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Comprehensive Assessment of Clinical Parameters in Dialysis Patients with Glucose Disturbances: An Observational Study

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Abstract **Background:** Dialysis patients frequently experience anaemia and glucose disturbances. This study aimed to assess clinical parameters in dialysis patients with glucose disturbances, identify patient phenotypes and explore sex-based differences. **Methods:** This cross-sectional, observational study involved 21 adult patients on maintenance haemodialysis at a tertiary nephrology centre. Metabolic profiles were identified by analysing haematologic and biochemical parameters and performing hierarchical clustering. Serum creatinine was moderately negatively correlated with fasting glucose. **Results:** Patients had moderate anaemia (median haemoglobin 76.00 g/L [68.00-80.00]) and high glucose (8.09+/-2.76 mmol/L). Female patients had significantly higher MCV (90.73+/-6.28 vs 83.13+/-5.53 fL, $p<0.05$) and MCH (27.55+/-2.32 vs 25.21+/-1.55 pg, $p<0.05$) than males. Also, systolic blood pressure decreased from 161.90+/-25.41 to 146.67+/-26.19 mmHg during lying in bed, with an average weight loss of 2.19 kg. Haemoglobin correlated strongly with RBC count ($r = 0.90$), but less so with MCH ($r = 0.52$) or SF ($r = 0.55$). Serum creatinine demonstrated a moderate inverse correlation with fasting glucose. **Conclusion:** Our results indicate that hierarchical clustering might be a promising exploratory analytic approach to characterize metabolic heterogeneity among haemodialysis patients. However, validation in larger multicentre cohorts is needed before routine clinical implementation can be recommended.

Key Words Chronic Kidney Disease (CKD), Blood Glucose, haemodialysis, Cluster Analysis, Renal Dialysis

INTRODUCTION

Also referred to as chronic kidney disease (CKD), this condition not only impairs people's health but also poses a significant global health burden, accounting for 13.4% of the population and 4.9–7 million patients annually who require kidney transplants and other renal replacement treatments. [1]. We can see from Awad [2], Dhaidan [3] and Saeed Saadi *et al.* [4] that since the prevalence of people requiring dialysis in Iraq is by mid-2011, 141 patients per million (Ppm), this region is paying for their high rates with diseases not only in adults but also in children. Their primary routes into end-stage renal failure remain through diabetes or hypertension; meanwhile, nephritis (a kidney inflammation disease), etcetera gives many side profits as its people fall victim to greater numbers of heart attacks after what looks like is a sudden recovery from one bad night's nausea due nothing more than eating too many fried foods-ideas clean-up machine The burden of disease moves far beyond simple kidney dysfunction. Complications relating to metabolism frequently follow for dialysis patients, such as glucose disorders, mineral imbalances and hypoalbuminaemia -- all conditions are common in non-dialysis patients [5,6]. During the past several decades, many studies have shown how kidney failure can severely interfere with glucose metabolism in numerous ways. First, uraemia toxins promote hyperinsulinemia in the body [7,8]. Because the body's cells can't use these high amounts of glucose effectively anymore, this phenomenon creates a situation which is marked by insulin resistance, which seriously affects energy metabolism [9,10]. At the same time, the kidneys' functions decline so severely as to lose their own production of sugar and they take out less insulin, causing a major setback for sufferers in their attempts at metabolic control [11]. Hence, diabetic dialysis patients often have high blood sugar levels. Not only this, but patients undergoing peritoneal dialysis experience additional glucose loads from the peritoneal dialysate [8]. More than simply metabolic difficulty, taking care of these patients brings unique

monitoring challenges. Health care professionals have to juggle a number of different prominent facets of the disease all at once; when they do one better, it often results in fewer strikes elsewhere [12,13]. Likewise, sex-based differences also add even more complications to care delivery. Women receive fewer specialist referrals and guideline-recommended therapies, despite having different inflammatory and biochemical patterns than men [14,15]. These distinctions continue independent of disease severity, highlighting the necessity for personalised approaches. Still, there are well-known problems of critical knowledge left. Plus, clustering patterns of clinical parameters are not well understood either. That means predictive work on complications is postponed [13,16]. Some things remain unclear about how the haematological and metabolic markers all fit together [17]. Furthermore, everything only depends on how we classify patients at present--and this is based on a single parameter. Multiple interaction of a series of them is not taken into account [18]. Antibodies against these receptors probably cause intractable hypotension occasionally in dialysis patients with Type I diabetes. No research has been carried out in this area among patients with NIDDM. Therefore, our research is to study clinical parameters. We would like to go into every detail of such cases by taking a comprehensive approach. We particularly aim to answer three questions: (1) Whether clusters of patients' "haematological markers" vary with sex, (2) Do different combinations in metabolic interactions show correlations with one. Most previous studies have focused on isolated biochemical or haematological parameters. Relatively few investigations have explored the complex interactions among metabolic markers by multivariate analytical approaches. In particular, the use of hierarchical clustering to identify clinically relevant metabolic phenotypes in haemodialysis patients has been limited, especially in developing countries and Middle Eastern populations. Moreover, conflicting evidence exists regarding the association of glucose abnormalities with routine laboratory parameters in patients on maintenance haemodialysis. While some studies have reported significant associations between glycaemic status and haematological or biochemical indices, other studies have not been able to demonstrate consistent findings, suggesting that the heterogeneity of patients may influence these relationships. Therefore, there is a need for integrated analytical approaches to disclose hidden patterns not detectable by conventional statistical methods alone.

To our knowledge, no previous study has fully integrated routine haematologic parameters, biochemical biomarkers and hierarchical cluster analysis for the description of metabolic heterogeneity in Iraqi haemodialysis patients. Filling this knowledge gap may offer preliminary evidence for improved patient stratification and produce hypotheses for future precision-based management strategies. Therefore, the present study was performed to assess the interrelations between glucose derangements and basic haematological and biochemical parameters in maintenance haemodialysis patients by using traditional statistical analysis together with hierarchical clustering methods. Therefore, the present study aimed to investigate the relationships between glucose abnormalities and routine haematological and biochemical parameters in patients undergoing maintenance haemodialysis using conventional statistical analysis together with hierarchical clustering techniques.

METHODS

Study Design and Patients

This observational, cross-sectional study aimed to assess clinical parameters in dialysis patients at Al-Batoul Teaching Hospital for Children and Maternity who also have glucose abnormalities. The Research Ethics Committee of the Teaching Hospital approved the study protocol from March to August,2025. Before participation, each subject provided informed consent. A total of 21 adult patients undergoing maintenance haemodialysis were recruited for this study. Inclusion criteria: 1) confirmed diagnosis of end-stage renal disease requiring regular haemodialysis, 2) abnormalities in glucose metabolism (fasting glucose levels above 7.0 mmol/L and/or history of diabetes mellitus), 3) a stable dialysis regimen for at least three months. Excluded criteria: 1) hospital or acute illness within the past month, 2) active malignancy, 3) pregnant or 4) has not signed informed consent. In addition to the predefined inclusion and exclusion criteria, clinical variables that may influence haematological parameters were considered during patient assessment whenever available. This included dialysis duration (months on maintenance haemodialysis), dialysis adequacy assessed by Kt/V, diabetic status, current medications (particularly erythropoiesis-stimulating agents, iron supplementation and antidiabetic therapy) and the presence of major comorbidities such as hypertension, cardiovascular disease, chronic inflammatory disorders and liver disease. These variables were obtained from the patients' medical records so as to reduce the possible confounding effect of these variables on the haematologic and biochemical measurements.

Anthropometric and Laboratory Analysis

Before and after each dialysis session, with the help of calibrated digital scales, we recorded the patient's body weight. Patients were in light clothes without shoes and just to keep consistency, bound onto the same scale. Furthermore, blood samples were drawn before the mid-week haemodialysis session and placed in EDTA tubes. These included haemoglobin concentration (Hb), packed cell volume (PCV), red cell (RBC's) count, mean cell volume (MCV), mean cell haemoglobin concentration (MCH), mean cell haemoglobin content (MCHC). All analyses were performed using automated haematology analysers within two hours of collection Every result was calibrated against the control ingredient. Concurrently, biochemical markers were evaluated, which included serum glucose, urea and calcium levels as well as the strength of the iron. Glucose

measurements were performed after a fasting period of 8 hours. All biochemical analyses were carried out according to standard laboratory

Haemodynamic Monitoring

Initial dialysis and blood pressure were recorded at three points in time measurements: before starting dialysis (SBP-1, DBP-1); halfway through the dialysis session (SBP-2, DBP-2); and just at the end of dialysis (SBP-3, DBP-3). Measurements followed the conventional protocols from standard calibrated automated sphygmomanometers, with the patient seated after resting for five minutes.

Statistical Analysis

R has been used in this version. Statistical analysis utilised it quite well. For each variable, descriptive statistics have been calculated; whether not it is a normally distributed dataset has been shown with medians [quartiles] and normally distributed datasets can be shown as means (with standard deviations). Categorical data were expressed in frequencies and percentages. Normally distributed variables were compared across male and female patients using independent t-tests, whereas the non-normally distributed variables underwent Mann-Whitney U tests. Changes in blood pressure and weight were observed over dialysis stages by means of density plots. Pearson's correlation coefficient was used to assess the correlations between haematological as well biochemical parameters. It is the corresponding heatmap here which tells you this visually. Principal Component Analysis (PCA) was performed on the data's structure.

RESULTS

All parameters for the basic and clinical characteristics of dialysis patients are presented in Table 1.The study population consisted of 21 patients (including 11 females at 52.4% and 10 males at 47.6%).Haematological parameters revealed moderate anaemia among patients, with a median haemoglobin concentration of 76.00 g/L (IQR: 68.00-80.00)and a median packed cell volume (PCV) of 0.24 L/L (IQR: 0.22-27).Median red blood cell count stood at 2.70 million/μL (IQR: 2.40-3.10).Moreover, the renal function markers are all as expected in dialysis patients. Median creatinine levels soared to 410.00 mmol/L (IQR: 234.00-590.00) in addition to mean urea concentrations of 15.66 mmol/L (SD: 6.46). In addition, glucose levels were on average at 8.09 mmol/L (SD: 2.76), which confirms disturbances in glucose metabolism. Mineral metabolism parameters gave a median serum iron of 42.00 μg/L (IQR: 31.00-60.00), mean serum calcium (Table 1).

Haematological indices showed varied relationships between male and female dialysis patients, as exemplified by the relationship between haemoglobin levels and haematocrit (Figure 1). Haemoglobin levels averaged an all-time high in males (77.80±17.01 g/l) compared to females (74.64±11.02 g/l), though the margin of difference did not reach statistical significance (p>0.05, In addition, PCV and

Table 1: Descriptive statistics of basic and clinical characteristics

Characteristics	Value
Male	11 (52.4)
Female	10 (47.6)
Hb (g/L)	76.00 (68.00, 80.00)
PCV (L/L)	0.24 (0.22, 0.27)
RBC count (million/c.c.)	2.70 (2.40, 3.10)
MCV (fL)	87.11 (6.97)
MCH (pg)	26.43 (2.28)
MCHC (g/L)	306.95 (17.52)
Glucose (mmol/L)	8.09 (2.76)
Urea (mmol/L)	410.00 (234.00, 590.00)
Creatinine (mmol/L)	15.66 (6.46)
Iron (mg/L)	42.00 (31.00, 60.00)
Calcium (mmol/L)	2.18 (0.40)

For normally distributed variables, the data are displayed as mean (standard deviation), for non-normally distributed variables, as median [interquartile range] or for categorical variables (sex), as n (%). Hb stands for haemoglobin; PCV for packed cell volume; RBCs for red blood cells; MCV for mean corpuscular volume; MCH for mean corpuscular haemoglobin; and MCHC for mean corpuscular haemoglobin concentration.

RBC showed minimally increased numbers for men. These disparities, however, also failed to achieve statistical significance. MCV values were significantly larger in females (90.73±6.28 fL) than in males (83.13±5.53 fL, p 0.05). Iron levels were significantly greater in females (48.36±18.18 ug/l) than in males (37.70±21.72 ug/l), which may suggest the better iron status of female patients. Calcium levels were similar between the two sexes indicated slightly higher values for women (2.23±0. 39 mmol/1) than for men (2.13±0.42 mmol/1).

Density plots of blood pressure measurements demonstrate a clear trend in the effectiveness of dialysis in treating high blood pressure among patients (Figure 4). Before patients underwent dialysis, the mean SBP-1 (systolic blood pressure) reading was 161.90±25.41 mmHg, thus indicating that many of them had hypertension. The density function for this pre-dialysis measurement would of this wider disappear and move to higher values. As the process of dialysis went on, we can clearly see a shift in the distribution of blood pressure. During dialysis, the systolic blood pressure (SBP -2) fell to a mean value of 153.33±31.62 mmHg. The density of cases at the peak for this mid-dialysis measurement is probably distributed as they move from high to low. This continued into post-dialysis measurements (SBP-3), where the mean declined further to 146.67±26.19 mmHg. The density of cases near the mid-point for SBP-3 would show a dramatic shift and most would fall at those low, closer-to-normal values after dialysis. Moreover, diastolic blood pressure showed a different trend (Figure 5). The pre-dialysis mean (DBP-1) was 83.33±37.37 mmHg, while later measurements saw little change (DBP -2: 82.38±22.62 mmHg; DBP-3: 82.86±16.78 mmHg). The density functions for DBP likely had a smoother spread across all three times, with noticeable reductions in variability as reflected by decreasing standard deviations in the data. Regarding weight, the density plots show that dialysis takes fluid out of the body. (Figure 6) The distribution of pre-dialysis weight (mean 79.57±24.32 kg) was right-shifted compared to the post dialysis distribution

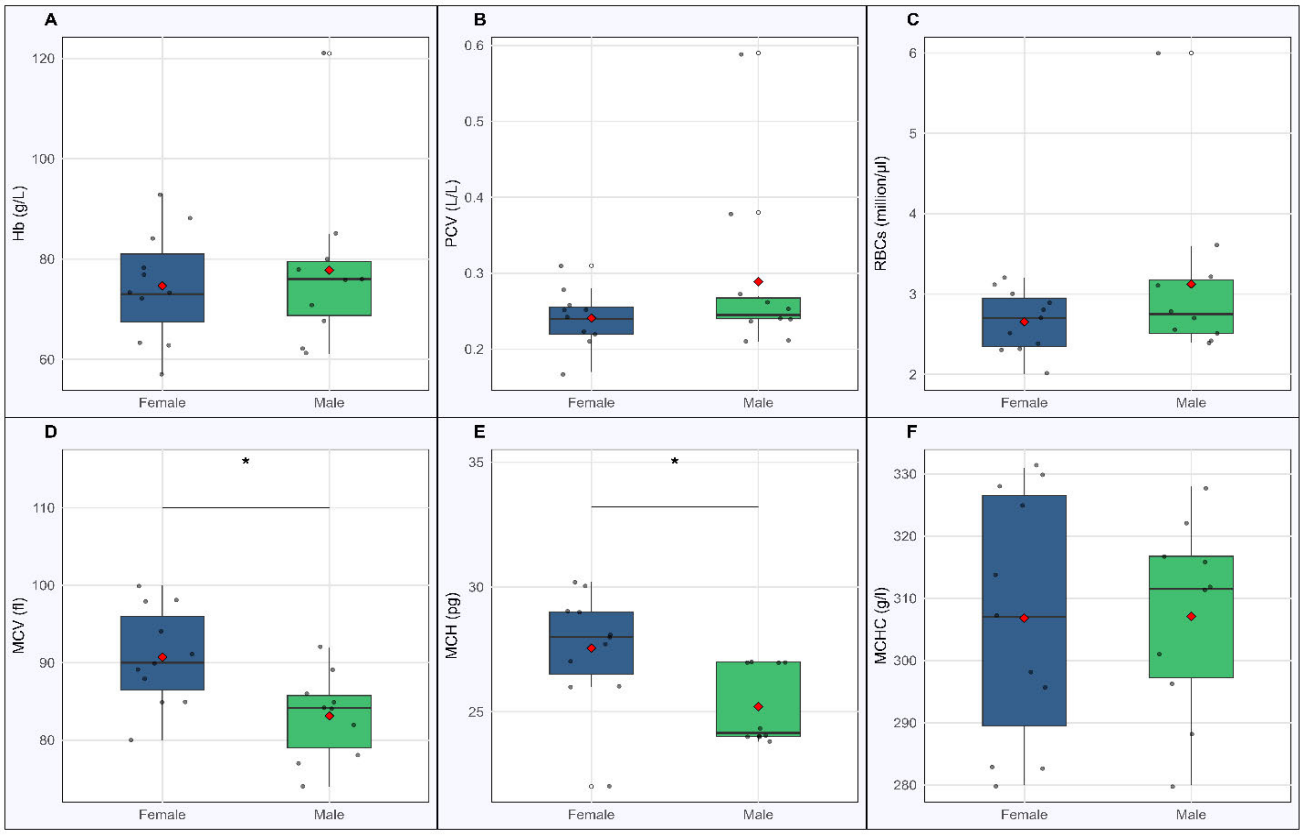

Figure 1(A,B,C,D,E,F): Haematological parameters by sex in dialysis patients. Among the parameters are: A) Haemoglobin (Hb), Packed cell volume (PCV), red blood cell count (RBCs), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH) and mean corpuscular haemoglobin concentration (MCHC). Male and female patient data are displayed side by side for each metric. The median is shown by a horizontal line and the boxes show the interquartile range (IQR). Within 1.5 times the IQR, whiskers reach the maximum and lowest values. The distribution is displayed by superimposing individual data points. If present, asterisks (*) above the boxes denote statistically significant differences between the sexes ($p<0.05$)

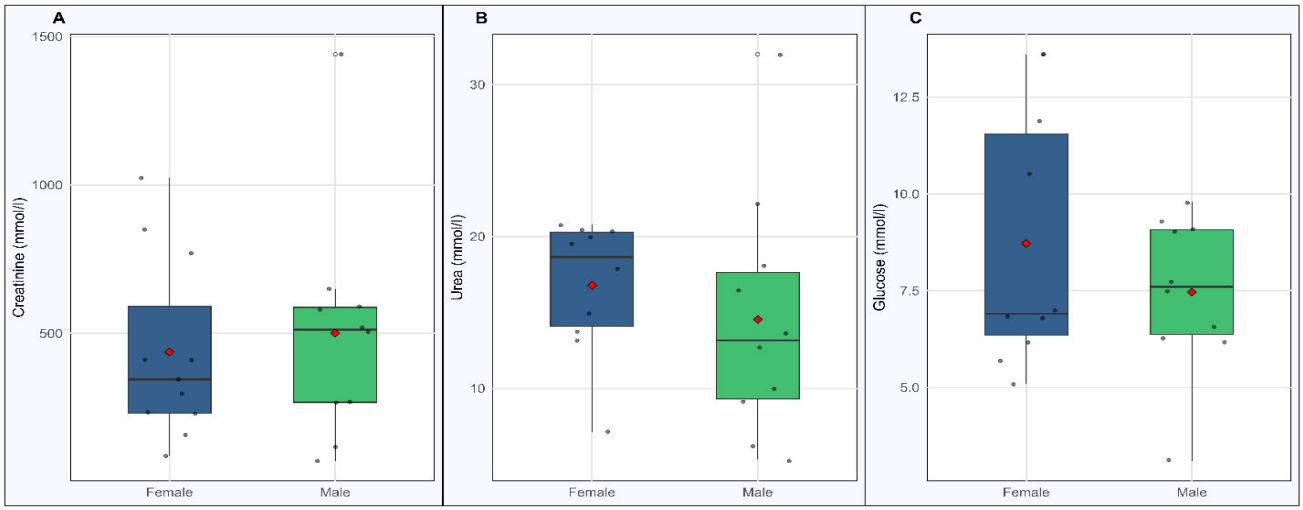

Figure 2(A,B,C): Renal function parameters and glucose in male and female dialysis patients. The following parameters are shown: A) Creatinine, B) Urea and C) Glucose. Each box plot represents the distribution of this parameter for male and female patients. The boxes show the IQR with the median line as well as whiskers to minimum and maximum values within 1.5 times its length. Individual data points are plotted in order to illustrate spread of datum sets. Statistically significant differences between sexes, where present, are indicated by asterisks (*) above the respective boxes. ($p<0.05$)

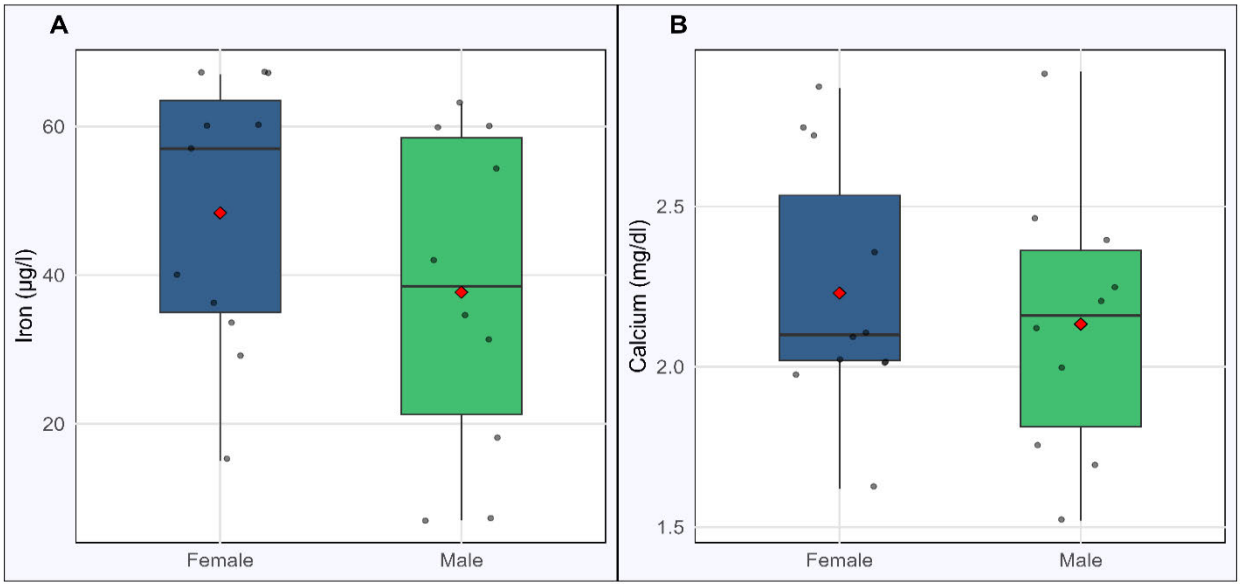

Figure 3 A&B: Serum iron and calcium levels in male and female dialysis patients: According to sex, the range of serum iron and calcium. For each parameter, box plots show the IQR (box), range (whiskers extending 1.5 times the height of the IQR) and median. For a full picture of the distribution, individual points are superimposed on top of this. Place an asterisk (*) over the relevant box for every statistically significant difference in means between male and female patients ($p<0.05$).

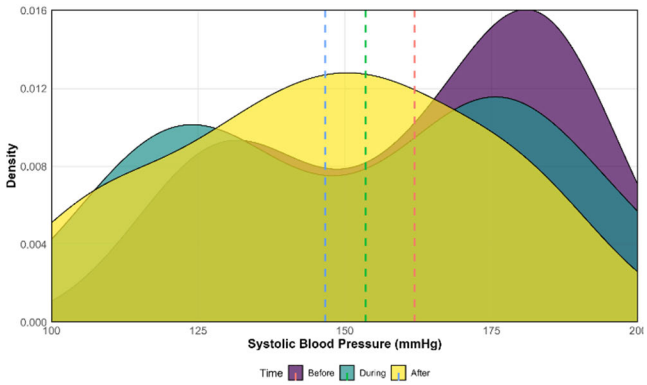

Figure 4: Different dialysis stages blood pressure of system distribution. Studying the effects of dialysis on systolic blood pressure values for patients at different stages. As with before dialysis, SBP-1, during dialysis (SBP-2) and after dialysis (SBP-3). The curves of distribution graph are the probability density function of SBP values at a particular time. The x-axis shows SBP in mmHg and the y-axis represents density. Overlapping areas signify that within the area are similar SBP intervals at all stages, while shifting positions of peaks would indicate change of regular mean SBPs during the dialysis process. The vertical dashed lines are mean SBP for each stage.

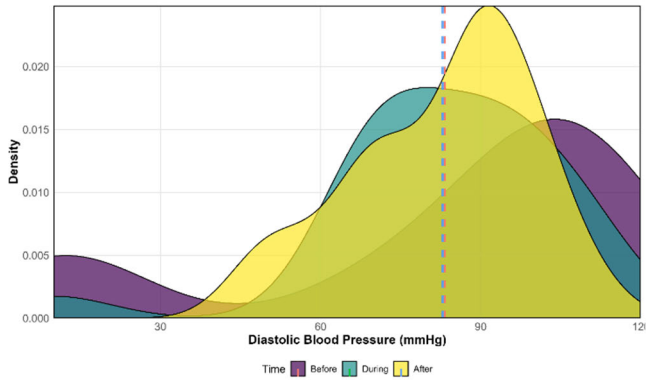

Figure 5: Distribution of fasting blood glucose levels in haemodialysis patients and healthy controls. Data are presented as boxplots showing the median, interquartile range and outliers. Statistical significance was assessed using the Mann–Whitney U test.

(mean 77.38±23.73 kg). This shift from above to below for the peak in the plot shows that weight loss was quite consistent across patients by the time dialysis ended. According to our records, an average of 2.19 kg was lost every treatment session in an average patient group.

According to Pearson's product-moment analysis (Figure 7), there are many interesting correlations among haematological and biochemical markers in dialysis patients. PCV was moderately correlated with Hb (r = 0.49) and RBCs (r = 0.49), while Hb was highly correlated with RBC count (r = 0.90). Both MCV and MCH had negative correlations with RBCs (r = -0.55 and r = -0.39 respectively), but positive associations (r = 0.71). Moreover, creatinine was negatively associated with calcium (r = -0.53) and glucose (r = -0.49) and rather positively associated with urea (r = 0.68). MCH (r = 0.56) and MCHC (r = 0.49) had rather good relations with iron. Finally, calcium was moderately related to PCV (r = 0.40) and moderately negatively associated with creatinine (r = -0.53).

We used Principal Component Analysis (PCA) (Figure 8) to uncover the intricate, multifaceted linkages in the dialysis

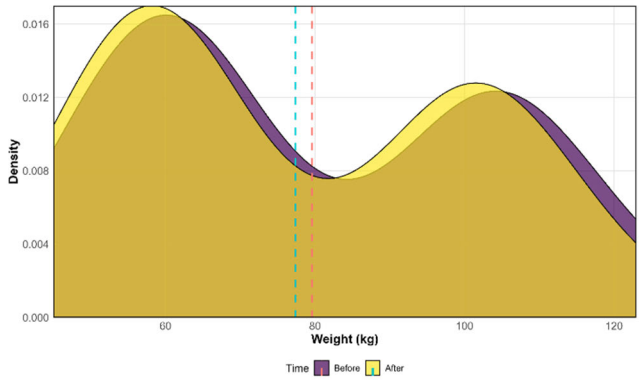

Figure 6: Compared with pre-dialysis, patient weight differs after dialysis. This density plot compares the distribution of patient weights before and after dialysis. Weight is on the x-axis in kilograms, while density is shown on the y-axis. These two curves demonstrate that there is a shift in weight distribution between pre- and post-dialysis. Having the portion volume that is fluid from far-left end of curves (which must reflect patient weights), marked by a vertical dashed line, removed for dialysis and leaving only the bit right here in the middle really makes for a great demonstration effect. Horizontal dashed lines mark mean weight for each time point, making a visually clear indication of the shift in average weight

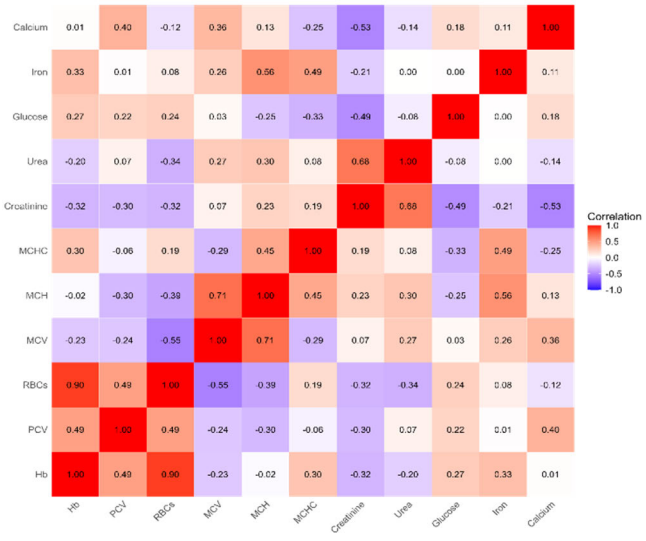

Figure 7: A heat colour scale is used to depict correlation coefficients. This ranges from -1 (dark blue) to 1 (dark red). Every cell in the matrix displays correlation coefficients. Hb represents Haemoglobin; PCV is Packed Cell Volume; RBCs Red Blood Cells; MCV Mean Corpuscular Volume; MCH Mean Corpuscular Haemoglobin; and MCHC Mean Corpuscular Haemoglobin Concentration

patient data that may not be seen from straightforward pairwise correlations. According to this method, PC1 and PC2--the first two principal components explained 25.17% and 18.68% of the total variance in the dataset, respectively,

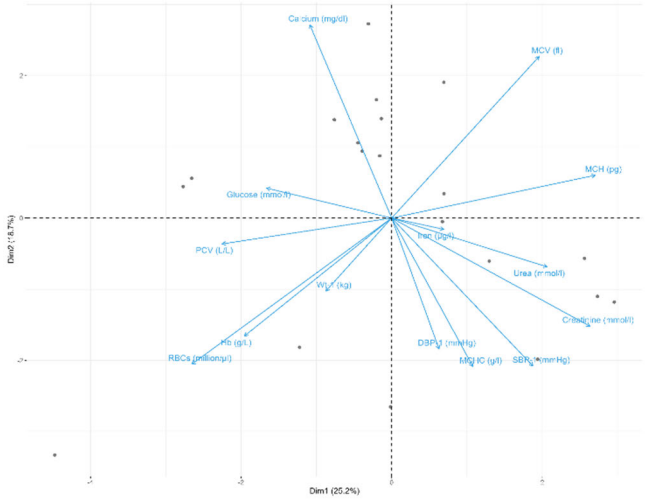

Figure 8: Heatmap illustrating Pearson correlation coefficients among haematological and biochemical parameters.

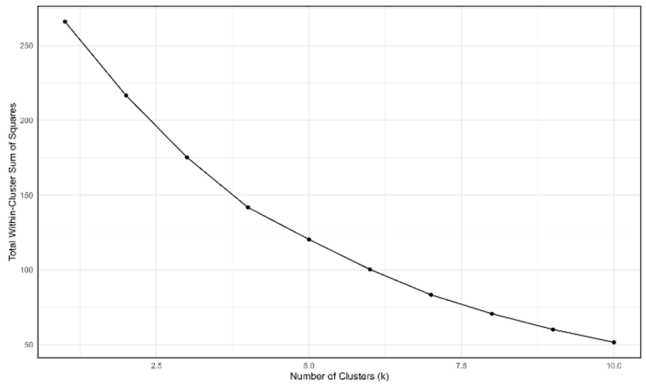

Figure 9: An elbow plot on dialysis patient data by K-means clustering. The x-axis denotes the number of clusters (k) and the y-axis represents the total within-cluster sum of squares (WSS). As Ask goes up, WSS tends to fall. The reducing rate breaking point, which balances cluster tightness and number, is the best k.

accounting for 43.85%. With fewer than half of all variabilities covered by just two of these first components, relationships across normally measured parameters among dialysis patients must be very complex. The first two principal components explain 43.85% of the total variance. This indicates that over half of the biological variability is not explained by the first two principal components. This is expected for clinical datasets with heterogeneous patient populations and multifactorial biological processes. Thus, PCA should be considered a dimensionality reduction method for visualising dominant trends and not as a complete representation of the underlying biological variability.

The PCA biplot also reveals relationships among variables and how they contribute to principal components, making it possible for patterns and relationships among these

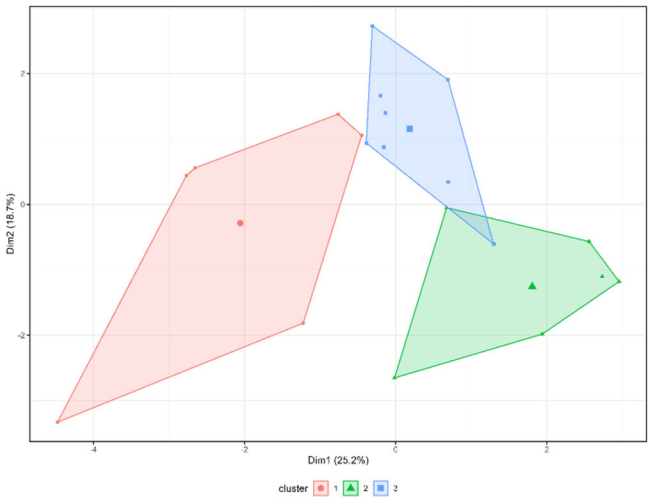

Figure 10: Principal component analysis (PCA) biplot showing sample distribution and variable loadings. PC1 and PC2 explained 43.85% of the total variance.

measured parameters to become evident. Furthermore, we used the elbow plot (Figure 9) to determine the optimal number of clusters for K-means clustering. From the plot, three clusters were identified as the optimum number, balancing between the number of clusters and the within-cluster sum of squares. The K-means clustering algorithm was then used to group patients with similar characteristics. Here, the resultant cluster plot (Figure 10) shows these three distinctive groups of patients in terms of the principal components, with each cluster represented by a different colour (red, green and blue). Each theoretically represents a different clinical profile in dialysis patients. Cluster 1 (red) is characterised by higher haemoglobin levels (mean 80 gl" I) and packed cell volume (0.325 L/L), implying better anaemia management. Cluster 2 (green) has the smallest haemoglobin levels (70.2 g/L) and packed cell volume (0.223 L/L); possibly a situation of more severe anaemia. Cluster 3 (blue) is intermediate in terms of haemoglobin levels (76.8 g/L) but highest on average corpuscular volume (92 fL), a pattern which could suggest an alternative aetiology for anaemia.

Nevertheless, multivariate analysis showed heterogeneous dialysis patients. Alternatively, the use of haematological and biochemical parameters to delineate patient clusters is a good way for clinicians help predict what course a patient with ESRD might experience should infarction or sepsis occur again. Given this, cluster 2 patients may need to be given more aggressive anaemia management, while cluster 1 patients appear to be already receiving optimal therapy. In addition, the differences in other parameters such as creatinine, urea and blood pressure across clusters (as shown by the cluster centroids) suggest that these groups may differ. While several biomarkers had statistically significant differences between the groups, the interpretation of the differences should not be based on statistical significance alone. Elevated creatinine and urea are suggestive of impaired renal clearance and reduced glomerular filtration which are characteristic of end-stage kidney disease and not isolated biochemical abnormalities. Similarly, decreased levels of haemoglobin are clinically consistent with decreased production of erythropoietin and chronic inflammation that is often found in dialysis patients. Therefore, the observed statistical differences also have obvious biological and clinical significance in the pathophysiologic context of chronic kidney disease.

DISCUSSION

This investigation demonstrated severely abnormal clinical pictures of glycaemia derangement in dialysis patients, with a median haemoglobin concentration = 76 g/L (moderate anaemia). This is consistent with the many reports that show the prevalence of anaemia of between 57.7-89.8% in HD populations [19,20]. The degree of anaemia in this cohort is of special concern as haemoglobin levels <80 g/L have been reported to be associated with double the mortality risk [21]. Second, the median packed cell volume (0.24 L/L) of the patients in our study is consistent with those reported in other CKD populations [22,23] and clearly reflects a marked degree of erythropoietic dysfunction. These patients' haemoglobin concentrations are well out of the range advocated in current guidelines (10-12 g/dL) yet closely represent the discordant haematocrit levels described and measured globally [24,25].

The average level of Gb 8.09 mmol/L observed in the present dialysis patients represented a severe disturbance of glucose metabolism which correlates with previous studies indicating that disturbances of glucose are very common among these patients. New-onset hyperglycaemia is detected in 27.3% of non-diabetic patients treated with PD and even mild hyperglycaemia adversely affects survival [26]. The present findings are in the critical zone where attentive control is warranted, as both hyperglycaemia and hypoglycaemia carry similar risk in dialysis patients [27,28]. The difficulty of glycaemic control in dialysis is reported in that hyperglycaemia due to dialysis has distinct features, as those patients have a more dynamic condition of glycaemic changes than non-kidney-disease individuals [29].

An interesting observation was the marked sex differences in erythrocyte indices, wherein females showed higher values of MCV (90.73±6.28 fL) and MCH (27.55±2.32 pg) as compared to males. These findings correspond with emerging evidence on sex-related differences in CKD complications [14,15]. Nominally, women had a lower haemoglobin but higher corpuscular indices indicating likely compensatory or indeed different iron metabolic pathways. This is corroborated by studies, which demonstrate that although women with CKD are in general at lower risk of progression of the disease, they may exhibit differences in the patterns of complications [30,31]. The clinical implications of these disparities require consideration as sex-specific anaemia-management strategies might better optimise clinical outcomes.

The decreasing trend of SBP from 161.90 to 146.67 mmHg observed in our study during dialysis is indicative of a successful intradialytic blood pressure control in this study population. This trend also follows previous reports that the

prevalence of pre-dialysis systolic blood pressure ≥160 mmHg is as high as 24.6% in haemodialysis patients [32] and underlines that effort for BP control are still insufficient for this cohort subset. The average fluid removal of 2.19 kg per treatment is within the spectrum of standard amounts required for volume control, however novel data implicate that ultrafiltration rates should be meticulously controlled since an UF rate exceeding 10-13 ml/h/kg leads to increased mortality [33,34]. The consistent diastolic blood pressure profile during dialysis within this population indicates sound fluid removal tactics which are used to achieve the fine line between volume control and haemodynamic stability.

The negative relationship between creatinine and glucose (r = -0.49) further supports the possibility of complex metabolic interactions in uraemia possibly including the thus far undescribed effect of changes in glucose metabolism with advanced kidney disease, where derangements in renal gluconeogenesis and insulin clearance lead to different underlying metabolic phenotypes [35]. In addition, the negative correlation found between calcium and creatinine (r = -0.53) is consistent with previous studies demonstrating derangement of bone mineral metabolism in CKD patients as there a reduction in kidney function leads to hypocalcaemia [36].

In this analysis, multidimensional evaluation of the entire range of parameters serves to underline the interrelated nature of complications among dialysis patients with glucose disorders. Interrelationships between anaemia, glucose metabolism and mineral disorders highlight the importance of integrated management strategies. Mineral bone disorders, such as calcium–phosphate balance and parathyroid hormone status, have been demonstrated to be associated with anaemia in CKD patients [37]. In addition, the attainment of guideline-recommended targets for both mineral metabolism and anaemia therapy continues to be disappointing, with therapeutic inertia being more frequent than overtreatment [38-40].

CONCLUSIONS

In summary, this study suggests that PCA and K-means clustering may be useful exploratory analytical methods to detect potential biological heterogeneity among patients on haemodialysis. However, these findings should be regarded as preliminary, as the clustering analysis was conducted in a rather small sample without external validation. Larger multicentre studies with independent validation cohorts are needed before these clustering patterns can be translated into clinically applicable patient phenotypes or individualised therapeutic strategies.

Strengths

However, this is one of the few studies to combine unsupervised machine learning techniques with traditional statistical analysis to characterize the biochemical and haematological profiles of haemodialysis patients with glucose abnormalities. This framework of integrated analysis gives an exploratory basis for future research in precision nephrology.

Limitations

There are several limitations to the present study. First, the cross-sectional design does not allow for causal inference. Second, the small sample size (n = 21) may reduce statistical power and decrease cluster stability. Third, the clustering results were internally generated, without external validation. Finally, the single-centre nature of the study limits the generalisability of the results. Therefore, larger, multi-centre studies are needed to confirm these preliminary findings.

Ethical Statement

The study was conducted following the ethical principles of the before the sample was collected, written informed consent was obtained from all participants prior to sample collection. The University of Diyala, college of Education for Pure Sciences, reviewed and approved the study protocol.

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