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## AI-Driven Precision Nutrition for Chronic Kidney Disease Management Through Machine Learning Prediction of Phosphorus Bioavailability

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**Objectives :** Effective management of dietary phosphorus is critical for preventing hyperphosphatemia and its related complications in Chronic Kidney Disease (CKD) care. However, existing guidelines offer broad recommendations that overlook the variability in individual dietary habits and phosphorus absorption rates. This study develops a machine learning-based approach to estimate the bioavailability of phosphorus in meals consumed by CKD patients, aiming to deliver personalized dietary advice for improved phosphorus management.

**Methods :** Involving 500 CKD patients at stages 3-4 with diverse diets, we collected 3-day food diaries, serum phosphorus levels, and detailed data on medications, comorbidities, and gut microbiomes. Using Natural Language Processing (NLP), we extracted nutrient profiles, emphasizing phosphorus sources and amounts. Deep Neural Networks (DNNs) and Convolutional Neural Networks (CNNs), both machine learning techniques, predicted serum phosphorus levels using dietary data, gut microbiomes, and patient factors, assessed by accuracy, AUC, and MAE.

**Results :** The DNN model outperformed other approaches, achieving an AUC of 0.94, 87.5% accuracy, and an MAE of 0.56 mg/dL in predicting serum phosphorus levels. Importantly, integrating gut microbiome data significantly enhanced the model's ability to predict outcomes ( $p < 0.05$ ), indicating the vital influence of the microbiome on phosphorus bioavailability. Patients who received personalized dietary recommendations based on AI experienced a 30% decrease in hyperphosphatemia incidents over six months, a substantial improvement over the 5% decrease seen in the control group. Moreover, compliance with these dietary recommendations increased by 40%, with a 95% confidence interval of 35-45%, attributed to the tailored, actionable advice provided.

**Conclusions :** Utilizing AI to estimate dietary phosphorus in CKD patients represents a major step forward in renal nutrition. This approach improves phosphorus level control and enhances patient adherence to dietary guidance. Our results support the integration of AI-driven tools in CKD nutritional planning, potentially setting a new standard in kidney disease dietary management.