Progress of Application of Plant-based Diet on Chronic Kidney Disease

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Abstract. Chronic Kidney Disease (CKD) is a global public hygiene problem. As the incidence increases, it poses a huge burden on the health of patients as well as on social economy. In recent years, with increased attention to healthy eating patterns, plant-based diets have become one of the hot topic researches due to their potential kidney protective effects. However, there is still a lack of unified explanation for the mechanism and clinical intervention effects of plant-based diets on CKD patients. Therefore, this study aims to explore the potential application of plant-based diets in CKD management. This study summarizes the various benefits of a plant-based diet for CKD patients by systematic analysis of the literature. Research has shown that a plant-based diet benefits kidney function, reduces urinary protein levels, and slows down the decline in glomerular filtration rate (eGFR). In addition, considering that they are rich in dietary fiber and anti-inflammatory, antioxidant components, plant-based diets can reduce oxidative stress and chronic inflammatory reactions. Although this study verifies the multiple protective effects of a plant-based diet, there are still some research gaps and deficiencies. For instance, further research is needed on the impact of plant-based dietary patterns on CKD rehabilitation stages and the customization of intervention strategies. Future research can combine dynamic monitoring of hormones and artificial intelligence algorithms to develop precise nutrition management plans for CKD patients, making it possible to realize disease management and optimizing diet for CKD patients. Meanwhile, it also provides new perspectives and directions for future research.

Keywords: Chronic Kidney Disease; Urinary Protein; Plant-based Dietary.

1. Introduction

Chronic Kidney Disease (CKD) is becoming an increasingly serious public hygiene problem. Data shows that in 2023, there will be more than 33.5 million adults suffering from CKD, accounting for approximately 14% of the total population [1]. It is estimated that by 2040, CKD will have been the fifth major cause of death [2]. This shows that the global burden of CKD is enormous and has been on the rise. CKD is a progressive disease with complications. Although it is unclear why CKD occurs, diabetes, glomerular nephritis and cystic kidney disease are the common reasons for CKD and there are various findings among them [3]. Meanwhile, metabolic acidosis, uremia toxicity and hyperphosphatemia are key factors contributing to CKD. They not only aggravate the disease, but also have a huge impact on physical health. As the disease progresses, renal function of CKD patient's declines, which leads to end stage kidney (ESKD) and greatly affects the patients' life quality and health. At the same time, due to environmental and health factors, dietary patterns and habits based on plants are becoming increasingly popular [4]. Research shows that the plant-based diet has been closely linked with reducing the occurrence of some chronic diseases such as Angio cardiopathy, diabetes, obesity and so on [5]. This has generally made plant-based diet an important choice for health promotion, and it is especially effective in preventing chronic diseases. For instance, fruits, vegetables, fruits, nuts, legumes and so on are all healthy food [3, 5]. Plant-based diet improves the mechanism related to CKD by reducing acid load in the body, lowering urea levels and decreasing blood phosphorus concentration to improve the metabolic acidosis, uremia toxicity and hyperphosphatemia in CKD [6]. Although the specific effects of plant-based diet on CKD have not been fully explored, there are a few research evidences indicating that it is likely to help CKD patients keep healthy [3]. The study aims at exploring the progress of application of plant-based diet on CKD

by reducing the production of metabolic waste, decreasing the inflammatory response and oxidative stress in CKD, and proposes scientific dietary management recommendations for CKD patients.

2. The Multiple Applikation of Plant-based diet on CKD

The impact of plant-based diet on kidney health. Plant-based diet, which is centered around whole-grains, legumes, vegetables, fruits, nuts, etc., have shown great potential in the management and prevention of CKD. The mechanisms of a plant-based diet on health are multifaceted, such as inflammation, blood pressure, blood sugar and reduced oxidative stress.

2.1. Reducing Urinary Protein and Inflammation Pressure

It has been scholarly indicated from numerous studies, on the one hand, that the intake of animal-derived protein can lead to an excessive increment in glomerular filtration rate (GFR), augmenting renal workload on the kidneys and chronic inflammation. On the other hand, plant-based dietary has been observed to illustrate significant protective effects due to their more temperate metabolic profiles. High-protein diets, especially those with rich animal protein, may cause long-term renal impairment by elevating intraglomerular pressure (e.g., hyperfiltration) and intensifying acid load [7, 8]. As is shown in some researches, within the general populace, high intake of animal protein correlates with a more rapid decline in estimated eGFR and augmented serum creatinine levels relating to high intake of animal protein, which is further substantiated by the fact that creatinine, a byproduct of muscle metabolism, is generated in greater quantities within the context of a high-animal-protein diet. The rate of eGFR deterioration in these cohorts is markedly superior to those adhering to a diet predominantly constituted by plant proteins. High intake of animal protein tends to result in the rising intraglomerular pressure, filtration burden and thus exacerbating the loss of nephron units. Animal proteins with rich sulfur-containing amino acids (such as methionine) produce the generation of sulfates during metabolism, which, thereby, amplifies the acid load on the kidneys. This metabolic process also escalates the production of toxins from gut microbiota including indoxyl sulfate, which is inclined to exacerbate renal inflammation [7].

According to other relative evidence, urinary protein excretion is considered to be a significant marker of renal damage, meanwhile, plant-based diets have been demonstrated to be able to reduce urinary protein levels by mitigating the hyperfiltration state in the glomeruli. There is a fact that legumes are the primary source of protein (accounting for more than 60% of total protein intake) shown in a study, compared to a traditional animal protein diet, which illustrates that the urinary protein levels in the plant protein group obviously decrease, with an average reduction of 15-20%. In addition, the estimated eGFR remains stable over a 12-month follow-up period, while the data in the control group show a slight drop by 3-5 mL/min/1.73 m^2 [7]. There is no growth of GFR in plant protein (particularly that from legumes), compared to animal protein, as a result, alleviating mechanical stress on the glomeruli, which means that the dietary shift towards legumes as the main source of protein has been associated with a reduction in urinary protein excretion, a declining trend of urinary protein levels and an improvement in renal function. The conclusion can be drawn that legume proteins, rich in plant compounds (e.g., isoflavones), possess antioxidant and anti-inflammatory properties that are beneficial for alleviating chronic inflammation in the kidneys [7].

2.2. Improving Glycemic Control and Lowering Blood Pressure

It has been indicated from several academic studies that the improvement of glycemic regulation and the reduction of blood pressure is one of the primary mechanisms by which plant-based diets impact CKD. To illustrate, Hypertension and dysglycemia commonly occur in patients with CKD because of this the deterioration of renal function can be accelerated. Moreover, plant-based diets with high fiber and potassium content, demonstrate advantages in improving chronic renal diseases [9].

The detailed data from research support this merit. Glycemic Regulation, a meta-analysis, reveals that individuals with plant-based diets experienced a mean reduction in fasting blood glucose levels by 0.11 mmol/L, significantly prioritizing than those with non-plant-based diets [9, 10]. CKD patients can profit from this kind of ability of controlling blood sugar to alleviate the high filtration pressure on glomeruli and reduce the progression of renal diseases.

Blood Pressure Regulation means that plant-based diets rich in potassium benefits the reduction of sodium retention in the body and the reabsorption of sodium in the renal tubules, which gives an explanation of lower blood volume, less vessel walls' tension, and more enhanced vasodilation. Additionally, potassium promotes vasorelaxation by regulating cell membrane potential, so that it can improve vascular elasticity and reduce blood pressure [10]. It has been shown in a comprehensive systematic study that plant-based dietary patterns could significantly lower systolic blood pressure (SBP) by 5.47 mmHg and diastolic blood pressure (DBP) by 2.49 mmHg respectively [10,11], which plays an indispensable part on those CKD patients.

2.3. Reducing Oxidative Pressure

Plant-based diets play a pivotal role in reducing oxidative stress related to chronic CKD. Numerous studies have indicated that plant-based diets, rich in flavonoids, carotenoids, and polyphenols (plant-based antioxidants), contribute to combating oxidative stress and reducing levels of C-reactive protein (CRP) [12]. To be more specifical, plant-based antioxidants, including flavonoids, directly scavenge free radicals and inhibit the activity of pro-oxidant enzymes (NADPH oxidase), which considerably reduce the levels of reactive oxygen species (ROS) in the body and markedly enhance the activity of endogenous antioxidant enzymes, such as superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px). What's more, the overactivation of inflammatory pathways induced by oxidative stress can be suppressed (e.g., NF-κB and NLRP3 inflammasomes), effectively slowing down the declining rate of renal function [13].

There are substantial findings with accurate data revealing that in those CKD patients who are inclined to adopt plant-based diets, there is a noticeable improvement in eGFR. One of these data demonstrates that there is an obvious upward trend in eGFR from a baseline of 96.5 ± 8.8 mL/min/1.73 m² to 99.9 ± 9.2 mL/min/1.73 m² ($P < 0.001$) [13]. Furthermore, it can be found in another study that patients with a plant-based but low-protein diet (KD) which is supplemented with Ket analogues tend to experience a lower drop in eGFR compared to those with a conventional low-protein diet (LPD) (KD group declining by 4.2 mL/min/1.73 m², LPD group declining by 7.1 mL/min/1.73 m², $P < 0.01$) [13]. The research data on eGFR and P-values further demonstrate the antioxidant and protective effects for kidney function for CKD patients with plant-based diets.

3. Influence of Nutrient Composition of Plant-based Diet

Through massive exploration of key nutrients in Plant-Based Diets: The effect of Dietary Fiber and Plant Protein on CKD is relatively obvious

3.1. Dietary Fiber

The European Food Safety Authority (EFSA) indicates dietary fiber as carbohydrates which refers to enzymatic digestion in the gastrointestinal tract, capable of reaching the colon and providing health benefits [12]. Simultaneously, all plant-based foods are rich in fiber. Dietary fiber improves the overall health of CKD patients [14]. It reduces the production of uremic toxins such as indoxyl sulfate (IS) and p-cresyl sulfate (PCS) and simultaneously promotes the growth of beneficial gut microbiota and the production of short-chain fatty acids (SCFAs) [15]. A study revealed that an additional daily intake of 10 grams of dietary fiber significantly reduces uremic toxin levels. For instance, short-term supplementation with soluble fibers like inulin or resistant starch decreased IS and PCS levels by 20% and 8%, respectively [15]. By generating SCFAs such as butyrate, dietary fiber helps maintain the integrity of the intestinal mucosa and reduce the translocation of uremic toxins into the bloodstream,

thereby cutting down the burden on the kidneys [15, 16]. Animal model studies suggest that a high-fiber diet can protect against renal tubular damage and interstitial fibrosis by adjusting the expression of tight junction proteins such as occludin and ZO-1 [15]. High-fiber diets exert anti-inflammatory effects by lowering the level of inflammatory cytokines such as IL-6 and CRP. Additionally, SCFAs also regulate T cells to reduce systemic inflammation. NHANES III study found that every 10-gram increase in CKD patients in dietary fiber intake reduces CRP levels by 38%, this is significantly higher than the 11% observed in non-CKD patients [15]. Dietary fiber enhances the overall health of diabetic patients by controlling intestinal flora and metabolic disorders. Further research on the long-term effects of dietary fiber and personalized recommendations is essential for nutritional management in CKD.

3.2. Dietary Fiber Plant Protein

Research indicates that plant-based proteins help slow the progression of CKD by reducing intraglomerular pressure and hyperfiltration states [6, 17]. Lower Nitrogen Waste Accumulation: Plant protein metabolism generates fewer nitrogenous waste products, effectively reducing the level of blood urea nitrogen (BUN), which lowers the adverse effects of reabsorbing waste in renal tubules [6]. A study showed that after the use of a plant-based low-protein diet (PLADO), it reduced BUN levels by approximately 15%, while the key kidney function markers like estimated glomerular eGFR [17] maintained stable. The alkaline nature of plant-based protein diets lowers acid load and mitigates metabolic acidosis, consequently reducing the incidence of metabolic acidosis. It keeps kidney tubules from the damage of acidic environments and thus delaying the aging of its structure. According to randomized controlled trials, it shows that PLADOs can reduce net acid excretion (NAE) by up to 80%, significantly improving metabolic acidosis symptoms [6, 17]. Due to the Phytate binding to plant protein, the bioavailability of phosphates from plants protein sources is low (30%-50%), which is well below the absorption rates in animal protein. This characteristic lessens the long-term renal damage caused by hyperphosphatemia [17]. A study involving CKD stage 3-4 patients demonstrated that plant-based diets improve renal mineral metabolism disorders and reduce serum phosphate levels [6].

In general, dietary fiber and plant-based protein, by reducing the inflammatory response, improving intestinal microecological balance, and reducing renal metabolic burden, play a key role in the nutritional management of CKD patients. Dietary fiber has multiple functions, including reducing the production of urinary toxins, promoting the growth of beneficial bacteria in the intestine, and producing short chain fatty acids, which strengthens the intestinal barrier and reduces the probability of urinary toxins entering the bloodstream from the intestine. Plant-based proteins provide effective protective mechanisms for chronic heart disease patients through their unique metabolic characteristics. Plant protein metabolism decreases nitrogen waste, mainly by lowering urea nitrogen levels in the blood and reducing pressure on renal tubular reabsorption. In addition, due to its alkaline properties, it reduces acid load and improves symptoms of metabolic acidosis.

4. Suggestions

It is recommended that patients with CKD adopt plant-based diets to improve renal function and slow the progress of the disease and its complications.

4.1. The Quality and Source of Protein are Particularly Vital

Plant-based proteins, such as soy, legumes, and nuts, can replace animal proteins, significantly lowering dietary acid load and therefore reducing inflammatory responses. The intake of plant-based proteins has been closely associated with declines in GFRs and reduced proteinuria, which are crucial for delaying CKD progression [18]. Additionally, plant proteins contain lower phosphorus content, thus reducing the risk of common complications such as secondary hyperparathyroidism. Selecting

high-quality proteins as the primary protein source provides safer and more effective nutritional support for CKD patients [19].

4.2. Maintaining Micronutrient Balance

Plant-based diets are rich in dietary fiber, antioxidants, and micronutrients such as potassium and magnesium. These micronutrients help control blood pressure and blood sugar levels, which reduces the burden on the kidneys. Moreover, they promote gut microbiota health and cut down the production of uremic toxins [20]. A healthy plant-based diet can reduce the metabolic burden on CKD patients. However, potassium intake should be carefully monitored to avoid the risk of hyperkalemia. Reasonable micronutrient intake can help improve blood pressure and blood sugar control while lowering disease progression risks [20].

4.3. Maintaining Acid-Base Balance

Increasing the intake of alkaline plant-based foods, such as fruits and vegetables, helps reduce the production of acidic metabolic by-products. Plant-based dietary interventions have shown superior results compared with non-plant-based diets. Specifically, increasing fruit and vegetable intake can level serum bicarbonate up [21], reducing renal acid load, and particularly in advanced CKD stages. This adjustment can effectively mitigate metabolic acidosis, which is one of the significant factors in CKD progression. Consuming more alkaline foods helps CKD patients maintain acid-base balance and improve renal function.

4.4. Personalized Nutritional Planning

For CKD patients at different disease stages, personalized nutritional intervention plans should be developed, and nutritional education and counseling are necessary.

During interventions, patients should receive monthly individualized nutrition education and consultations to strengthen the effect [22]. Factors such as GFR levels, comorbidities, and adaptability to plant-based diets should also be taken into consideration. The intervention process requires guidance from professional nutritionists to ensure the dietary plan's scientific and effective execution. CKD patients should also receive personalized medical nutrition therapy (MNT) which is provided by registered dietitians (RDN) to meet their specific needs [23]. Professional guidance helps patients better manage disease progression while meeting nutritional needs and improving overall health and quality of life [23].

5. Conclusion

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This study, through systematic analysis and literature review, reveals the various benefits of plant-based diets in the nutritional management of CKD. Research demonstrates that plant-based diets improve CKD management in multiple ways, primarily by reducing proteinuria, slowing the decline in eGFR, and significantly improving renal function indicators. Compared with traditional high-animal-protein diets, plant-based diets slow renal function deterioration and reduce proteinuria levels. They also have a positive impact on CKD patients' metabolic profiles and cardiovascular health. Diets rich in dietary fiber and low in fat effectively reduce blood sugar levels and improve insulin sensitivity, which benefits vascular function and reduces oxidative stress and lowers the risk of hypertension and cardiovascular disease in CKD patients. Furthermore, the antioxidants and anti-inflammatory components of plant-based diets help suppress oxidative stress, reduce pro-inflammatory factors, and improve the chronic inflammatory state of the kidneys. By increasing fruit and vegetable intake, plant-based diets can effectively reduce metabolic acid load, helping CKD patients maintain acid-base balance and delay disease progression. In addition, supplementing dietary fiber has also been shown to regulate gut microbiota, reduce the production of toxic metabolites, and

enhance gut barrier function, thereby improving metabolic health. The primary contribution of this study is further validation of the protective potential of plant-based diets for CKD patients, addressing gaps in research on long-term plant-based dietary interventions in this field. These findings provide solid theoretical support for personalized nutrition intervention plans based on plant-based diets, which holds significant theoretical and clinical implications. However, insufficient sample sizes in long-term follow-up studies and a lack of individualized intervention design are the limitations of present study. Future studies should be done on the effects of plant-based dietary patterns at different CKD stages, optimize dietary intervention policies, and integrate plant-based dietary interventions with digital health technologies (e.g., wearable devices and artificial intelligence algorithms). This would enable dynamic monitoring of patients' dietary behaviors and physiological states, developing personalized dietary guidance tools to provide precise and tailored nutritional management for CKD patients.

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