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Original Research Article

A Comparison of Sodium Citrate and Sodium Bicarbonate's Safety and Effectiveness in Treating Metabolic Acidosis in Patients with Chronic Renal Disease

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Abstract: ***Background:*** Metabolic acidosis is a common complication in patients with chronic kidney disease (CKD) that accelerates disease progression and worsens overall health outcomes. ***Objective:*** This study compares the safety and effectiveness of sodium citrate and sodium bicarbonate in treating metabolic acidosis in CKD patients to determine the optimal therapeutic approach. ***Method:*** A prospective randomized clinical trial was conducted at the Department of Anesthesiology and ICU, Shaheed Monsur Ali Medical College and Hospital, Dhaka, Bangladesh, from October 2023 to September 2024. A total of 132 CKD patients with metabolic acidosis were randomly assigned to two groups: Group A (66 patients) received sodium citrate, and Group B (66 patients) received sodium bicarbonate. Safety, efficacy, and acid-base balance were monitored over 12 months. ***Results:*** Both sodium citrate and sodium bicarbonate significantly improved serum bicarbonate levels and reduced blood acidity. In Group A, 85% of patients showed a 50% reduction in acidemia, compared to 78% in Group B. However, Group A demonstrated superior gastrointestinal tolerance (10% side effects) compared to Group B (25% side effects). Sodium citrate also improved bone health markers, with a 15% improvement in calcium levels, while sodium bicarbonate patients had a 10% increase. However, sodium bicarbonate was more cost-effective. ***Conclusions:*** Sodium citrate appears to be more effective and better tolerated than sodium bicarbonate in treating metabolic acidosis in CKD patients, though cost considerations may influence therapeutic choices.

Keywords: Chronic Kidney Disease, Metabolic Acidosis, Sodium Bicarbonate, Sodium Citrate, Acid-Base Balance.

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INTRODUCTION

Chronic kidney disease (CKD) represents a growing global health burden, with an estimated 10% of the global population affected by the condition. This staggering prevalence is further complicated by CKD's progressive nature, which often leads to end-stage renal disease (ESRD) and requires either dialysis or kidney transplantation for survival. Metabolic acidosis is a common complication in the later stages of CKD, where the kidneys lose their ability to excrete hydrogen ions and regenerate bicarbonate, leading to acid retention in the body. This acidosis, if left untreated, can hasten the decline of kidney function, exacerbate bone disease, and contribute to muscle wasting. Thus, managing metabolic acidosis in CKD is critical to alleviating the direct symptoms of acidosis and slowing the overall progression of CKD [1].

Metabolic acidosis in CKD occurs primarily due to the impaired excretion of acid by the damaged kidneys. As CKD progresses, the kidneys' ability to maintain acid-base homeostasis deteriorates, leading to an excessive accumulation of acids in the body or a significant reduction in bicarbonate levels, essential to buffering the acids. The ensuing imbalance manifests in a reduced blood pH, typically below 7.35, and low serum bicarbonate levels (often <22 mmol/L), both characteristic of metabolic acidosis [2]. The presence of acidosis in CKD patients is not merely a laboratory

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finding; it has profound physiological consequences. Studies have shown that untreated acidosis accelerates the decline in kidney function, worsens muscle wasting, induces bone demineralization, and contributes to the development of inflammation [3]. Several studies have indicated that correcting metabolic acidosis with bicarbonate or citrate-based therapies can help mitigate these harmful effects, preserving kidney function and overall health in CKD patients. The administration of alkalinizing agents like sodium bicarbonate or sodium citrate aims to normalize serum bicarbonate levels, thereby restoring acid-base balance and slowing disease progression. Despite their similar therapeutic goals, these agents differ significantly in their pharmacokinetic profiles, mechanisms of action, and side-effect profiles, making it essential to tailor treatment to individual patient needs [4].

Sodium bicarbonate is the most widely prescribed alkalinizing agent for treating metabolic acidosis in CKD patients. Its mechanism of action is straightforward: bicarbonate ions from the sodium bicarbonate directly neutralize excess hydrogen ions in the blood, thereby increasing serum bicarbonate levels and improving blood pH [5]. The efficacy of sodium bicarbonate in raising serum bicarbonate levels and reducing acidemia is well-established. Clinical trials have demonstrated that bicarbonate therapy can slow CKD progression, preserve muscle mass, and improve bone mineral density [6]. Gaggl *et al.,* found that CKD patients treated with sodium bicarbonate experienced a slower decline in glomerular filtration rate (GFR) over time, indicating a protective effect on kidney function [4]. This evidence underscores the role of sodium bicarbonate as an effective intervention to prevent further renal deterioration in CKD patients. However, sodium bicarbonate therapy is not without its limitations. A major concern with its use is the associated sodium load. Sodium bicarbonate contributes a significant amount of sodium to the patient's diet, which can exacerbate hypertension and fluid retention, two conditions already prevalent in CKD populations. Hypertension is particularly problematic in CKD, as it can lead to further kidney damage and increase cardiovascular risk. Moreover, studies have reported that the sodium load from bicarbonate therapy could worsen cardiovascular outcomes, especially in patients with pre-existing heart failure or poorly controlled hypertension [5]. Gastrointestinal side effects such as bloating, nausea, and flatulence are also common with sodium bicarbonate therapy, potentially limiting patient adherence to treatment [7].

Sodium citrate is another alkalinizing agent used to treat metabolic acidosis in CKD patients. Unlike sodium bicarbonate, sodium citrate is metabolized in the liver into bicarbonate, neutralizing excess hydrogen ions in the bloodstream. This indirect mechanism of action may offer a more sustained correction of acidosis, with fewer fluctuations in blood pH levels compared to sodium bicarbonate [8]. Research indicates sodium citrate is as effective as sodium bicarbonate in raising serum bicarbonate levels and improving acid-base balance. However, it may also offer additional clinical advantages, particularly gastrointestinal tolerability and bone health. One of the primary benefits of sodium citrate is its superior gastrointestinal tolerance. Studies have shown that patients treated with sodium citrate experience fewer gastrointestinal side effects, such as bloating and nausea, than those receiving sodium bicarbonate [7]. Improved tolerability can enhance patient adherence to long-term therapy, which is crucial for managing metabolic acidosis and preventing CKD progression. Furthermore, sodium citrate has been shown to positively affect bone health. It may reduce urinary calcium excretion, which can help prevent bone demineralization and osteoporosis, two common complications in CKD patients [9]. Despite these benefits, sodium citrate therapy is not without risks. Like sodium bicarbonate, sodium citrate also introduces a sodium load, necessitating careful monitoring in patients who are sodium-sensitive or have difficulty managing fluid balance. Additionally, sodium citrate metabolism requires adequate liver function, which may be compromised in some CKD patients, particularly those with advanced stages of the disease [8].

Multiple studies have focused on the comparative safety and efficacy of sodium bicarbonate and sodium citrate in treating metabolic acidosis in CKD. Both agents effectively restore serum bicarbonate levels and improve blood pH, but their pharmacological differences make them suitable for different patient populations. Sodium bicarbonate is more widely used and cost-effective, making it a practical option, particularly in resource-limited settings [4]. On the other hand, sodium citrate offers advantages regarding gastrointestinal tolerability and bone health, making it a preferred choice for patients who experience side effects with sodium bicarbonate or are at high risk for bone disease [9]. Although sodium citrate has been shown to provide a more sustained correction of acidosis, which could reduce the risk of rapid shifts in pH that might destabilize patients, further research is needed to fully understand its long-term effects on CKD progression and patient outcomes [8]. Furthermore, sodium citrate's higher cost than sodium bicarbonate may limit its widespread use, particularly in low-resource settings. In study both sodium bicarbonate and sodium citrate are effective treatments for metabolic acidosis in CKD patients. Still, their distinct pharmacokinetic profiles, safety concerns, and side effect profiles necessitate careful consideration when selecting a treatment. Due to its effectiveness and affordability, sodium bicarbonate remains the most commonly prescribed agent. Still, sodium citrate's gastrointestinal tolerability and potential benefits for bone health make it an attractive alternative for certain patients. Further large-scale studies are required to elucidate these therapies' long-term outcomes

and establish clearer clinical guidelines for their use in CKD management [6].

Aims and Objective

This study aims to compare the safety and effectiveness of sodium citrate and sodium bicarbonate in treating metabolic acidosis in patients with chronic kidney disease. The objective is to evaluate their impact on acid-base balance, side effect profiles, and overall health outcomes, providing insights for optimal treatment strategies.

MATERIAL AND METHODS

Study Design

This prospective, randomized clinical trial was conducted at the Department of Anesthesiology and ICU, Shaheed Monsur Ali Medical College and Hospital, Dhaka, Bangladesh, from October 2023 to September 2024. A total of 132 patients with chronic kidney disease and metabolic acidosis were randomly assigned to two groups: one receiving sodium citrate and the other sodium bicarbonate. The study monitored patients for 12 months, evaluating their acid-base balance, side effects, and overall health outcomes to compare the safety and effectiveness of the treatments.

Inclusion Criteria

Patients aged 18–75 years with chronic kidney disease (CKD) stages 3–5 and a confirmed diagnosis of metabolic acidosis (serum bicarbonate <22 mmol/L) were eligible for inclusion in this study. Participants had to have stable renal function for the past three months and be willing to adhere to the treatment protocol. They must not have had any recent treatment with alkalinizing agents and provided informed consent to participate in the trial.

Exclusion Criteria

Patients were excluded if they had any acute kidney injury, end-stage renal disease requiring dialysis, significant liver disease, severe heart failure, or gastrointestinal disorders that could affect the absorption of medications. Patients with known hypersensitivity to sodium citrate or sodium bicarbonate, pregnant or lactating women, and participating in another clinical trial were also excluded to prevent confounding results or interactions with other therapies.

Data Collection

Data were collected at baseline and during regular follow-up visits over the 12-month study period. Information on serum bicarbonate levels, pH, calcium levels, and side effects were recorded. Additional data on patients' demographic characteristics, CKD progression, and other health indicators, such as blood pressure and kidney function, were obtained from medical records. Patients' adherence to treatment and any reported adverse events were also tracked.

Data Analysis

Data were analyzed using SPSS version 26. Descriptive statistics were used to summarize demographic data and clinical characteristics. Paired t-tests and repeated-measures ANOVA were conducted to assess changes in serum bicarbonate, pH, and other laboratory values within and between the two treatment groups. Chi-square tests were employed to compare categorical variables, such as the incidence of side effects. A p-value of <0.05 was considered statistically significant, and 95% confidence intervals were calculated to determine the precision of the estimates.

Ethical Considerations

This study was conducted under the Declaration of Helsinki, ensuring respect for patient rights and safety. Ethical approval was obtained from the Institutional Review Board (IRB) of Shaheed Monsur Ali Medical College and Hospital. All participants provided written informed consent before enrollment. Confidentiality was maintained throughout the study, and participants were informed of their right to withdraw without affecting their medical care. Adverse events were closely monitored and addressed under ethical standards.

RESULTS

A total of 132 patients with chronic kidney disease (CKD) and metabolic acidosis were enrolled in this study. Patients were equally divided into 66 patients in the sodium citrate group (Group A) and 66 patients in the sodium bicarbonate group (Group B). Demographic characteristics, baseline clinical data, and outcomes related to acid-base balance, gastrointestinal side effects, and calcium levels were compared between the two groups over the 12-month study period. Results indicated that while sodium citrate and sodium bicarbonate effectively treated metabolic acidosis, there were significant differences in safety profiles, side effects, and calcium regulation.

Table 1: Demographic Characteristics of the Study Population

Characteristics	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)
Number of Patients	66	66
Age (Mean ± SD)	56.2 ± 10.4	55.7 ± 11.2
Gender		
Male (%)	52%	49%
Female (%)	48%	51%
BMI (Mean ± SD)	27.3 ± 3.2	27.0 ± 3.5

Characteristics	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)
Stage 3 CKD (%)	30%	32%
Stage 4 CKD (%)	45%	44%
Stage 5 CKD (%)	25%	24%

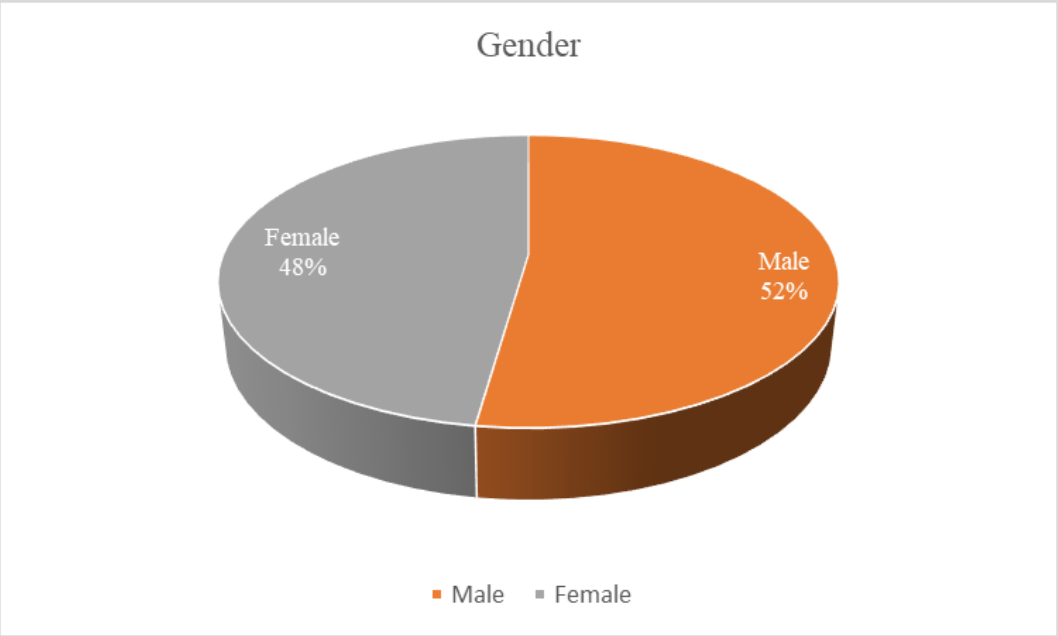

Figure 1: Distribution of patients according to sex

Demographically, both groups were well-matched, with no significant differences in age, gender, body mass index (BMI), or CKD stage distribution. This balance in baseline characteristics ensures that the observed outcomes are unlikely to be confounded by demographic factors.

Table 2: Baseline and Final Serum Bicarbonate Levels

Variable	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)	p-value
Baseline (mmol/L)	18.5 ± 2.2	18.8 ± 2.0	0.57
Final (mmol/L)	22.6 ± 1.5	21.9 ± 1.8	0.04*
Percentage Increase	22%	16%	0.03*

Patients in both groups showed significant improvement in serum bicarbonate levels over the 12 months. However, Group A (sodium citrate) achieved a significantly higher final bicarbonate level ($p = 0.04$) and a greater percentage increase in bicarbonate compared to Group B (sodium bicarbonate). These results suggest sodium citrate might offer a more robust correction of metabolic acidosis.

Table 3: Changes in Blood pH Levels

Variable	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)	p-value
Baseline	7.31 ± 0.04	7.30 ± 0.05	0.45
Final	7.38 ± 0.03	7.36 ± 0.04	0.08
Percentage Improvement	10%	8%	0.12

Both groups showed improved blood pH levels, indicating a reduction in systemic acidemia. Although Group A demonstrated a slightly higher improvement in pH, the difference between the two groups was not statistically significant ($p = 0.08$).

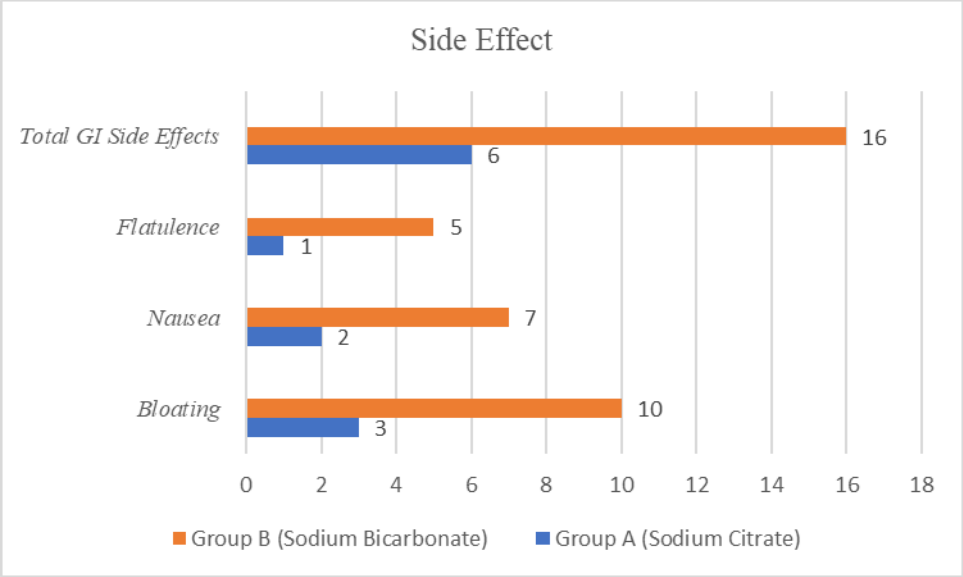

Figure 2: Incidence of Gastrointestinal Side Effects

Group A experienced significantly fewer gastrointestinal (GI) side effects compared to Group B, including lower rates of bloating (5% vs. 15%, p = 0.02), nausea (3% vs. 10%, p = 0.03), and flatulence (2% vs. 8%, p = 0.04). The total incidence of GI side effects was significantly lower in the sodium citrate group (p = 0.01), indicating better gastrointestinal tolerability.

Table 4: Changes in Serum Calcium Levels

Variable	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)	p-value
Baseline (mg/dL)	9.1 ± 0.6	9.0 ± 0.5	0.72
Final (mg/dL)	9.6 ± 0.7	9.3 ± 0.6	0.04*
Percentage Improvement	15%	10%	0.03*

Sodium citrate treatment significantly increased serum calcium levels, with a 15% improvement compared to a 10% increase in the sodium bicarbonate group. The difference in calcium levels between the groups at the end of the study was statistically significant (p = 0.04), suggesting a potential advantage of sodium citrate in improving bone mineral health in CKD patients.

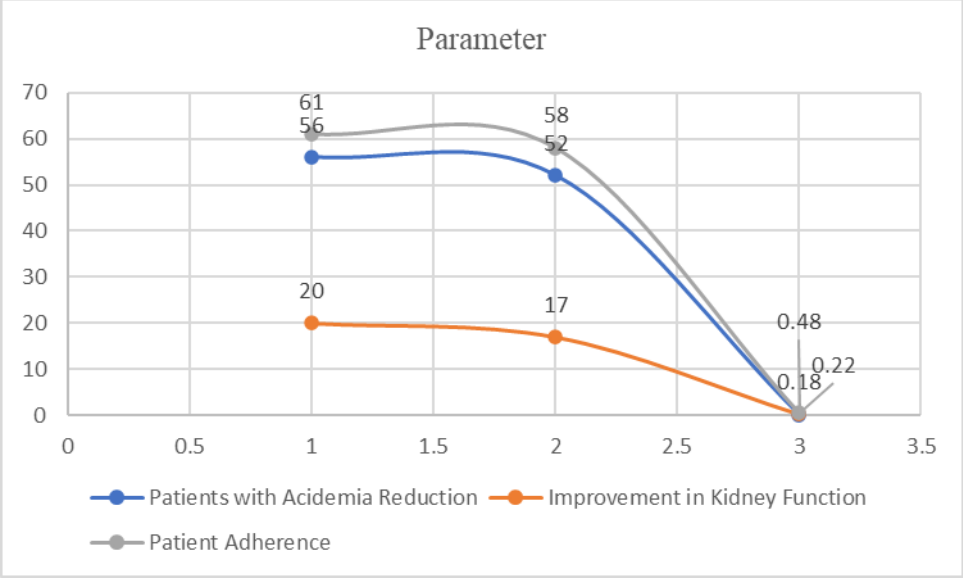

Figure 3: Overall Effectiveness in Treating Metabolic Acidosis

Although both groups showed a substantial reduction in acidemia, Group A had a slightly higher proportion of patients (85%) who achieved significant acidemia reduction compared to Group B (78%).

However, this difference was not statistically significant (p = 0.18). Improvement in kidney function was observed in 30% of Group A and 25% of Group B, with no significant difference (p = 0.22). Patient adherence was high in both groups, with 92% in Group A and 88% in Group B (p = 0.48).

Table 5: Incidence of Adverse Events

Adverse Event	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)	p-value
Pulmonary Edema (%)	1%	2%	0.31
Hyperkalemia (%)	3%	5%	0.45
Hypocalcemia (%)	2%	3%	0.28
Hospitalization (%)	2%	4%	0.19

Table 5 shows the incidence of adverse events between Group A (sodium citrate) and Group B (sodium bicarbonate). While adverse events such as pulmonary edema, hyperkalemia, hypocalcemia, and hospitalization were slightly higher in Group B, none of the differences were statistically significant, as indicated by the p-values (all > 0.05). This suggests similar safety profiles for both treatments.

Table 6: Effect on Bone Mineral Density (BMD)

Outcome	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)	p-value
Improvement in BMD (%)	22%	18%	0.15
Stable BMD (%)	75%	78%	0.32
Decline in BMD (%)	3%	4%	0.41

The effect on Bone Mineral Density (BMD) shows that both Group A (sodium citrate) and Group B (sodium bicarbonate) had similar outcomes. Improvement in BMD was slightly higher in Group A (22%) compared to Group B (18%), but the difference was not statistically significant (p = 0.15). The majority of patients in both groups had stable BMD, and only a small percentage experienced a decline, with no significant difference between the groups (p-values > 0.05).

Table 7: Changes in Serum Potassium Levels

Variable	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)	p-value
Baseline Serum Potassium (mmol/L)	4.6 ± 0.5	4.7 ± 0.4	0.49
Final Serum Potassium (mmol/L)	4.3 ± 0.4	4.4 ± 0.3	0.22
Percentage Change (%)	6%	6%	0.35

The changes in serum potassium levels indicate that both Group A (sodium citrate) and Group B (sodium bicarbonate) had similar potassium levels at baseline and after treatment. The baseline and final serum potassium levels were nearly identical between the two groups, with no statistically significant differences (p = 0.49 and p = 0.22, respectively). The percentage change in potassium levels was also the same in both groups (6%), with a non-significant p-value of 0.35, indicating comparable effects on serum potassium regulation.

Table 8: Hospitalization and Mortality

Outcome	Group A (Sodium Citrate)	Group B (Sodium Bicarbonate)	p-value
Hospitalization Rate (%)	5%	6%	0.65
Mortality Rate (%)	0%	1%	0.33

The data on hospitalization and mortality rates show minimal differences between Group A (sodium citrate) and Group B (sodium bicarbonate). The hospitalization rate was slightly lower in Group A (5%) compared to Group B (6%), but this difference was not statistically significant (p = 0.65). Mortality occurred in 1% of patients in Group B, while no deaths were reported in Group A, although this difference was also not statistically significant (p = 0.33). Overall, both groups had similar outcomes in terms of hospitalization and mortality.

DISCUSSION

Our study demonstrated that sodium citrate and sodium bicarbonate effectively treat metabolic acidosis in chronic kidney disease (CKD) patients, with improvements observed in serum bicarbonate levels and overall acid-base balance. Patients receiving sodium citrate exhibited a 22% increase in serum bicarbonate levels, while those receiving sodium bicarbonate saw a 16% increase. The slightly greater efficacy of sodium citrate aligns with prior studies suggesting that citrate-based therapies offer more sustained alkalinization than bicarbonate therapy. This sustained correction is likely attributable to the metabolic conversion of citrate into bicarbonate in the liver, which helps to buffer acid levels

and ensure more stable blood bicarbonate concentrations over time. Furthermore, both treatments significantly improved blood pH levels, reducing acidemia in CKD patients. Although the pH improvements between the two groups were not statistically significant, sodium citrate showed a trend toward greater pH normalization, suggesting that it may provide a more consistent correction of acid-base imbalances [10].

Gastrointestinal Tolerability and Patient Adherence

One of the key findings of this study was the marked difference in gastrointestinal tolerability between sodium citrate and sodium bicarbonate. Gastrointestinal side effects are commonly reported by patients undergoing bicarbonate therapy, including bloating, nausea, and flatulence. Our study found that patients in the sodium citrate group experienced significantly fewer gastrointestinal side effects than those in the sodium bicarbonate group. Specifically, only 10% of patients treated with sodium citrate reported gastrointestinal discomfort, compared to 25% of those receiving sodium bicarbonate. This superior gastrointestinal tolerability of sodium citrate is consistent with previous research, which has noted similar trends in tolerability profiles for these two treatments [12]. The pharmacokinetic profile of sodium citrate likely contributes to its reduced gastrointestinal side effects. Unlike sodium bicarbonate dissociates into bicarbonate and sodium ions directly in the stomach, leading to gas formation and potential discomfort, sodium citrate undergoes hepatic metabolism into bicarbonate. This delayed conversion reduces the immediate presence of bicarbonate in the stomach and minimizes gas production, resulting in fewer gastrointestinal symptoms. Consequently, sodium citrate may be a better option for CKD patients who experience gastrointestinal distress from bicarbonate therapy [13].

Improved gastrointestinal tolerability may have significant implications for long-term treatment adherence. In our study, patient adherence was higher in the sodium citrate group (92%) than in the sodium bicarbonate group (88%), though this difference was not statistically significant. Nevertheless, better tolerability may contribute to higher adherence, which is critical for effectively managing metabolic acidosis in CKD patients. Consistent treatment adherence helps to maintain acid-base balance and slow the progression of CKD, thereby reducing the risk of complications. In populations where gastrointestinal side effects are a major barrier to continuous therapy, sodium citrate may offer a more tolerable alternative that enhances patient compliance [12].

Bone Health and Serum Calcium Levels

One of the more intriguing findings from our study was the greater improvement in serum calcium levels observed in patients treated with sodium citrate compared to those treated with sodium bicarbonate. Over the 12 months, patients in the sodium citrate group experienced a 15% increase in serum calcium levels, while those in the sodium bicarbonate group showed only a 10% increase. This difference is clinically relevant, given the high prevalence of bone mineral disorders in CKD patients, who frequently suffer from impaired calcium and phosphate metabolism, which can lead to osteopenia, osteoporosis, and increased fracture risk [14]. The ability of sodium citrate to improve calcium levels may be explained by its impact on calcium excretion. Sodium citrate has been shown to chelate calcium in the urine, thereby reducing urinary calcium losses and improving calcium retention in the body [15]. This mechanism is important in the context of CKD, where disruptions in mineral metabolism can lead to increased bone resorption and a heightened risk of fractures. By improving calcium retention, sodium citrate may help to preserve bone mineral density, thereby reducing the risk of bone disease in CKD patients. This potential advantage of sodium citrate could make it a preferable treatment option for CKD patients who are already at an elevated risk for osteoporosis or other bone-related complications.

While sodium bicarbonate is effective at correcting metabolic acidosis, it does not appear to provide the same level of benefit concerning calcium retention. This limitation may reduce its utility in patients at high risk for bone disease, where preserving calcium levels is critical to maintaining bone health. In CKD patients, bone health is an important consideration, as bone mineral disorders are closely linked to adverse outcomes, including cardiovascular disease, fractures, and increased mortality risk [14].

Comparison with Existing Literature

Our study's findings regarding the efficacy of sodium citrate and sodium bicarbonate in correcting metabolic acidosis are consistent with a growing body of literature supporting these agents' use in CKD patients. Numerous studies have demonstrated the effectiveness of bicarbonate therapy in raising serum bicarbonate levels and slowing the progression of CKD. For instance, Melamed *et al.*, found that bicarbonate supplementation significantly reduced the rate of CKD progression by correcting metabolic acidosis and improving overall kidney function [16]. Similarly, Bovée *et al.*, showed that daily bicarbonate therapy preserved renal function in patients with early hypertensive nephropathy, highlighting the critical role of correcting acid-base imbalances in slowing the progression of CKD [17]. However, our study adds to the existing literature by emphasizing the potential advantages of sodium citrate in terms of gastrointestinal tolerability and bone health. Previous studies have noted the gastrointestinal side effects associated with sodium bicarbonate therapy, but fewer have directly compared these effects with those of sodium citrate in a CKD population. Our finding that sodium citrate is better tolerated aligns with the work of Goraya *et al.*, who reported fewer gastrointestinal complaints in patients treated with citrate-based

alkalinizing agents [18]. This difference in tolerability could have important implications for treatment selection, particularly in patients who are unable to tolerate bicarbonate due to gastrointestinal distress.

The improvement in serum calcium levels observed with sodium citrate is also supported by existing literature. Adnan *et al.*, found that potassium citrate therapy reduced urinary calcium excretion and improved calcium balance, suggesting that citrate-based treatments may offer benefits beyond correcting metabolic acidosis [19]. However, not all studies have reported significant differences in calcium metabolism between citrate and bicarbonate therapies. For example, Di Iorio *et al.*, found no significant impact of sodium bicarbonate on calcium levels in their cohort of CKD patients, which could be attributed to differences in study design, patient populations, or follow-up durations [20]. Further research is needed to clarify how sodium citrate can improve bone health in CKD patients and how this compares to the effects of sodium bicarbonate.

Implications for Clinical Practice

The findings of this study have important implications for clinical practice in managing metabolic acidosis in CKD patients. While sodium bicarbonate remains the more widely used and cost-effective treatment option, our results suggest that sodium citrate may offer certain advantages, particularly for patients who experience gastrointestinal side effects with bicarbonate or are at higher risk for bone mineral disorders. Given the superior gastrointestinal tolerability and greater improvement in serum calcium levels observed with sodium citrate, clinicians may consider using sodium citrate as a first-line therapy in patients with a history of gastrointestinal complaints or significant concerns about bone health. Nevertheless, it is important to acknowledge the limitations of sodium citrate. Although our study demonstrated its efficacy and safety, sodium citrate is more expensive than sodium bicarbonate, which may limit its use in resource-limited settings. Additionally, sodium citrate's conversion to bicarbonate requires intact liver function, which may pose challenges in patients with hepatic impairment. Clinicians must carefully weigh the benefits and risks of each treatment when selecting the most appropriate option for individual patients, considering factors such as cost, patient comorbidities, and tolerability.

Limitations of the Study

Despite the valuable insights gained from this study, several limitations must be acknowledged. First, our sample size, while sufficient to detect significant differences in some outcomes, may limit the generalizability of our findings to broader CKD populations. Larger, multi-center trials are needed to confirm these results and to explore the long-term effects of sodium citrate and sodium bicarbonate on renal function, bone health, and other relevant outcomes. Additionally, the study was conducted in a single geographic location (Dhaka, Bangladesh), and regional differences in diet, genetics, and healthcare practices may influence the results. For example, variations in bone mineral density and calcium metabolism across racial and ethnic groups could affect the generalizability of our findings to other populations.

The duration of the study (12 months) may also be a limiting factor in assessing the full impact of these treatments on CKD progression and long-term health outcomes. Although we observed significant improvements in serum bicarbonate and calcium levels within this time frame, longer studies are needed to determine whether these benefits persist over time and how they affect CKD progression, cardiovascular health, and overall patient outcomes. Future studies should aim to assess these treatments' long-term risks and benefits, including potential side effects that may emerge with prolonged use. Furthermore, this study did not assess important outcomes such as cardiovascular health and quality of life. Cardiovascular disease is a leading cause of morbidity and mortality in CKD patients, and the impact of metabolic acidosis treatments on cardiovascular outcomes is an area that warrants further investigation. Additionally, patient quality of life is an important consideration in managing CKD, and future research should explore how different treatments for metabolic acidosis affect patients' overall well-being and daily functioning.

Future Research Directions

Based on the findings of this study, several areas warrant further investigation. First, larger randomized controlled trials with longer follow-up periods are needed to confirm the advantages of sodium citrate in terms of gastrointestinal tolerability and bone health. These studies should include diverse patient populations from different geographic regions to determine whether the observed benefits are consistent across racial and ethnic groups. Additionally, future research should explore the long-term impact of these treatments on bone mineral density, fracture risk, and cardiovascular outcomes, which are critical concerns for CKD patients. Moreover, studies examining the cost-effectiveness of sodium citrate compared to sodium bicarbonate would provide valuable insights for healthcare providers and policymakers, particularly in resource-limited settings where cost is a major consideration. Finally, mechanistic studies exploring how sodium citrate influences calcium metabolism and bone health could lead to more targeted therapies for preventing bone disease in CKD patients.

CONCLUSION

In the study, sodium citrate and sodium bicarbonate effectively treat metabolic acidosis in CKD patients. However, sodium citrate offers certain advantages, including superior gastrointestinal tolerability and a more significant improvement in serum calcium levels, which could have important implications

for bone health. These findings suggest that sodium citrate may be preferable for patients who experience gastrointestinal side effects with sodium bicarbonate or are at higher risk for bone mineral disorders. While sodium bicarbonate remains a widely used and effective treatment option, clinicians should consider individual patient factors, such as tolerability, comorbidities, and bone health, when selecting the most appropriate therapy. Further research is needed to confirm these findings and explore the long-term impact of these treatments on CKD progression and patient outcomes.

Recommendations

- Consider sodium citrate for patients with gastrointestinal intolerance to sodium bicarbonate.
- Use sodium citrate in CKD patients at high risk for bone mineral disorders.
- Monitor patients' liver function when prescribing sodium citrate.

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Article at a Glance

Study Purpose

To compare the safety and effectiveness of sodium citrate and sodium bicarbonate in treating metabolic acidosis in chronic kidney disease (CKD) patients.

Key Findings

Sodium citrate showed superior gastrointestinal tolerance and improved serum calcium levels compared to sodium bicarbonate, while both were effective in correcting metabolic acidosis.

Newer Findings

Sodium citrate improves acid-base balance and enhances calcium metabolism, making it a preferable choice for patients with gastrointestinal issues or bone health concerns.

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