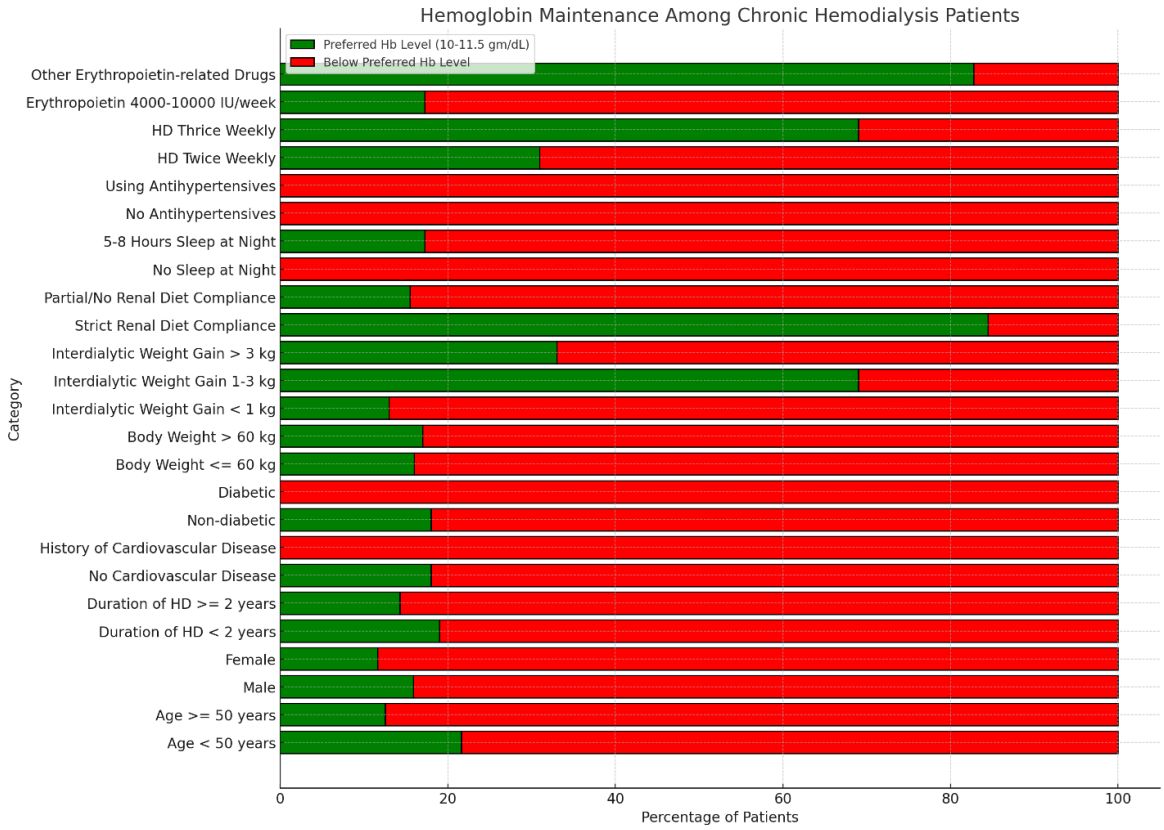

Figure 1; Haemoglobin maintenance based on patients' characteristics

1. This study could be able to identify the key factors like Age, History of diabetes, Duration of sleep at night and the use of erythropoietin-related agents; which affect the maintenance of Hb among Chronic HD patients.

2. The study could be able to identify the need for behavioural and lifestyle modification for the maintenance of Hb among chronic HD patients by revealing the effect of renal diet adherence and interdialytic management in Hb maintenance among Chronic HD patients.

3. Regarding clinical implications; This study could observe the effect of cardiovascular health on Hb maintenance among Chronic HD patients. Especially the history of cardiovascular disease and history of hypertension showed its effect on the maintenance of Hb among the patients.

4. This study suggests some change in Patient management and Treatment plans of Hb maintenance by incorporating factors like age, diabetes status, sleep duration, choice of erythropoietin-related agents, diet adherence and fluid management.

5. This study recommends implementing comprehensive education programs focusing on diet, sleep and overall lifestyle modification to help Hb maintenance among Chronic HD patients.

Analogies Between Hb Dynamics and System Equilibrium in Physics:

The findings highlight the potential of applying computational models from physics to clinical data analysis, offering new perspectives in interdisciplinary research.

- Behavioral and Lifestyle Modifications: Adherence to renal diets and adequate sleep patterns emerge as critical factors for improving Hb levels, like maintaining boundary conditions in physical systems.

- Clinical Implications: Insights from this study suggest a need for personalized treatment plans incorporating interdisciplinary methodologies to optimize patient outcomes.

5. Conclusion:

This study contributes valuable knowledge and practical recommendations that can enhance the management of anemia in chronic HD patients. By addressing a wide range of factors affecting Hb maintenance, the findings can help improve patient outcomes and quality of life, ultimately benefiting chronic HD patients not only in Punjab but globally. Age, History of diabetes, duration of sleep at night and long-acting erythropoietin-related agents are associated with Hb maintenance in the Preferred range with statistical significance. Overall, there is an observation about some of the factors and their effect on Hb maintenance in the Preferred range.

Our study could reveal the importance of considering factors like Age, Diabetes, sleep at night, and long-acting erythropoietin-related agents while managing anaemia among chronic HD patients. This study will help to implement more strategies to maintain the Hb level among chronic HD patients because it could explore most of the factors and their effects on Hb maintenance related to demographics, clinical, and behavioural characteristics of the patients.

Overall, This study underscores the value of interdisciplinary approaches in clinical research, drawing parallels between Hb maintenance in HD patients and system dynamics in high-energy physics. By exploring factors such as age, diabetes, and erythropoietin derivatives, the research provides actionable insights with broad scientific relevance. Future studies should expand on these methodologies, integrating computational tools from physics to enhance the understanding of complex clinical systems

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Conflict of interest:

There is no conflict of interest by any of the authors.

Declarations

Title of the Manuscript: "Interdisciplinary Dynamics of Haemoglobin Stability in Chronic Haemodialysis: A Statistical and Computational Approach". We, the authors, hereby declare that the manuscript entitled "Interdisciplinary Dynamics of Haemoglobin Stability in Chronic Haemodialysis: A Statistical and Computational Approach"is our original work and has not been submitted for publication nor has it been published in whole or in part elsewhere.

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The authors declare that there are no conflicts of interest or competing interests regarding the publication of this manuscript.

Ethics approval:

The paper was prepared from the PhD research “The effect of drinking water quality on Blood Pressure maintenance among the Chronic Kidney Disease Patients on Maintenance Haemodialysis” Ethical approval for the study sanctioned by Chitkara University Ethical Committee, Punjab. Ethics Committee Registration No. EC/NEW/INST/2020/531, issued under Biomedical & Health Research (NECRBHR), Department of Health Research (DHR), Government of India, New Delhi 110001).

Consent to participate:

Informed consent was obtained from all individual participants included in the study.

Consent for publication:

Not applicable

Availability of data and material:

The data supporting the findings of this study are available within the article and its supplementary materials. Any additional data can be provided upon reasonable request to the corresponding author.

Code availability:

Not applicable

Authors' contributions:

- Kiran VT: Conceptualization, Data Collection, Data Analysis, Manuscript Writing
- Jyotsna Kaushal: Supervision, Data Analysis, Review, and Editing
- Lakshmi Narayanan G R: Methodology, Manuscript Review.
- Daniel V: Review and editing.
- Bhagyashree Mishra: Review and editing.
- Ashok P.M. Reddy: Review and editing.

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