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Original Research Article

Prevalence of Mineral and Bone Disorder in Chronic Kidney Disease and Its Biochemical Correlates

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Abstract:

Background: Chronic kidney disease-mineral and bone disorder (CKD -MBD) is a frequent and clinically significant complication of chronic kidney disease, which develops in response to abnormalities in the metabolism of calcium, phosphate, parathyroid hormone (PTH) and vitamin D. These deformities cause skeletal morbidity and cardiovascular problems, hence high mortality is seen in patients with CKD. There is limited information on CKD-MBD prevalence and biochemical profile in eastern India.

Objectives: The present study aimed to determine the prevalence of mineral and bone disorder among patients with chronic kidney disease and to evaluate its biochemical correlates, including serum calcium, phosphate, intact parathyroid hormone (iPTH), vitamin D, and alkaline phosphatase levels.

Methods: This hospital-based cross-sectional study was conducted in the Department of General Medicine, Nalanda Medical College and Hospital, Patna. A total of 88 adult CKD patients were enrolled using simple random sampling. Biochemical parameters assessed included serum calcium, phosphate, iPTH, 25-hydroxy vitamin D, total alkaline phosphatase, and bone-specific alkaline phosphatase. Data were analyzed using SPSS version 20, and associations were evaluated using chi-square test and ANOVA.

Results: CKDMBD was very common in the research population. Hypocalcemia was found in 54.5 percent of the patients, hyperphosphatemia in 65.9 percent, high levels of IPTH in 81.8 percent and vitamin D deficiency/insufficiency in 81.8 percent. The majority of patients had moderate to the very high bone turnover. There was a significant rise in the levels of serum phosphate, alkaline phosphatase, and bone-specific alkaline phosphatase with an increase in the levels of iPTH ($p < 0.05$).

Conclusion: Mineral and bone disorder occurs so high in CKD patients, and the biochemical derangements are greatly correlated with bone turnover conditions. Biochemical surveillance should be done in routine to detect and manage CKD–MBD early so that there are fewer skeletal and cardiovascular complications.

Keywords: Chronic kidney disease; CKD–MBD; Parathyroid hormone; Vitamin D deficiency; Hyperphosphatemia; Bone turnover; Alkaline phosphatase.

Introduction

Chronic kidney disease (CKD) comprises one of the greatest public health issues on a global scale, which is a progressive and irreversible loss of renal functioning culminating in the development of end-stage renal disease "unless properly managed [1]. The deterioration of kidney functions leads to the fact that the maintenance of mineral homeostasis by the kidneys is impaired, which causes a range of systemic complications. Chronic kidney disease-mineral and bone disorder (CKD-MBD) is one of the most prevalent and clinically relevant metabolic disorders that accompany CKD. One of the conditions associated with CKD-MBD includes the presence of abnormalities of calcium metabolism, phosphorus metabolism, parathyroid hormone (PTH) metabolism, and vitamin D metabolism; bone turnover, mineralization, bone volume, bone linear growth or strength, and extra-skeletal calcification [2]. The rate of CKD-MBD is progressively rising with the advanced stage of CKD and can start at the stage 3 of the disease [3]. The mineral metabolic disturbances are caused mainly by the decreased excretion of phosphate, the defect of renal active vitamin D (1, 25-dihydroxyvitamin D) synthesis,

hypocalcemia, and secondary hyperparathyroidism. Such biochemical abnormalities do not only result in skeletal problems involving renal osteodystrophy but also cardiovascular morbidity due to vascular and soft-tissue calcification, which is a great contributor to the phenomenon of death among CKD patients [4].

The diagnosis and monitoring of CKD-MBD is based on the biochemical changes. One of the first abnormalities that can be detected is hyperphosphatemia which is caused by the reduction of glomerular filtration and the accumulation of phosphates. This provokes the compensatory processes such as increased fibroblast growth factor-23 (FGF-23) and PTH concentrations, which will initially serve to stabilize phosphate balance but ultimately lead to bone pathology and cardiovascular injuries [5]. Hypocalcemia also increases secretion of parathyroid hormone, which causes secondary hyperparathyroidism that is a characteristic of chronic CKD-MBD [6]. Another important element of CKD-MBD, which is caused by a lack of renal hydroxylation of 25-hydroxyvitamin D, is vitamin D deficiency, which increases the negative consequences of bone turnover defects [7]. Constant increase in PTH causes the high-turnover bone disease and excessive treatment causes the low-turnover or dynamic bone disease, so mineral and bone disorders in CKD patients are complex and dynamic [8].

Skeletal manifestation of CKD-MBD is not the only clinical issue. Many studies indicate a close relationship between pathological mineral metabolism and Cardiovascular events, stiffness of arteries, left ventricular hypertrophy and mortality in populations with CKD [9]. Hence, it is important to detect the presence of biochemical derangements early so that intervention is administered in a timely manner to minimize complications in the long run and increase patient outcomes. Although CKD-MBD is increasingly taking a major burden, there is limited information on its prevalence and biochemical correlates in most territories especially in developing countries whereby patients present with the end stages of CKD. Differences in the diet, socioeconomic position, healthcare access, and treatments are other factors that affect the trend and intensity of mineral and bone abnormalities [10]. The awareness of CKD-MBD frequency and the biochemical parameters is critical in terms of creating region-specific management techniques and clinical care optimization. This research is expected to determine the commonness of mineral and bone disorder in chronic kidney disease patients and to determine the biochemical correlates of mineral and bone disorder, such as the levels of serum calcium, phosphorus, parathyroid hormone, and vitamin D. This type of evaluation will help to learn more about CKD-MBD patterns and provide evidence-based care to CKD patients.

Materials and Methods

Study Design: The study was a hospital-based cross-sectional study, which aimed at determining the prevalence of mineral and bone disorder (MBD) in patients with chronic kidney disease (CKD) as well as determining the biochemical correlates of mineral and bone disorder. The research was conducted in Nalanda Medical College and Hospital (NMCH) Department of General Medicine, Patna, Bihar, India for six months from April 2025 to September 2025

Study Population and Sample Size: The population of the study included adult patients suffering chronic kidney disease who were visiting the Department of General Medicine at the time of the research. The sample size used in the study was 88 CKD patients. The sample size was calculated in terms of feasibility, access to the eligible patients within the study time frame, and the reference to previous prevalence-based research on CKD-associated mineral and bone disorder. All the eligible patients that met the inclusion criteria were recruited to the study up to the required sample size by consenting to take part.

Inclusion and Exclusion Criteria: The study included patients who had a confirmed diagnosis of chronic kidney disease and are aged 18 years and above. The inclusion criteria were that the participants had to be of a sound mind and had to give written informed consent before being enrolled in the study. Patients who were acutely injured with kidney injury, had known malignancies, active infections or other severe systemic illnesses were excluded. Patients who are under medications, which have been known to have a great impact on bone metabolism like bisphosphonates or chronic corticosteroids were also excluded. No patient with regular CKD-related therapies, including phosphate binders, calcium supplements or vitamin D analogues, was excluded to participate, though.

Sampling Technique: A simple random sampling technique was employed to select study participants. A list of eligible CKD patients attending the outpatient and inpatient services of the Department of General Medicine was prepared using hospital records. From this sampling frame, participants were randomly selected to ensure unbiased representation of the study population.

Biochemical Assessment: All participants were sampled using venous blood under aseptic conditions although this was not always done before dialysis where necessary. Biochemical parameters evaluated were serum calcium, serum phosphate, intact parathyroid hormone (iPTH), 25-hydroxy vitamin D, total alkaline phosphatase (ALP) as well

as bone-specific alkaline phosphatase (BSAP). Results were interpreted using the standard laboratory reference ranges. The level of vitamin D was classified as sufficient, insufficient and deficient, according to the set cut-off values. Patients were also categorized into various groups of bone turnover depending on iPTH levels that indicated the low, normal and high levels of bone turnover.

Statistical Analysis: All the data obtained were put in Microsoft Excel and analyzed through SPSS software version 20 (IBM Corp., Armonk, USA). The Shapiro-Wilk test was used to test any given continuous variable in regard to normality. Data that were normally distributed were in terms of mean and standard deviation whereas the non-normally distributed data were in terms of median and interquartile range. Frequency and percentages are the ways of expressing categorical variables. The Chi-square test and Analysis of Variance (ANOVA) was used to establish associations of biochemical parameters and CKD-MBD. The p-value below 0.05 was deemed statistically significant.

Results

A total of 88 patients with chronic kidney disease were included in the present study to evaluate the prevalence of mineral and bone disorder (CKD–MBD) and its biochemical correlates. All enrolled participants completed the clinical and biochemical assessments, and no missing data were recorded for the primary study variables. The results are presented in relation to demographic characteristics, biochemical abnormalities, iPTH-based bone turnover categories, and associations between CKD–MBD and biochemical parameters.

Demographic and Clinical Characteristics: Table 1 presents the demographic and baseline clinical characteristics of the study population. Out of the 88 respondents, most were male (n = 56, 63.6) although females were 36.4 (n = 32) of the respondents. The age of the respondents was 52.4 +11.8 with majority of the patients occupying the 41-60 age range. The length of chronic kidney disease was different among patients with a large percentage of chronic kidney disease of over three years. The most prevalent comorbidities in the study population were hypertension and diabetes mellitus, taken singly, or in both. These data represent the usual demographic picture of the CKD patients admitted to the tertiary care facility.

Table 1: Demographic and Clinical Profile of Study Participants

Variable	Category	Number (%)
Age (years)	≤40	18 (20.5)
	41–60	46 (52.3)
	>60	24 (27.2)
Gender	Male	56 (63.6)
	Female	32 (36.4)
Comorbidities	Hypertension	34 (38.6)
	Diabetes mellitus	22 (25.0)
	Both HTN & DM	20 (22.7)
	None	12 13.7)

Prevalence of Biochemical Abnormalities in CKD–MBD: Table 2 shows the prevalence of the biochemical abnormalities in the mineral and bone disorder. Forty-eight patients (54.5%) exhibited hypocalcemia and 58 patients (65.9) exhibited hyperphosphatemia. Post-renal hyperthyroidism was high as 72 patients (81.8% of the total) were found to have elevated levels of intact parathyroid hormone (iPTH) above the normal range. The deficiency of vitamin D was very common whereby 50 patients (56.8) had deficiencies and another 22 patients (25.0) had sufficient vitamin D levels. Total ALP and BSAP levels showed high concentrations in 44.3% and 39.8% of the patients respectively indicating the presence of higher bone turnover activity in a significant percentage of the study group.

Table 2: Distribution of Biochemical Parameters in CKD Patients

Parameter	Normal n (%)	Abnormal n (%)
Serum Calcium	40 (45.5)	48 (54.5)
Serum Phosphate	30 (34.1)	58 (65.9)
iPTH	16 (18.2)	72 (81.8)
Vitamin D	16 (18.2)	72 (81.8)
Total ALP	49 (55.7)	39 (44.3)
BSAP	53 (60.2)	35 (39.8)

iPTH-Based Bone Turnover Classification: Table 3 shows the categorization of patients into four bone turnover groups depending on the serum iPTH levels. Most of the patients were of the moderate-to-high bone turnover classes. The low bone turnover was observed in 14 patients (15.9%), and in 32 patients (36.4) the upper normal limit of 2-5 times was observed. The bone turnover states were high, with 26 patients (29.5) represented in the 5 to 9 times upper normal limit as well as 16 patients (18.2) represented in the extremely high levels of iPTH (>9 times upper normal limit). These results show that secondary hyperparathyroidism and high-turnover bone disease are identified in the advanced CKD patients.

Table 3: Distribution of Patients According to iPTH-Based Bone Turnover Groups

Bone Turnover Group	iPTH Range (pg/ml)	Number (%)
Low turnover	<130	14 (15.9)
Moderate turnover	130–325	32 (36.4)
High turnover	325–585	26 (29.5)
Very high turnover	>585	16 (18.2)

Association Between Biochemical Parameters and Bone Turnover Status: Table 4 shows the relationship between the biochemical parameters and the bone turnover status. There was a significant progressive change of mean serum phosphate, ALP, and BSAP levels as the level of iPTH increased and these were found to be statistically significant ($p < 0.05$). The very high turnover patients had very low mean serum calcium and vitamin D levels as opposed to the low and moderate turnover patients. The statistical analysis of variance (ANOVA) revealed that there was a statistically significant difference among bone turnover statuses in serum calcium, phosphate, iPTH, vitamin D, and ALP, which was highly biochemical correlated with the severity of CKD-MBD.

Table 4: Comparison of Biochemical Parameters Across Bone Turnover Groups

Parameter (Mean ± SD)	Low	Moderate	High	Very High	p-value
Calcium (mg/dL)	8.9 ± 0.6	8.4 ± 0.7	8.1 ± 0.8	7.8 ± 0.9	0.02
Phosphate (mg/dL)	4.6 ± 0.8	5.2 ± 0.9	5.8 ± 1.1	6.3 ± 1.2	<0.001
Vitamin D (ng/mL)	26.4 ± 6.2	21.8 ± 5.9	18.3 ± 4.6	14.9 ± 3.8	<0.001
ALP (IU/L)	96 ± 22	118 ± 26	142 ± 34	168 ± 41	<0.001

CKDMBD was very common in the patients with this tertiary care center and most of the patients had various biochemical disorders. The most frequent results were elevated iPTH, hyperphosphatemia as well as vitamin D deficiency. Biochemical derangements were more severe in high bone turnover status, which supports the need to detect it early and monitor its level on a regular basis in CKD patients.

Discussion

The current research work highlights high prevalence of the chronic kidney disease- mineral and bone disorder (CKD-MBD) in the patients who visit a tertiary care hospital in eastern India. The biochemical abnormalities, i.e., the increased levels of iPTH, hyperphosphatemia, and hypocalcemia, and the lack of vitamin D are all the results of the systemic disruptions in mineral metabolism that accompany progressive renal failure. These results coincide with the rising incidence of CKD reported in India, in which late manifestation and restricted access to early screening are some of the factors that lead to advanced disease manifestations upon diagnosis [11,16].

The demographic characteristics of the study population, with the dominant representation of males and the prevalence of middle-aged and older patients, are similar to the national statistics of large-scale epidemiological surveys. Similar demographic patterns have been reported in both SEEK study and the Indian CKD Registry where hypertension and diabetes mellitus have shown as the major risk factors towards CKD among the Indian population [11,16]. The existence of these comorbidities probably expedites mineral and bone disruptions by means of complicated interaction with perturbed phosphate metabolism, vitamin D metabolism, and parathyroid hormone homeostasis.

The major conclusion of this paper involved the existence of secondary hyperparathyroidism in high rates with over four-fifths of the patients having been found to have high levels of iPTH. The observation has been consistent with the findings of other Indian tertiary care centers, which showed that, disordered mineral metabolism is recorded even at earlier stages of CKD and the severity is growing along with the degradation of renal functions [13]. The same has been observed in South Asian CKD hotspots, where nutritional deficiency, late referral to the nephrology and poor biochemical surveillance further complicate CKD–MBD [12]. The presence of high ratio of patients in moderate to very high bone turnover groups in the current study reflects the progression status of secondary hyperparathyroidism in CKD.

Another outstanding abnormality between this cohort was vitamin D deficiency. The fact that deficient and inadequate levels of vitamin D are high is consistent with other studies that have been conducted in India which have attributed this to impaired renal hydroxylation, dietary inadequacy, limited sunlight exposure, and protein-energy wasting that is typical of CKD patients [13,18]. Low vitamin levels are also a factor committing not only secondary hyperparathyroidism but also bone mineralization impairment and high risk of fracture, which is why regular examination and early correction are necessary.

This study showed a progressive rise in the level of serum phosphate, ALP, and BSAP with the upsurge in the iPTH level, which indicates greater bone turnover activity. The bone turnover indices have become significant as noninvasive to evaluate skeletal engagement in CKD-MBD. Multiple researches have shown that, markers (ALP and BSAP) are more or less correlated with bone histology, especially in high-turnover bone disease [14,17]. Even though bone biopsy is the gold standard in the diagnosis of renal osteodystrophy, it is an invasive procedure, limiting its application in day to day practice, particularly in resource-limited countries such as India. Thus, biochemical markers still remain critical in clinical decision-making [15].

The great correspondence between biochemical parameters and the status of bone turnover analyzed in the present study is one more indication of the usefulness of the integrated biochemical profiling in patients with CKD. Both Indian" and international studies have reported similar results with high levels of phosphate and ALP being strongly related with severe bone disease and unfavourable clinical outcomes [13,19]. A similar trend of CKD–MBD in the case of haemodialysis patients was also reported in the study conducted in Nigeria by Abdu et al., which means that mineral bone disorders are a worldwide complication of CKD, especially in low- and middle-income nations [19].

The current research has some limitations despite its strengths. It has the cross-sectional design that does not allow the determination of the causal relationships or the time development of CKD-MBD. Bone imaging and histological confirmation had not been done either and the biochemical parameters were not conducted at a single point. However, the study is important and sheds light on the burden and biochemical profile of CKD-MBD in an Indian tertiary care unit.

Conclusion

The current research indicates that chronic kidney disease-mineral and bone disorder is very common among CKD patients visiting a tertiary care hospital and a good percentage of these patients has shown some severe biochemical anomalies including high levels of iPTH, hyperphosphatemia, hypocalcemia and lack of vitamin D. The gradual deterioration of the mineral parameters as the bone turnover status advances underscores the strong relationship between deteriorating renal activity and abnormal bone metabolism. These results emphasize the need to monitor biochemical routinely to identify CKD-MBD at an early stage. Early intervention by personalized control of the calcium, phosphate, vitamin D, and parathyroid hormone may assist in lowering skeletal complications, enhancing the quality of life, and possibly reducing morbidity in chronic kidney disease patients.

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