Research Article

Correlations of parathormone and biochemical parameters in chronic kidney disease

Hamide Shllaku-Sefa[1*], Ndok Marku[1]

[1]*Laboratory Department, Catholic Hospital "Our Lady of Good Counsel", Tirana, Albania*

Article Info

[*]***Corresponding Author:***
Hamide Shllaku-Sefa
E-mail: sefadea@gmail.com
Tel.: 00355695305242
Address: Street Dritan Hoxha, Tirana, Albania

Keywords

Calcium, CKD, eGFR, phosphorus, PTH

Abstract

Introduction: Hyperparathyroidism due to chronic kidney disease (CKD) is a common complication characterized by elevated parathyroid hormone (PTH) levels secondary to derangements in the homeostasis of calcium and phosphorus. The aim of our study was to figure out PTH, calcium, phosphorus, and magnesium levels in CKD and the possible correlations between them and the stages of CKD.

Materials and Methods: We performed a prospective study including 217 outpatients with levels of serum creatinine out of reference range from February 2023 to July 2024. We calculated the glomerular filtration rate (eGFR) with the 2021 CKD-Epi equation using serum creatinine. We used Jamovi Statistical Software version 2.3.28. A "p" value equal to or less than 0.05 was considered statistically significant.

Results: We had 105 females (48%) and 112 males (52%), median age 72 years (35-94yrs). We found differences in PTH and phosphorus levels between distinct stages of CKD. For PTH the differences were found between stages IIIa and IV ($p<0.001$), IIIb and IV ($p=0.001$), while for phosphorus between stages IIIa and IIIb ($p=0.003$), IIIa and IV ($p<0.001$), IIIb and IV ($p=0.01$). We found correlation between eGFR and PTH ($r= -0.360$, $p=0.001$), eGFR and calcium ($r=0.169$, $p=0.015$), eGFR and magnesium ($r= -0.153$, $p=0.028$), eGFR and phosphorus ($r= -0.336$, $p<0.001$).

Conclusions: We concluded that there is a statistically significant correlation between PTH and stages of CKD, but the strength of correlation is low, it cannot be generalized, therefore each patient with CKD must be assessed individually.

Introduction

Chronic kidney disease (CKD) is a progressive condition that affects more than 10% of the general population worldwide, amounting to over 800 million individuals [1].

One crucial complication of CKD is secondary hyperparathyroidism (SHPT), marked by elevated parathyroid hormone levels due to hyperphosphatemia, hypocalcemia, and low active vitamin D from impaired renal function [2].

According to the kidney disease: Improving Global Outcomes (KDIGO) guidelines, SHPT screening should begin at CKD stage III-that is, when the eGFR drops below 60 mL/min/1.73 m^2 [3].

In our daily practice, we have noticed that PTH as a biomarker in CKD is slightly overestimated by clinicians.

The aim of our study was to measure levels of PTH, calcium, phosphorus, and magnesium and assess their correlation with CKD stages.

Materials and methods

We performed a descriptive and prospective study. We identified patients with an elevated serum creatinine level more than 1.02 mg/dL for females and more than 1.3 mg/dL for males, from all patients subjected to blood sampling for chemistry analyses at Polyclinic Father Luigi Monti and Catholic Hospital "Our Lady of Good Counsel" Tirana, Albania during the period February 2023 through July 2024.

To keep the confidentiality of participants' data, we coded the identity of each participant in the study, according to The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

Peripheral venous blood was collected in BD Vacutainer SST II Advance 3.5 mL tubes and processed within 2 h from collection. Creatinine, calcium, magnesium, phosphorus, were analyzed on an integrated chemistry system Dimension EXL 200 (SIEMENS) according to the routine methods and the manufacturer's instructions. We stored 1 mL of serum for each patient, including in our study at -20 degrees Celsius and measured PTH on ADVIA Centaur XPT (SIEMENS) with chemiluminescence.

We calculated the estimated glomerular filtration rate (eGFR) with the 2021 CKD-Epi equation using serum creatinine.

Statistics

All data management and statistical analyses were performed using Jamovi Statistical Software version 2.3.28. We performed basic descriptions for all variables, and we have studied frequencies. We used the Shapiro-Wilk test for normal distribution. We tested differences with Kruskal-Wallis for non-parametric variables between more than two groups. We performed Pearson's correlations; a two-sided p-value of 0.05 or less was considered statistically significant. We did linear regression analysis, and we used coefficient "t" to measure the statistical significance of an independent variable in explaining the dependent variable, and r^2 (coefficient of determination) to measure the percentage of the variation in the dependent variable that is explained by variation in the independent variable.

Results

From February 2023 to July 2024, 4731 patients performed a serum creatinine test in our laboratory, of which 217 patients had abnormal serum creatinine levels. The prevalence of chronic kidney disease for our patients was 4.6%. Our sample had 105 females and 112 males, with a median age of 72 years old (35-94 years old).

The key characteristics of the patients according to age group classification are summarized in Table 1.

Table 1: The key characteristics of the patients according to age group classification.

	Age group	eGFR (mL/min/1.73 m2)	PTH (pg/mL)	Calcium (mg/dL)	Magnesium (mg/dL)	Phosphorus (mg/dL)
Reference ranges*		≥ 90 G1 60-89 G2 45-59 G3a 30-44 G3b 15-29 G4 < 15 G5	18.5-88	8.5-10.1	1.8-2.4	2.6-4.7
Number of patients	≤ 65 yrs	47	47	47	47	47
	66–75 yrs	82	82	82	82	82
	> 75 yrs	88	88	88	88	88
Median	≤ 65 yrs	49	66	9.3	2	3.6
	66–75 yrs	44	74	9.4	1.9	3.4
	> 75 yrs	42	96	9.3	2.1	3.6

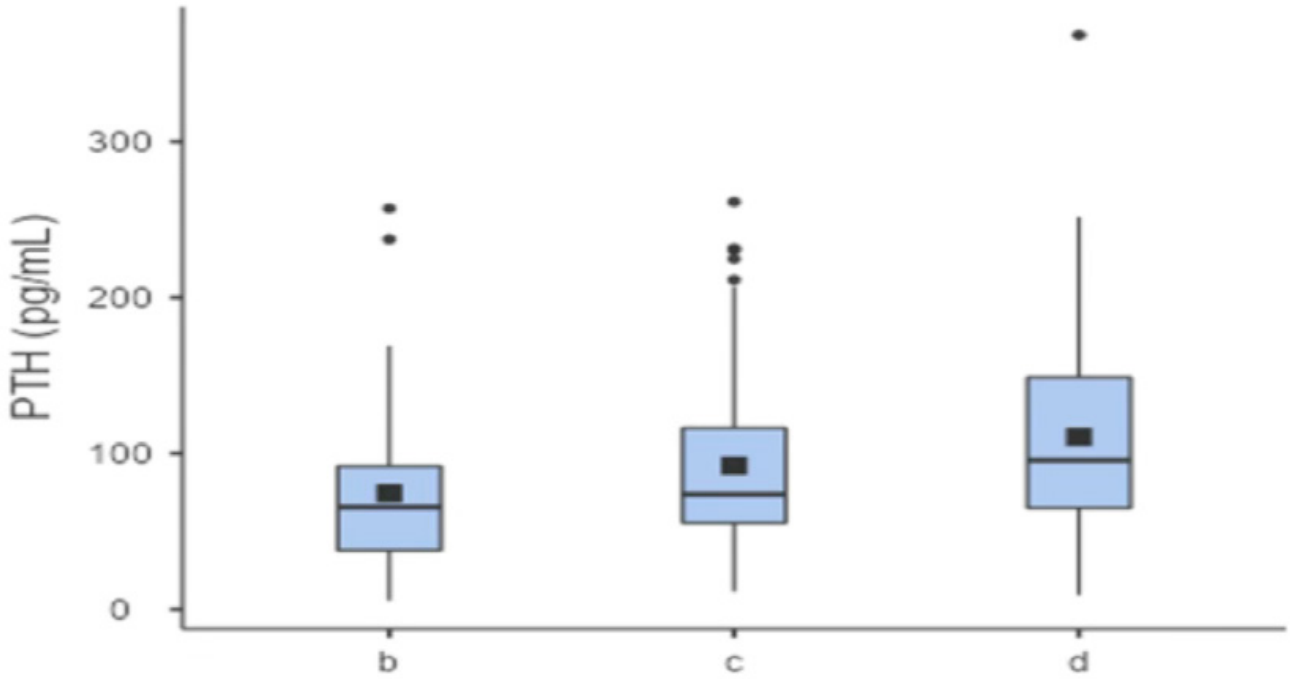
Minimum	≤ 65 yrs	21	6	6.9	1.3	2.6
	66–75 yrs	20	11	8.2	1.3	1.6
	> 75 yrs	7	9	6.6	1.3	1.8
Maximum	≤ 65 yrs	73	257	12.5	3.2	5.9
	66–75 yrs	59	261	12	2.9	5.4
	> 75 yrs	58	368	12.2	4	6.3
IQR	≤ 65 yrs	41-58	38-92	8.8-9.6	1.8-2.3	3.3-4.1
	66–75 yrs	37-52	55-116	9.0-9.8	1.7-2.2	3.1-3.8
	> 75 yrs	34-47	65-149	9.0-9.7	1.9-2.3	3.2-4.0

*The reference range for the eGFR was based on the KDIGO 2012 clinical practice guidelines, while the reference range for the PTH, calcium, magnesium and phosphorus were based on instructions for use papers provided by manufacturers.

Patients were divided into three groups: ≤ 65 years old, 66-75 years old, and older than 75 years old. The groups had more than 30 outpatients, but the data was not normally distributed. We used the median instead of the mean to show the central tendency and the IQR (interquartile range) instead of standard deviation to measure the variability.

We found that the dominant age group was > 75 years, with 40%, while only 22% of outpatients were ≤ 65 years old. It is noticeable that, except for PTH (Figure 1), in the age group over 75 years old where median was higher than the reference, all the other variables have a median within the range of reference values. The maximum value for all variables was present in the age group > 75 years, except for calcium, which was found in patients ≤ 65 years old. We found that for all age groups the IQR was within the range of reference values for all variables except for PTH which had an upper limit of IQR outside the reference value.

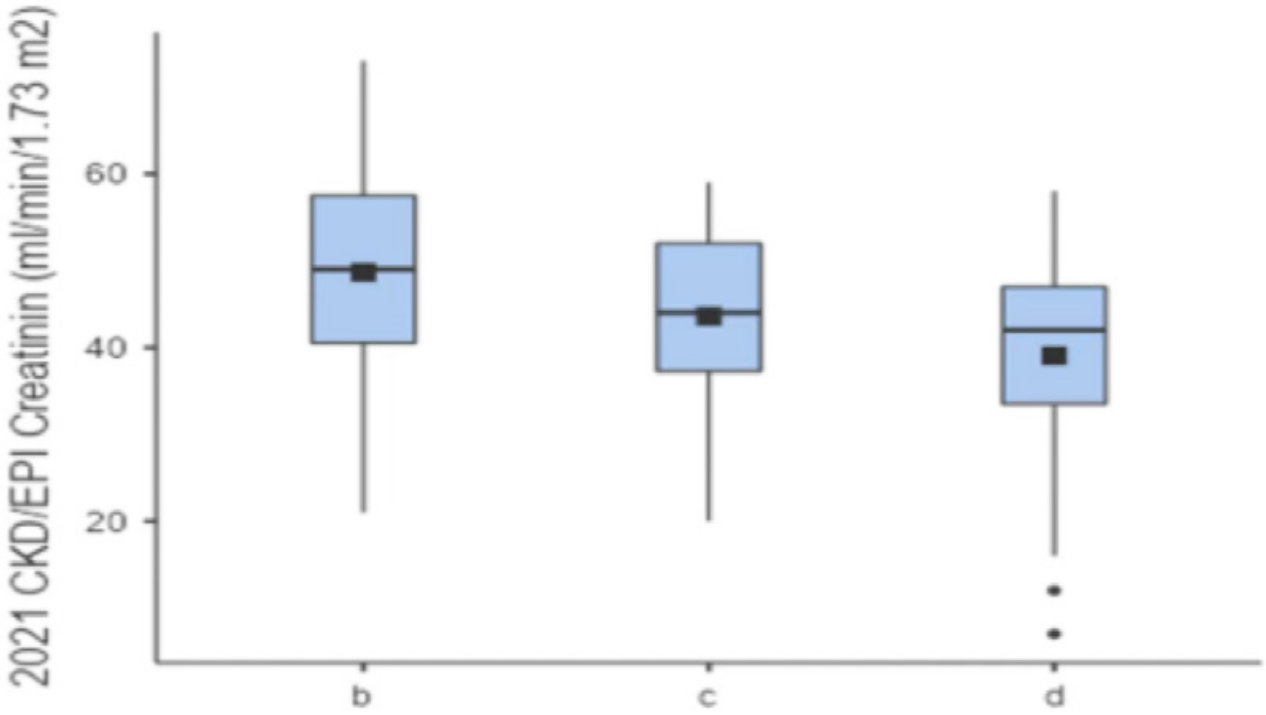
Figure 1: Distribution of PTH levels according to age groups (b is ≤ 65 yrs, c is 66-75yrs and d is > 75 yrs).



We noticed that about the eGFR (Figure 2), the minimum value in patients over 75 years old was 7 mL/min/1.73 m2, stages G5, kidney failure, while patients ≤ 65 years old and 66–75 years old had the minimum value 21 mL/min/1.73 m2 and 20 mL/min/1.73 m2 respectively, stages G4, severely decreased.

Regarding the maximum value, age group ≤ 65 years old was in stages G2, mildly decreased, and age groups 66-75 years old and > 75 years old were in stages G3a, mildly to moderately decreased.

Figure 2: Distribution of CKD stages according to age groups.



The age group classification helped us also to find the differences of biochemical parameters between them. For this reason, we used the Kruskal-Wallis test for non-parametric variables in Table 2.
We found age-related differences in PTH, and magnesium levels as follows: PTH was significantly higher in patients over 75 years old compared to younger groups, and magnesium levels differed significantly between the 66–75 years old and >75 years old age groups.

Table 2: One-Way ANOVA (Non-parametric) Kruskal-Wallis for different age groups.

	χ^2	df	p	ε^2
PTH	15.302	2	< .001	0.07084
Calcium	1.793	2	0.408	0.0083
Magnesium	8.738	2	0.013	0.04046
Phosphorus	6.632	2	0.056	0.03071

About the distinct stages of chronic kidney disease, we found that G3a predominated with 44% followed by G3b with 38%. This distribution allowed us to examine biochemical trends across a range of CKD severities, as shown in Table 3.

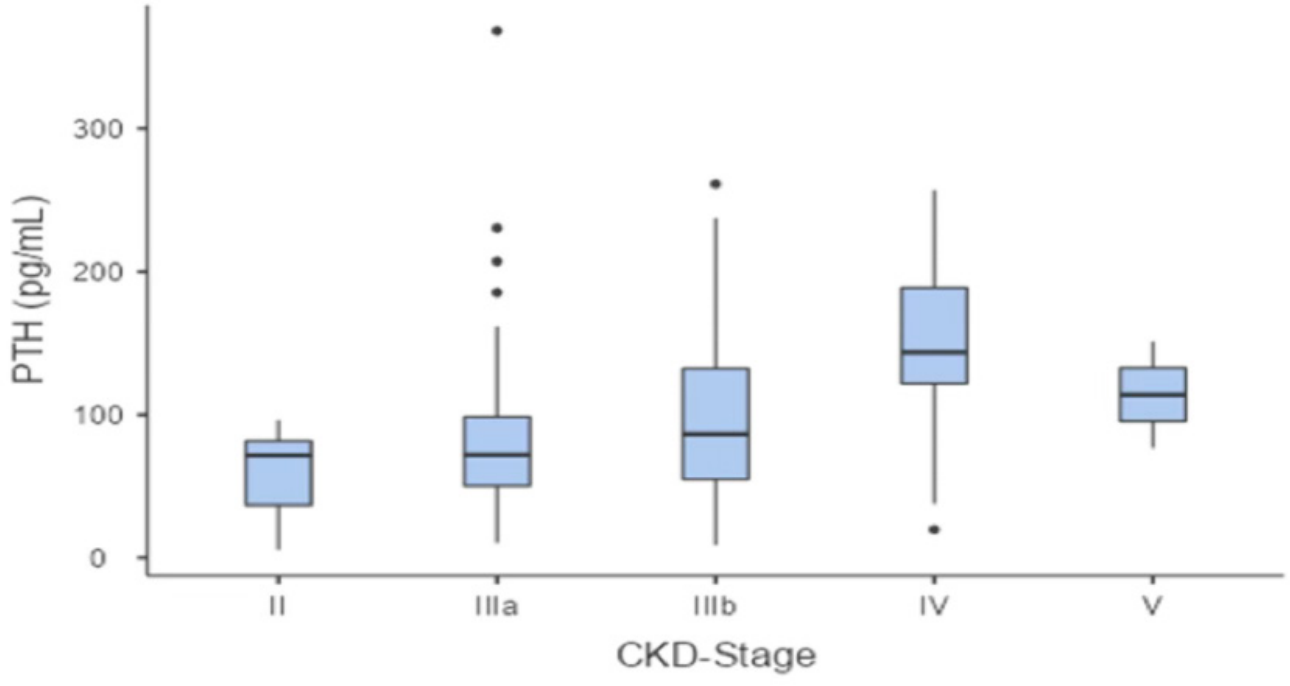
Table 3: Biochemical trends across distinct stages of chronic kidney disease.

	CKD-Stages	PTH (pg/mL)	Calcium (mg/dL)	Magnesium (mg/dL)	Phosphorus (mg/dL)
Number of patients	G2	9	9	9	9
	G3a	96	96	96	96
	G3b	83	83	83	83
	G4	27	27	27	27
	G5	2	2	2	2
Median	G2	72	9.5	2	3.6
	G3a	72	9.4	2	3.4
	G3b	87	9.3	2.1	3.6

	G4	144	9.2	2.1	4
	G5	114	8.7	2.7	5.8
Minimum	G2	6	8.4	1.6	2.9
	G3a	11	6.9	1.3	2.3
	G3b	9	6.6	1.3	1.8
	G4	20	7.3	1.7	1.6
	G5	77	8.2	2.4	5.3
Maximum	G2	96	12.5	2.6	4.7
	G3a	368	12.2	2.8	5.9
	G3b	261	11.9	3.2	5.4
	G4	257	10.7	4	5.8
	G5	151	9.1	2.9	6.3
IQR	G2	37-82	8.7-10.6	2-2.4	3.2-3.9
	G3a	50-99	9.0-9.8	1.7-2.3	3.0-3.6
	G3b	55-132	9.1-9.7	1.8-2.2	3.3-4.0
	G4	122-189	8.8-9.5	1.9-2.3	3.7-4.3
	G5	95-133	8.4-8.9	2.5-2.8	5.6-6.1

PTH median value and the IQR were out of the reference range only in G4 and G5 stages of CKD (Figure 3). In stages of G3a and G3b, only the upper limits of IQR were beyond the reference range.

Figure 3: Distribution of PTH across distinct stages of CKD.



For calcium, magnesium, and phosphorus, the median values were inside the reference range, except in stages G5 where for magnesium and phosphorus they were higher than the reference (Figure 4,5,6). The IQR was within the reference for all variables in all CKD stages, except in G5 where calcium trended to be lower, and magnesium and phosphorus trended to be higher.

Figure 4: Distribution of calcium across distinct stages of CKD.

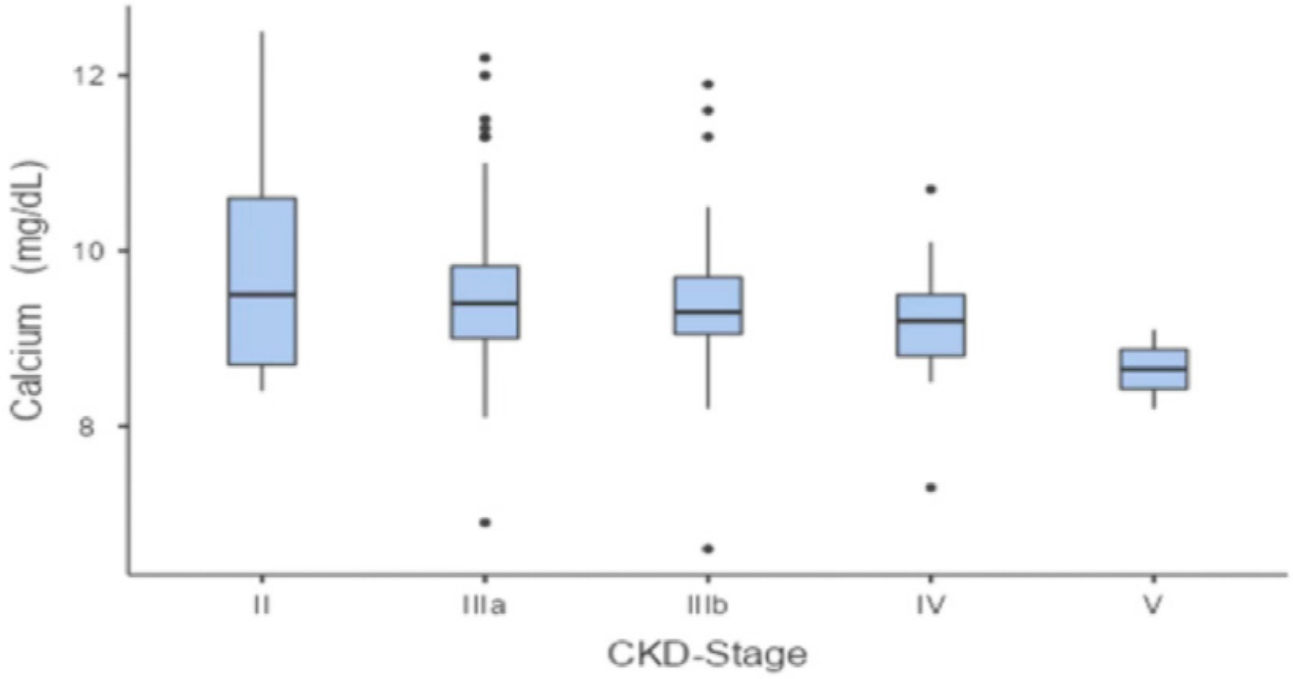


Figure 5: Distribution of magnesium across distinct stages of CKD.

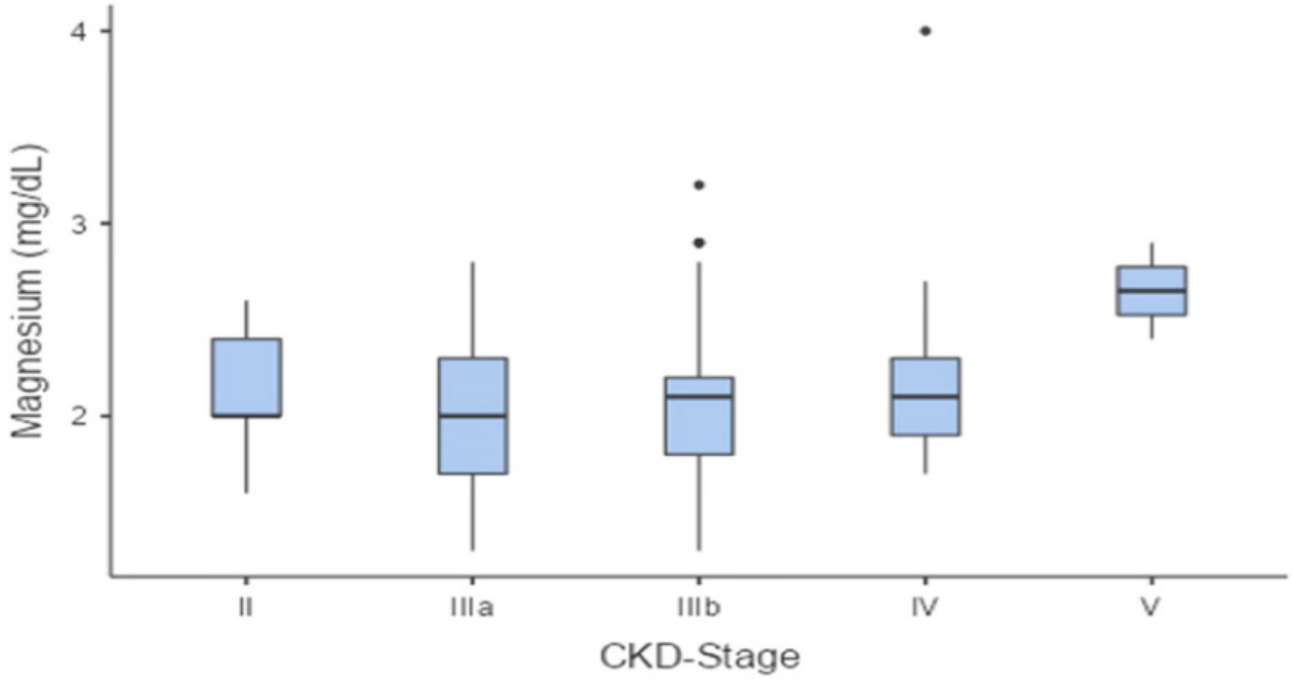
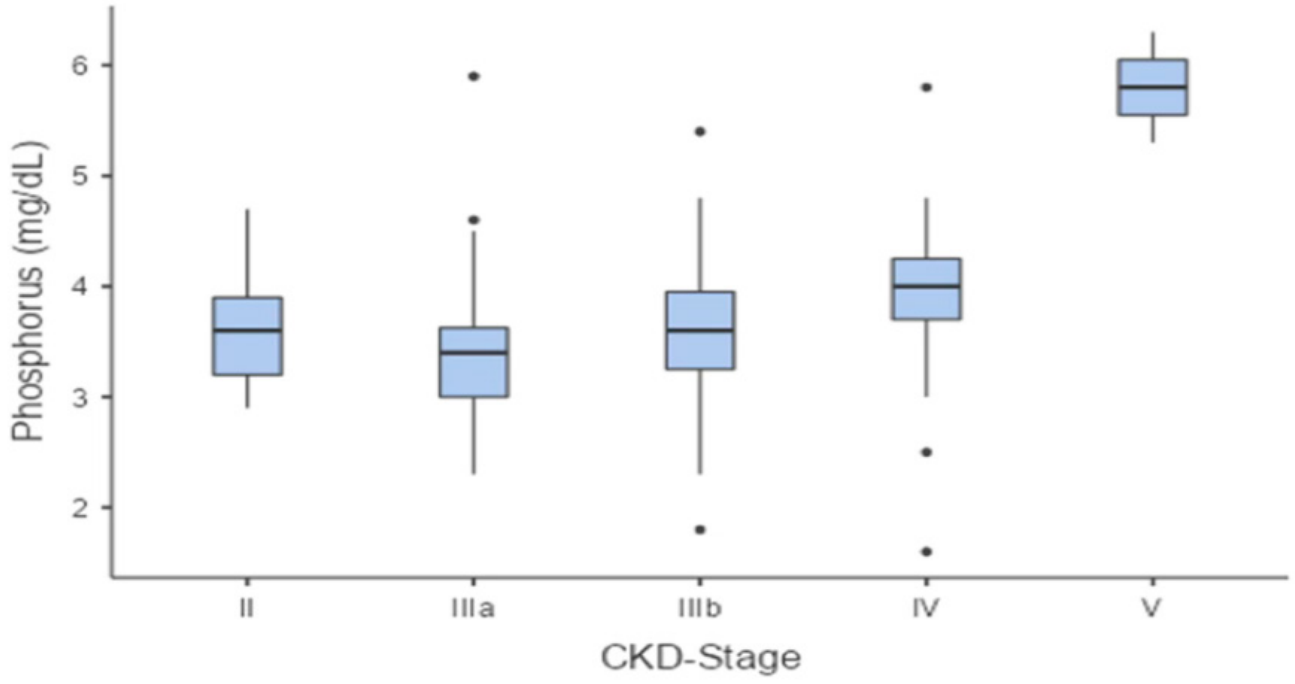


Figure 6: Distribution of phosphorus across distinct stages of CKD.



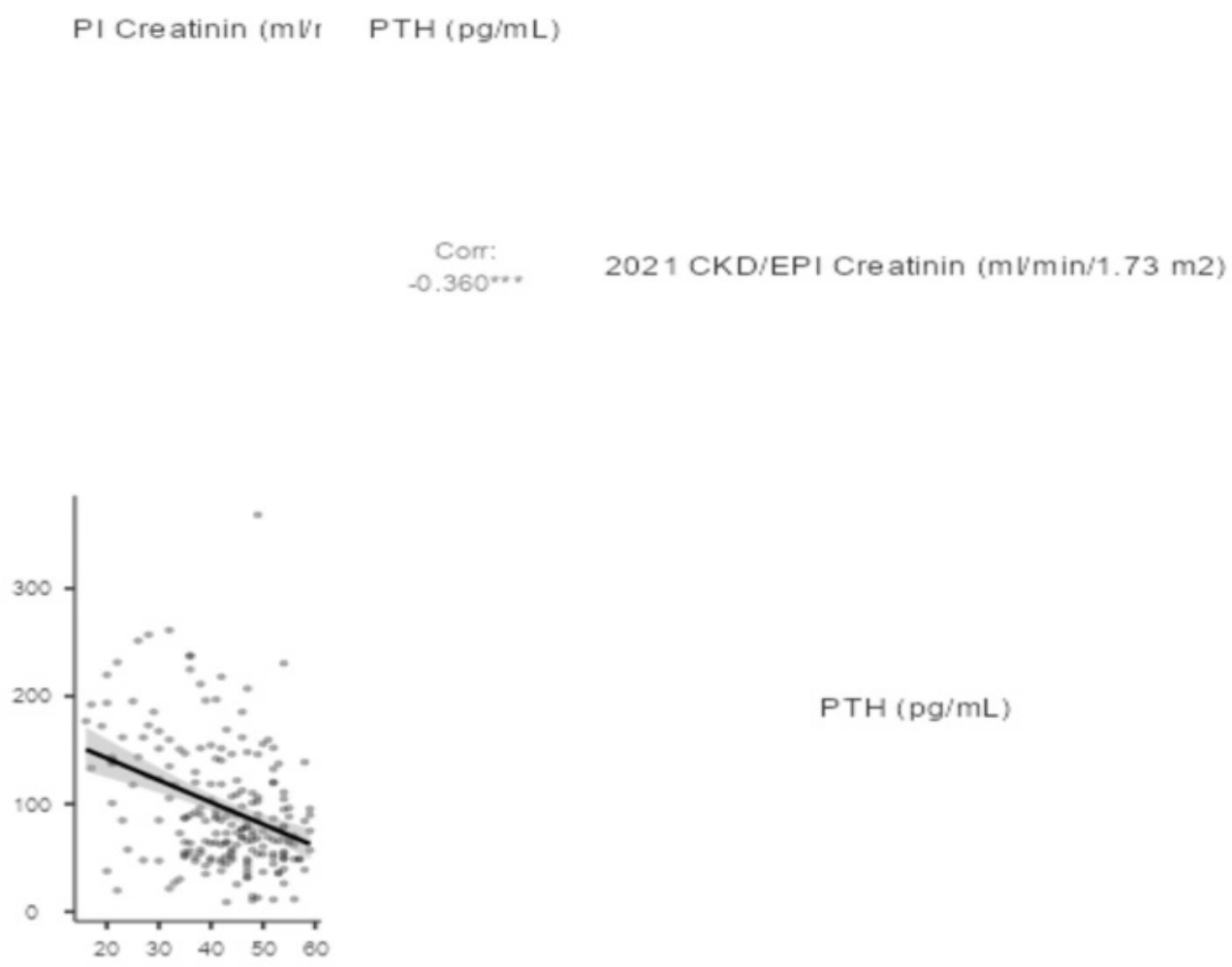
Because the number of patients in stages of G2 and G5 is exceedingly small, with 9 and 2 patients respectively, in the following statistical tests these patients were excluded. According to the Kruskal-Wallis test for non-parametric variables (Table 4), we saw significant differences in PTH levels between stages G3a and G4 ($p<0.001$), and G3b and G4 ($p=0.001$). For phosphorus, we noted differences between stages G3a and G3b ($p=0.003$), as well as G3a and G4 ($p<0.001$), and G3b and G4 ($p=0.01$). These differences reinforce the biochemical complexity of CKD progression.

Table 4: One-Way ANOVA (Non-parametric) Kruskal-Wallis for different CKD- stages.

	χ^2	df	p	ε^2
PTH	23.34	2	< .001	0.1138
Calcium	4.11	2	0.128	0.0201
Magnesium	3.14	2	0.208	0.0153
Phosphorus	26.14	2	< .001	0.1275

After performing the Pearson correlation (Table 5), we can state the following: eGFR has a negative correlation with PTH ($r= -0.360$, $p<0.001$), magnesium ($r= -0.153$, $p=0.028$), and phosphorus ($r= -0.336$, $p<0.001$). The magnitude, or strength, of the association, is weak ($0.3<|r|<0.5$) between both eGFR and PTH, eGFR and phosphorus, and very weak ($0.1<|r|<0.3$) between eGFR and magnesium. EGFR also has positive correlation with calcium ($r=0.169$, $p=0.015$), and the magnitude, or strength, of the association, is very weak ($0.1<|r|<0.3$).

Figure 7: Correlation plot of eGFR and PTH.



Similarly, magnesium shares a positive correlation with PTH (r=0.229, p<0.001), calcium (r=0.205, p=0.003), and phosphorus (r=0.260, p<0.001). The magnitude, or strength, of the association, is very weak (0.1<|r|<0.3).

Table 5: Pearson correlation.

		eGFR	PTH	Calcium	Magnesium	Phosphorus
eGFR	Pearson' r	1	-0.36	0.169	-0.153	-0.336
	df	204	204	204	204	204
	p-value		<0.001	0.015	0.028	<0.001
PTH	Pearson'r	-0.36	1	-0.1	0.229	0.002
	df	204	204	204	204	204
	p-value	<0.001		0.154	<0.001	0.982

Calcium	Pearson' r	0.16	-0.1	1	0.205	0.004
	df	204	204	204	204	204
	p-value	0.015	0.154		0.003	0.949
Magnesium	Pearson's r	-0.153	0.229	0.205	1	0.26
	df	204	204	204	204	204
	p-value	0.028	<0.001	0.003		<0.001
Phosphorus	Pearson's r	-0.336	0.002	0.004	0.26	1
	df	204	204	204	204	204
	p-value	<0.001	0.982	0.949	<0.001	

For all the correlations of eGFR that turned out to be statistically significant, we performed the regression analysis procedure to see if the variables have a predictive effect on each other (Table 6).

Table 6: Regression analysis.

Independent variable	b	m	t	r^2	p	Dependent variable
PTH	183.32	-2.04	-5.52	0.13	<.001	eGFR
Calcium	8.88	0.013	2.45	0.029	<.001	eGFR
Magnesium	2.27	-0.006	-2.33	0.023	<.001	eGFR
Phosphorus	4.39	-0.02	-5.09	0.113	<.001	eGFR

From the table we see that PTH as an independent variable can serve as a predictor of eGFR (t=-5.52, p<0.001). Estimating r^2 we had quantified the percentage of this predictive effect. This means that, if we find an increased value of PTH, the probability of finding a decreased value of eGFR is calculated to be 13%. This predictive effect for magnesium is 2.3% and for phosphorus is 11.3%.

Meanwhile, if we find a decreased value of calcium, the probability of finding a decreased value of eGFR is 2.9%.

Linear regression also gives an equation that can be used to predict the value of a response variable based on the predictor variable.

The formula for simple linear regression is Y = mX + b, where Y is the response (dependent) variable, X is the predictor (independent) variable, m is the estimated slope, and b is the estimated intercept.

Using linear regression, we modeled PTH, calcium, magnesium and phosphorus as a function of eGFR:

PTH = (-2.04 × eGFR) + 183.32

Calcium = (0.013 × eGFR) + 8.88

Magnesium = (-0.006 × eGFR) + 2.27

Phosphorus = (-0.02 × eGFR) + 4.39

Examples:

eGFR = 60 ml/min/1.73 m2 (G2)

PTH = [(-2.04) x 60] + 183.32 = 60.92 pg/mL, (95% CI, 14.59 - 136.4 pg/mL)

eGFR = 40 ml/min/1.73 m2 (G3b)

PTH= [(-2.04) x 40] + 183.32 = 101.7 pg/mL, (95% CI, 40.8-162.6 pg/mL)

These examples illustrate how renal decline directly influences PTH secretion.

Discussion

In our daily work in the laboratory, we have noticed that nephrologists often claim that their patients with chronic kidney disease have high parathormone levels. Considering the pathophysiology of chronic kidney disease and the involvement of the parathyroid gland and phospho-calcium metabolism [2], we undertook this study to discover possible correlations between parathormone, calcium, magnesium and phosphorus in patients with chronic kidney disease.

The prevalence of CKD in our study resulted in 4.6% which compared with global prevalence,>10% is lower [1]. The interpretation of this result is related to the fact that most of the patients with CKD live in low-income and lower-middle-income countries, and a sizable proportion of these individuals lack access to kidney disease diagnosis, prevention, or treatment [4]. Albania is classified as an upper-middle-income country according to the World Bank, and our prevalence is inside the interval of the Europe region, where the adjusted CKD stages 1-5 prevalence varied between 3.31% (95% confidence interval [95% CI], 3.30% to 3.33%) in Norway and 17.3% (95% CI, 16.5% to 18.1%) in northeast Germany, and the adjusted CKD stages 3-5 prevalence varied between 1.0% (95% CI, 0.7% to 1.3%) in central Italy and 5.9% (95% CI, 5.2% to 6.6%) in northeast Germany [5].

Our sample has a slightly predominance of males 5.5% compared to females 3.9%. The higher CKD prevalence described in men go in the same line with experimental data

showing the protective effects of estrogen and potential deleterious effects of testosterone on nondiabetic CKD [6], as well as data that indicate a higher incidence of kidney failure in men [7-8].

Distribution by age results in 40% older than 75 years and only 22% were ≤65 years old, coinciding with literature reports which stated that chronic kidney disease stage 3-5 is common, especially in the elderly [9]. Indeed, the meta-analysis by Hill et al. assessed the impact of age on CKD prevalence and reported a linearly higher prevalence for CKD stages 1–5 associated with advancing age, ranging from 13.7% in the 30-40-years old group to 27.9% in patients aged >70 to 80 years [10]. Similar trends were reported in the United States during 2015 to 2016, where the prevalence of CKD stages 1–4 was 5.6% among individuals aged 20 to 39 years and 44% among those aged >70 years [11].

Evaluating the descriptive analysis of the variables taken in the study, we concluded that their median is within the reference range, and in terms of distribution we noted that the biochemical parameters of patients have normal values, except for PTH which had an upper limit of IQR outside the reference range. These findings of biochemical parameters in CKD are reported also on Journal of Nephrology on September 2018, by Raman, M et al as an analysis of the Salford Kidney Study, a prospective, longitudinal, observational study of 2,667 patients with eGFR < 60 ml/min/1.73 m2 [12]. Most patients with CKD Stages 3–5 already have PTH values above the upper reference limit [13], which is confirmed by a more recent study of 2021 by a cohort from Stokholm, Sweden [14].

Previous articles working on the establishment of age-adjusted reference intervals for parathyroid hormone in healthy individuals observed higher upper limit values of PTH in the elderly [15-16] corroborating our findings of age-related differences in PTH levels.

Regarding the age-related differences for magnesium this is supported by several articles as aging seems to be a risk factor for inadequate magnesium levels due to reduced intestinal absorption, and this could be related to the decrease in vitamin D levels [17]. Another reason that supports this statement is the increased urinary excretion of Mg [18], because with advanced age, renal function and tubular reabsorption decline [19].

Most of our patients were in stage G3a and G3b with 44% and 38%, respectively. The same trend was reported from a United Kingdom retrospective laboratory audit study [20], and from a systematic review and meta-analysis of observational studies estimating CKD prevalence in general populations was conducted through literature searches in 8 databases [10].

The trend of biochemical parameters in distinct stages of CKD highlights an increase in the median and IQR values for PTH in stage G4. The same findings were previously reported in Spain [21] [22], later in Taiwan [23], and most recently in India [24].

In the present study, the PTH and phosphorus levels progressively increased with the advancing stages of CKD, like that observed by Natikar et al. in 2020 [25], and Kumari et al in 2024 [24]. The authors compared the level of PTH in patients of various stages of CKD. As the disease progressed, there was a progressive increase in the PTH level.

In the current study we found a weak negative correlation between PTH and eGFR, which is in contrast with our Indian colleagues who had found a strong correlation of PTH and eGFR [24]. These differences are because they studied only stage 4 and 5 of CKD. Their results suggest that patients with CKD Grades 4 and 5 are at an 8.6 times higher risk of having increased serum PTH levels, and the prevalence of SHPT is amplified as the stage of CKD increases.

Correlations found by us between eGFR and phosphorus are related in epidemiological studies with adverse outcomes in patients with CKD [26].

Conclusions

We concluded that there are statistically significant correlations between the CKD stage and PTH, calcium, magnesium, and phosphorus levels. However, the strength of these correlations is low, so results cannot be generalized. Therefore, individualized assessment is crucial in managing CKD patients. In addition, the results of this survey should be helpful for improving patient education, the importance of which is also endorsed by international experience [27-28].

We expect local health caregivers to treat their patients more individually and in general, to focus more on chronic kidney disease-mineral and bone disorder issues, which have been seen internationally.

Collectively, we believe we have a correct and careful assessment of SPTH that includes clinical assessment, patient symptoms, and laboratory results beyond PTH levels that justify the type and timing of treatment initiation.

Disclosure

The authors have nothing to declare.

Ethical Approval

Our study involved human subjects and is following the ethical principles for medical research involving human subjects, in accordance with the Declaration of Helsinki.

Authors contributions

Hamide Shllaku-Sefa contributed to conceptualization, data curation, formal analysis, investigation, validation, methodology, visualization, writing – original draft. Ndok Marku, role in conceptualization, data curation, supervision, and project administration.

Acknowledgement

We acknowledged the efforts of all laboratory staff during our research study.

Funding sources

Personal savings from authors.

Data Availability Statement
Data will be provided on request.

References

1. Kovesdy CP. Epidemiology of chronic kidney disease: an update 2022. Kidney Int Suppl (2011). 2022;12(1):7-11.
2. Tsai SH, Kan WC, Jhen RN, Chang YM, Kao JL, Lai HY et al. Secondary hyperparathyroidism in chronic kidney disease: A narrative review focused on therapeutic strategy. Clin Med (Lond). 2024;24(5):100238.
3. Kidney Disease: Improving Global Outcomes CKD-MBD Work Group. KDIGO 2017 clinical practice guideline update for the diagnosis, evaluation, prevention, and treatment of chronic kidney disease mineral and bone disorder (CKD-MBD). Kidney Int Suppl. 2017; 7:1–59.
4. Francis A, Harhay MN, Ong ACM, Tummalapalli SL, Ortiz A, Fogo AB, et al. American Society of Nephrology; European Renal Association; International Society of Nephrology. Chronic kidney disease and the global public health agenda: an international consensus. Nat Rev Nephrol. 2024;20(7):473-485.
5. Brück K, Stel VS, Gambaro G, Hallan S, Volzkes H, Ärnlöv J, et al. European CKD Burden Consortium. CKD Prevalence Varies across the European General Population. J Am Soc Nephrol. 2016;27(7):2135-2147.
6. Silbiger SR, Neugarten J. The impact of gender on the progression of chronic renal disease. Am J Kidney Dis. 1995; 25:515–533.
7. Hecking M, Bieber BA, Ethier J, Kautzky-Willer A, Sunder-Plassmann G, Säemann MD, et al. Sex-specific differences in hemodialysis prevalence and practices and the male-to-female mortality rate: the Dialysis Outcomes and Practice Patterns Study (DOPPS). PLoS Med. 2014;11(10).
8. Iseki K, Nakai S, Shinzato T, Nagura Y, Akiba T; Patient Registration Committee of the Japanese Society for Dialysis Therapy. Increasing gender difference in the incidence of chronic dialysis therapy in Japan. Ther Apher Dial. 2005;9(5):407-411.
9. Kampmann JD, Heaf JG, Mogensen CB, Mickley H, Wolff DL, Brandt F. Prevalence and incidence of chronic kidney disease stage 3-5 - results from KidDiCo. BMC Nephrol. 2023;24(1):17.
10. Hill NR, Fatoba ST, Oke JL, Hirst JA, O'Callaghan CA, Lasserson DS, et al. Global Prevalence of Chronic Kidney Disease - A Systematic Review and Meta-Analysis. PLoS One. 2016;11(7): e0158765.
11. Centers for Disease Control and Prevention Chronic kidney disease (CKD) surveillance system: 2021. https://nccd.cdc.gov/ckd/default.aspx (accessed: 10/07/2025).
12. Raman M, Green D, Middleton RJ, Kalra PA. Comparing the impact of older age on outcome in chronic kidney disease of different etiologies: a prospective cohort study. J Nephrol. 2018;31(6):931-939.
13. Inker LA, Grams ME, Levey AS, Coresh J, Cirillo M, Collins JF, et al., CKD Prognosis Consortium. Relationship of Estimated GFR and Albuminuria to Concurrent Laboratory Abnormalities: An Individual Participant Data Meta-analysis in a Global Consortium. Am J Kidney Dis. 2019;73(2):206-217.
14. Xu Y, Evans M, Soro M, Barany P, Carrero JJ. Secondary hyperparathyroidism and adverse health outcomes in adults with chronic kidney disease. Clin Kidney J. 2021;14(10):2213-2220.
15. Delgado JA, Bauça JM, Pastor MI, Barceló A. Use of data mining in the establishment of age-adjusted reference intervals for parathyroid hormone. Clin Chim Acta. 2020; 508:217–220.
16. Cavalcante LBCP, Brandão CMÁ, Chiamolera MI, Biscolla RPM, Junior JVL, de Sá Tavares Russo P, et al. Big data-based parathyroid hormone (PTH) values emphasize the need for age correction. J Endocrinol Invest. 2023;46(12):2525-2533.
17. Uwitonze AM, Razzaque MS. Role of Magnesium in Vitamin D Activation and Function. J. Am. Osteopat. Assoc. 2018; 118:181–189.
18. Denic A, Glassock RJ, Rule AD. Structural and Functional Changes with the Aging Kidney. Adv. Chronic Kidney Dis. 2016; 23:19–28.
19. Van der Burgh AC, Rizopoulos D, Ikram MA, Hoorn EJ, Chaker L. Determinants of the Evolution of Kidney Function with Age. Kidney Int. Rep. 2021; 6:3054–3063.
20. De Lusignan S, Tomson C, Harris K, Van Vlymen J, Gallagher H. UK. Prevalence of Chronic Kidney Disease for the Adult Population Is 6.76% Based on Two Creatinine Readings [Erratum]. Nephron Clinical Practice. 2012;120:c107.
21. Bureo JC, Arévalo JC, Antón J, Adrados G, Jiménez Morales JL, Robles NR. Prevalence of secondary hyperparathyroidism in patients with stage 3 and 4 chronic kidney disease seen in internal medicine is important. Endocrinol Nutr. 2015;62(7):300-305.
22. Toapanta Gaibor NG, Nava Pérez NC, Martínez Echevers Y, Montes Delgado R, Guerrero Riscos MÁ. PTH levels and not serum phosphorus levels are predictors of the progression of kidney disease in elderly patients with advanced chronic kidney disease. Nefrologia. 2017;37(2):149-157.
23. Hsiao PJ, Liao CY, Kao YH, Chan JS, Lin YF, Chuu CP, et al. Comparison of fractional excretion of electrolytes in patients at different stages of chronic kidney disease: A cross-sectional study. Medicine (Baltimore). 2020;99(2): e18709.
24. Kumari S, Singh PP, Kumar D, Kumar N, Kumar S, Shekhar R. Intact Parathyroid Hormone (iPTH) Assay: An Early Approach for Bone Health Assessment in Chronic Renal Failure. Cureus. 2024;16(10): e72510.
25. Natikar JA, Shailaja A. Secondary hyperparathyroidism in

patients with chronic kidney disease: a case control study. Int J Clin Biochem Res. 2020; 7:291–296.
26. Fourtounas C. Phosphorus metabolism in chronic kidney disease. Hippokratia. 2011;15(Suppl 1):50-52.
27. Toussaint ND, Pedagogos E, Beavis J, Becker GJ, Polkinghorne KR, Kerr PG. Improving CKD-MBD management in hemodialysis patients: barrier analysis for implementing better practice. Nephrol Dial Transplant. 2011; 26: 1319-1326.
28. Ward F, Watson A, Holian J. Chronic kidney disease-mineral and bone disorder (CKD-MBD) management and associated cost in an Irish hemodialysis cohort. Nephrol Dial Transplant. 2011; 26 (10): 3417.