Effect of Neighborhood Food Environment and Socioeconomic Status on Serum Phosphorus Level for Patients on Chronic Dialysis

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Due to the number of contributing authors, the affiliations are listed at the end of this article.

ABSTRACT

Background Elevated blood phosphorus levels are common and associated with a greater risk of death for patients receiving chronic dialysis. Phosphorus-rich foods are prevalent in the American diet, and low-phosphorus foods, including fruits and vegetables, are often less available in areas with more poverty. The relative contributions of neighborhood food availability and socioeconomic status to phosphorus control in patients receiving dialysis are unknown.

Methods Using longitudinal data from a national dialysis provider, we constructed hierarchical, linear mixed-effects models to evaluate the relationships between neighborhood food environment or socioeconomic status and serum phosphorus level among patients receiving incident dialysis.

Results Our cohort included 258,510 patients receiving chronic hemodialysis in 2005–2013. Median age at dialysis initiation was 64 years, 45% were female, 32% were Black, and 15% were Hispanic. Within their residential zip code, patients had a median of 25 “less-healthy” food outlets (interquartile range, 11–40) available to them compared with a median of four “healthy” food outlets (interquartile range, 2–6). Living in a neighborhood with better availability of healthy food was not associated with a lower phosphorus level. Neighborhood income also was not associated with differences in phosphorus. Patient age, race, cause of ESKD, and mean monthly dialysis duration were most closely associated with phosphorus level.

Conclusions Neither neighborhood availability of healthy food options nor neighborhood income was associated with phosphorus levels in patients receiving chronic dialysis. Modifying factors, such as nutrition literacy, individual-level financial resources, and adherence to diet restrictions and medications, may be more powerful contributors than food environment to elevated phosphorus.

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Elevated serum phosphorus levels can increase the risk of cardiovascular disease and mortality, yet the Dialysis Outcomes and Practice Patterns Study found that only 44% of patients receiving chronic dialysis achieved optimal phosphorus control.1 An important contributor to elevated phosphorus levels is its ubiquitous presence in food, either occurring naturally or used as a preservative.2,3 Because conventional (three times a week) hemodialysis removes only a modest quantity of phosphorus from the body,4–6 physicians prescribe oral phosphorus binders that must be consumed with meals and reduce intestinal absorption of phosphorus. Unfortunately, these medications can cause gastrointestinal distress, impose a serious pill burden, are inconvenient for patients, and add to health care costs.
costs. Despite routine prescribing of binders and nutritional counseling, phosphorus levels are persistently elevated in thousands of patients receiving dialysis in the United States. The intestinal absorption of phosphorus varies depending on the source of food: organic or inorganic, presence of phosphorus additives, and the presence of phytates, which can reduce the absorption of phosphorus. The Western diet is typically low in soluble fiber and phytates, with the major source of phytates being whole grains in breads and ready-to-eat cereals, and it also tends to be high in readily absorbable phosphorus included as additives in processed foods to enhance flavor and improve shelf life. Over 70% of phosphorus from processed foods, red meat, dairy, and sodas is absorbed. In contrast, because of the presence of phytates, only 30%–40% of phosphorus present in grains, legumes, fruits, and vegetables is absorbed.

Although food labels are intended to provide the consumer with easily understood and relevant information about nutritional content, the US Food and Drug Administration does not require food manufacturers to display the phosphorus content. When the phosphorus content of food is listed on labels, the label can be challenging to interpret, or the phosphorus content may be inaccurately stated. For example, a survey of food labels of bestselling, branded grocery products in Northeast Ohio showed that phosphorus additives were extremely common in prepared frozen foods, packaged meat, and bread and baked goods. The same study also found that phosphorus additive–free meals were often more expensive than meals with additives. Additionally, many patients on chronic dialysis have low health and nutrition literacy and limited income, creating further barriers to selecting meals low in phosphorus.

In summary, foods rich in phosphorus are prevalent in the American diet. Geographic areas with more poverty often have less availability of low-phosphorus alternatives, including fruits and vegetables. Because of the phosphorus-rich content of many types of food, we hypothesized that restrictions on food availability might affect phosphorus control for patients on dialysis, acknowledging that dietary choices are complex and depend on multiple factors, including gustatory preferences, sociocultural norms, and comorbidities such as diabetes, income, and nutrition literacy. Using data from a national dialysis provider linked to US Census data on food outlets and income, we characterized the neighborhood environment for patients on dialysis. We quantified the effect of neighborhood food access and socioeconomic status (SES) on longitudinal serum phosphorus concentrations.

METHODS

We used data from a national dialysis provider to assemble a cohort of adult patients (aged ≥18 years) receiving chronic hemodialysis therapy between January 1, 2005, and December 31, 2013. We included all patients on incident chronic dialysis who received conventional, in-center hemodialysis. We excluded patients who received home hemodialysis, peritoneal dialysis, and nocturnal dialysis. We also excluded patients who were on dialysis for <90 days. Data collected during the initial 90 days after starting dialysis (the baseline exposure period) were used to determine the baseline characteristics for each patient.

Outcome

Our primary outcome was serum phosphorus concentration. All patients had the opportunity of 1 year of follow-up after starting dialysis. The initial date for outcome measurement was the first day after the baseline exposure period (day 91). Phosphorus was measured serially during usual dialysis care and every patient in our dataset could contribute up to nine phosphorus values (one for each month). Patients were censored from analyses if they changed providers, discontinued dialysis, or died before the end of 1 year after starting dialysis. It is routine clinical practice among dialysis centers to measure monthly serum electrolyte levels, including phosphorus. In instances where the dataset contained more than one phosphorus level measured in a month, we selected the first measurement.

Exposures

Our primary exposure was the individual patient’s neighborhood food environment, on the basis of the patient’s home zip code. In instances where a patient did not have a zip code listed in the database at the time of dialysis initiation, we used the first available zip code for the patient.

To ascertain the food environment, we first identified food outlets within each zip code by using data from the US Census. We defined food outlets as either healthy or less-healthy, using the criteria defined by the Centers for Disease Control and Prevention Modified Retail Food Environment Index (further described in Supplemental Appendix 1). Finally, we divided zip codes into quartiles on the basis of food availability (low availability, medium-low availability, medium-high availability, and high availability of healthy food).
Our secondary exposure was SES, as measured by the Agency for Healthcare Related Quality (AHRQ) SES index. The AHRQ SES Index reflects the following domains: occupation (percentage unemployed), income, wealth, education, and housing (Supplemental Appendix 2). We then divided patients’ residential zip codes into four quartiles on the basis of the SES index that was determined at the zip code level.

Covariates
Covariates included patient demographic and clinical characteristics (age at dialysis initiation, sex, race, history of diabetes, and cause of ESKD). Because our dataset had detailed information about all dialysis treatments, we extracted information on the following time-updated variables: mean time patients spent on dialysis each month (measured in minutes), phosphorus binder use, and the number of dialysis treatments missed each month.

Statistical Analyses
We used descriptive statistics to compare baseline characteristics for patients according to their neighborhood availability of healthy and less-healthy food (low availability, medium-low availability, medium-high availability, and high availability).

Neighborhood Food Environment and Serum Phosphorus Level
Because of the longitudinal nature of our dataset, we fit hierarchical, linear mixed-effects models to account for time-updated variables and clustering of patients (within dialysis units and zip codes). For the primary analysis, we included variables that we identified a priori as clinically important for serum phosphorus control (see Covariates, above). We used the Akaike information and Bayesian information criteria to guide model selection.

Neighborhood SES and Serum Phosphorus Level
Similar to the prior model, to assess the relationship between neighborhood SES and the outcome of serum phosphorus level, we fit a hierarchical, linear mixed-effects model. First, we analyzed the effect of neighborhood SES alone on serum phosphorus level. We then included neighborhood food availability in the model, and, finally, we included an interaction term to evaluate the relationship between availability of food and SES regarding serum phosphorus levels.

Secondary Analyses
To examine the effect of food environment surrounding a dialysis unit (versus the patient residential neighborhood) on phosphorus control, we characterized the food environment around each dialysis unit. Again, applying criteria defined by the Centers for Disease Control and Prevention Modified Retail Food Environment Index, we first located dialysis units, and then constructed geographic boundaries using drivable distance around each dialysis unit. We geocoded the location of every dialysis unit in our dataset using R package “ggmap,” and then, using Network Analyst extension in ArcGIS Desktop 10.6.1 (Environmental Systems Research Institute, Redlands, CA), we identified 0.6-mile (1-km) driving distances around each dialysis unit. We then identified the number of food outlets (healthy and less healthy) located within the geographical boundary surrounding every dialysis unit in our dataset. Finally, we divided availability of healthy food outlets around dialysis units into quartiles (low availability, medium-low availability, medium-high availability, and high availability).

All analyses were completed using STATA version 15.1 (StataCorp, College Station, TX), R version 3.5.3 (R Core Team, Vienna, Austria), and ArcGIS version 10.6.1.

RESULTS

Neighborhood Environment of the Patient’s Residential Zip Code
Our cohort consisted of 258,510 patients on chronic, in-center hemodialysis (Figure 1). The mean number of phosphorus values for each patient was 7.7 (SD 2.3). The median age of the cohort was 64 years (interquartile range [IQR], 53–74 years), 45% were female, 32% were Black, and 15% were Hispanic (Table 1). Diabetes was the most common cause of

Figure 1. Flowchart for cohort generation. HD, hemodialysis.
ESKD (48%), followed by hypertension (30%) and GN (10%). Of the entire cohort, 14% lived in a rural zip code.

Availability of healthy food outlets varied widely (Table 1). Zip codes in the lowest quartile of availability of healthy food had a median of one healthy food outlet (IQR, 0–2), whereas zip codes in the highest quartile had a median of nine healthy food outlets (IQR, 7–11). A total of 9% of the cohort lived in a zip code without any healthy food outlet, and 31% lived in a zip code with at least six healthy food outlets (29% in an urban zip code and 19% in a rural zip code). Regardless of neighborhood income, there were fewer healthy food outlets compared with less-healthy food outlets (Figure 2). Overall, there were a median of 25 less-healthy food outlets (IQR, 11–40) compared with a median of four healthy food outlets (IQR, 2–6) per neighborhood. We also found that the median number of less-healthy food outlets declined in neighborhoods with incomes above $130,000 (12 versus 25 less-healthy food outlets in neighborhoods with incomes ≤$130,000).

Neighborhood Environment of the Dialysis Unit
Our cohort consisted of 2914 dialysis units located over a wide geographic area (Supplemental Figure 1). In the immediate proximity of a dialysis unit (1 km around a dialysis unit), there was a median of one healthy and one less-healthy food outlet (Supplemental Table 1). Surprisingly, we also found only weak correlation between neighborhood SES of the dialysis unit zip code and the residential zip code of the patient (Supplemental Table 2). For instance, 42% of patients who lived in a zip code classified as the lowest quartile of SES went to a dialysis unit in a zip code classified as having a higher quartile of SES.

Effect of Healthy Food Outlet Availability and SES on Phosphorus Control
The mean phosphorus value was 5.2 mg/dl (SD 1.47). Nearly 34% of patients had a phosphorus value >5.5 mg/dl in the first month of the observation period, and over 16% of patients had a phosphorus value >6.5 mg/dl during the same time period. The proportion of patients with a phosphorus value greater than either 5.5 mg/dl or 6.5 mg/dl did not vary across the observation period (Supplemental Figure 2).

The proportion of patients with an elevated phosphorus (phosphorus >5.5 mg/dl) at any time during the observation period did not vary between quartiles of access to healthy food or SES derived from patient residence. A mixed-effects, linear regression model did not show a statistically significant association between access to food and change in phosphorus control over time, even after accounting for prescriptions for phosphorus binders for patients residing in either urban or rural zip codes (Supplemental Table 3 and 4, Table 2). Similarly, we did not find a statistically significant association between neighborhood SES and change in phosphorus over time.

### Table 1. Demographic characteristics of patients by availability of healthy food outlets

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Healthy Food Outlet Availability, Quartilea</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median number of healthy food outlets (IQR)</td>
<td>Lowest 1 (0–2) Medium-Low 3 (3–4) Medium-High 5 (5–6) Highest 9 (7–11)</td>
<td></td>
</tr>
<tr>
<td>No. of patients</td>
<td>87,622 64,850 46,005 59,594</td>
<td></td>
</tr>
<tr>
<td>Age, yr, median (IQR)</td>
<td>64 (53–74) 64 (53–74) 64 (53–74) 63 (52–74)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cause of ESKD</td>
<td>Black race 27,379 (31.2%) 22,779 (35.1%) 14,720 (32.0%) 16,898 (28.4%)</td>
<td></td>
</tr>
<tr>
<td>SES category</td>
<td>Lowest Medium-Low Medium-High Highest</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>8708 (10.3%) 6060 (9.6%) 4314 (9.7%) 5316 (9.2%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hypertension</td>
<td>40,536 (47.8%) 29,663 (47.1%) 20,969 (47.0%) 28,350 (48.9%)</td>
<td></td>
</tr>
<tr>
<td>PKD/CAKUT</td>
<td>24,711 (29.1%) 19,437 (30.8%) 13,851 (31.0%) 17,680 (30.5%)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1750 (2.1%) 1271 (2.0%) 889 (2.0%) 1028 (1.8%)</td>
<td></td>
</tr>
<tr>
<td>Income quartile</td>
<td>Lowest Medium-Low Medium-High Highest</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>32,064 (36.6%) 22,547 (34.8%) 13,899 (30.2%) 19,164 (32.2%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hypertension</td>
<td>19,961 (22.8%) 15,418 (23.8%) 11,370 (24.7%) 14,684 (24.6%)</td>
<td></td>
</tr>
<tr>
<td>PKD/CAKUT</td>
<td>21,706 (24.8%) 16,258 (25.1%) 13,059 (28.4%) 17,033 (28.6%)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>13,891 (15.9%) 10,627 (16.4%) 7677 (16.7%) 8713 (14.6%)</td>
<td></td>
</tr>
<tr>
<td>Geographic region</td>
<td>Lowest Medium-Low Medium-High Highest</td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>28,126 (33.6%) 19,802 (30.7%) 12,417 (27.1%) 22,888 (38.4%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Rural</td>
<td>32,064 (36.6%) 22,547 (34.8%) 13,899 (30.2%) 19,164 (32.2%)</td>
<td></td>
</tr>
<tr>
<td>SES category</td>
<td>Lowest Medium-Low Medium-High Highest</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>17,925 (21.4%) 13,086 (20.3%) 9492 (20.7%) 12,266 (20.6%)</td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>16,702 (19.9%) 13,195 (20.5%) 9750 (21.2%) 9752 (16.4%)</td>
<td></td>
</tr>
<tr>
<td>PKD/CAKUT</td>
<td>1750 (2.1%) 1271 (2.0%) 889 (2.0%) 1028 (1.8%)</td>
<td></td>
</tr>
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<td>13,891 (15.9%) 10,627 (16.4%) 7677 (16.7%) 8713 (14.6%)</td>
<td></td>
</tr>
</tbody>
</table>

IQR, interquartile range; PKD, polycystic kidney disease; CAKUT, congenital anomalies of the kidney and urinary tract.

* Quartiles were divided on healthy food availability among all zip codes in the United States.
Notably, phosphorus binder use increased from 59% to 79% over the course of the study period (Figure 3).

Instead, patient age and race were the strongest determinants of serum phosphorus level. We found that older patients had a lower serum phosphorus than younger patients (serum phosphorus was 0.3 mg/dl lower for every 10-year increase in age; $P<0.01$). We also found that patients who self-identified as Black or Hispanic had a slightly lower phosphorus level (compared with White patients, the serum phosphorus of Black patients was lower by 0.2 mg/dl and the serum phosphorus of Hispanic patients was lower by 0.1 mg/dl; both $P<0.01$).

Secondary analyses examining the association between access to healthy and less-healthy food within 0.6 miles (1 km) of a dialysis unit again did not show a relationship of access to food outlets with serum phosphorus level (Supplemental Tables 6 and 7).

DISCUSSION

Elevated serum phosphorus is a pervasive problem for patients receiving chronic dialysis and has a negative association with survival. Management of hyperphosphatemia involves substantial dietary restrictions and significant pill burden. Because diet is a major contributor to phosphorus levels, we evaluated the relationship between access to healthy food, socioeconomic environment, and phosphorus control among patients on chronic dialysis. Although most patients in our study lived in neighborhoods with low access to healthy food, we did not find a clinically meaningful relationship between neighborhood food environment and hyperphosphatemia.

Our finding of a lack of association between neighborhood SES and healthy food options and serum phosphorus levels should be considered in the context of prior high-quality analyses by Gutiérrez et al. Using data from the National Health and Nutrition Examination Survey, the Gutiérrez group demonstrated that individual income level predicts phosphorus control for patients with CKD who are not yet on dialysis. There are several explanations for this observed difference. First, because of the nature of our dataset, our study evaluated SES at the neighborhood level, whereas the study by Gutiérrez et al. was at the individual level. Ascertainment of SES at the individual level may better predict individual-level outcomes, such as phosphorus. Second, patients on dialysis have frequent laboratory monitoring. Dialysis providers (and the Centers for Medicare and Medicaid Services) monitor serum phosphorus levels as a marker of quality of care, which may lead to providers intensifying treatments when serum phosphorus levels are high. Another possibility is that cultural and personal food preferences, as well as actual food cost, and not food availability, may drive selection of a high-phosphorus diet. This hypothesis is supported by a recent analysis in which patients with CKD enrolled in the Chronic Renal Insufficiency Cohort study, who had better access to grocery stores, did not have a healthier diet score. Specifically, a lack of knowledge about which foods to choose, and inability to make further restrictions on an already challenging set of dietary

(Supplemental Table 5, Table 3). Notably, phosphorus binder use increased from 59% to 79% over the course of the study period (Figure 3).

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recommendations because of diabetes, heart disease, or hyperkalemia, may inhibit the ability of patients to control phosphorus even when healthy food is locally available. Finally, the US Food and Drug Administration does not require manufacturers to report the phosphorus content on food labels, when even items such as unprocessed meats have phosphorus added to prolong their shelf life. The lack of phosphorus content in food labels, prevalence of phosphorus-containing additives, and health literacy all might be contributing to difficulty controlling serum phosphorus levels.

Even if patients have access to healthy food, individual food preference can vary significantly and affect overall food choice. Qualitative work by our group and others found that many patients on dialysis have difficulty identifying foods high in phosphorus. In a small pilot trial, our group found that financial incentives and additional nutritional counseling led to only a modest improvement in phosphorus control. It is possible that patients with high access to healthy food and personalized counseling may still make dietary choices that cause high-phosphorus intake. Furthermore, healthy food options may still lead to consumption of meals that are high in

Table 2. Mixed-effects linear model demonstrating the relationship between neighborhood availability of healthy food and serum phosphorus levels

<table>
<thead>
<tr>
<th>Variablea</th>
<th>Base Model</th>
<th>Base Model + Month</th>
<th>Base Model + Month + AHRQ SES Index</th>
<th>Base Model + Month + AHRQ SES Index + Demographics</th>
<th>Base Model + Month + AHRQ SES Index + Demographics + Time-updated variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy Food Availability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest quartile</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Medium-low quartile</td>
<td>0.0035</td>
<td>0.0037</td>
<td>0.0044</td>
<td>0.0034</td>
<td>0.0038</td>
</tr>
<tr>
<td>SEM</td>
<td>0.0078</td>
<td>0.0078</td>
<td>0.0079</td>
<td>0.0077</td>
<td>0.0077</td>
</tr>
<tr>
<td>P value</td>
<td>0.66</td>
<td>0.64</td>
<td>0.58</td>
<td>0.66</td>
<td>0.62</td>
</tr>
<tr>
<td>Medium-high quartile</td>
<td>0.0121</td>
<td>0.0124</td>
<td>0.0108</td>
<td>0.0045</td>
<td>0.0040</td>
</tr>
<tr>
<td>SEM</td>
<td>0.0079</td>
<td>0.0079</td>
<td>0.0081</td>
<td>0.0078</td>
<td>0.0078</td>
</tr>
<tr>
<td>P value</td>
<td>0.13</td>
<td>0.12</td>
<td>0.19</td>
<td>0.57</td>
<td>0.61</td>
</tr>
<tr>
<td>Highest quartile</td>
<td>0.0288</td>
<td>0.0292</td>
<td>0.0223</td>
<td>0.0028</td>
<td>0.003</td>
</tr>
<tr>
<td>SEM</td>
<td>0.0081</td>
<td>0.0081</td>
<td>0.0083</td>
<td>0.008</td>
<td>0.008</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.007</td>
<td>0.73</td>
<td>0.71</td>
</tr>
</tbody>
</table>

The base model only includes access to healthy food outlets. The month is the month during which the laboratory value was measured in exposure period after starting dialysis. Demographics were age, sex, race, and cause of ESKD. Time-updated variables were time spent on dialysis, treatments missed per month, and phosphorus binder use.

aAnalyses limited to urban zip codes.

Table 3. Mixed-effects linear model demonstrating the relationship between neighborhood SES and serum phosphorus levels

<table>
<thead>
<tr>
<th>Variablea</th>
<th>Base Model</th>
<th>Base Model + Month</th>
<th>Base Model + Month + Demographics</th>
<th>Base Model + Month + Demographics + Time-updated variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neighborhood SES Index</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest quartile</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Medium-low quartile</td>
<td>0.0022</td>
<td>0.002</td>
<td>0.0104</td>
<td>0.0102</td>
</tr>
<tr>
<td>SEM</td>
<td>0.0081</td>
<td>0.0081</td>
<td>0.0078</td>
<td>0.0078</td>
</tr>
<tr>
<td>P value</td>
<td>0.78</td>
<td>0.81</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Medium-high quartile</td>
<td>-0.0327</td>
<td>-0.0332</td>
<td>-0.0009</td>
<td>-0.0015</td>
</tr>
<tr>
<td>SEM</td>
<td>0.0082</td>
<td>0.0082</td>
<td>0.0081</td>
<td>0.0081</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.91</td>
<td>0.86</td>
</tr>
<tr>
<td>Highest quartile</td>
<td>-0.0635</td>
<td>-0.0646</td>
<td>0.017</td>
<td>0.015</td>
</tr>
<tr>
<td>SEM</td>
<td>0.0077</td>
<td>0.0078</td>
<td>0.0077</td>
<td>0.0077</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.03</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The base model only includes neighborhood AHRQ SES Index. The month is the month during which the laboratory value was measured in the exposure period after starting dialysis. Demographics were age, sex, race, and cause of ESKD. Time-updated variables were time spent on dialysis, treatments missed per month, and phosphorus binder use.

aAnalyses limited to urban zip codes.
phosphorus. Sharon Moe and others have proposed that the renal community needs to reimagine kidney nutrition counseling, such that advice should involve asking patients to avoid canned, boxed, or prepackaged foods, instead of providing patients with handouts about phosphorus. This advice alone might help in reducing serum phosphorus levels.

Our study has several limitations. Although we had access to detailed, longitudinal laboratory values and prescribed medications, we did not have exact dosing information, nor could we capture medication adherence in our dataset. Another limitation is that our analysis relied on North American Industry Classification System codes to specify if a food outlet was healthy or not, which has the potential to misclassify food outlets and might not be updated regularly. A third limitation of our approach is that we assumed that the neighborhood environment immediately surrounding patients’ homes would be similar to the aggregate food environment within their zip code. We acknowledge that zip codes can vary in size, and that a smaller geographic boundary (US Census block or tract) may have better accuracy at predicting an individual’s SES; however, we did not have access to individual patient addresses. Similarly, because of the nature of our dataset, we did not have access to high-granularity data on individual-level SES indicators (e.g., household income, education level), which might be a stronger predictor of health-related outcomes, but is also complex to measure. Finally, the AHRQ SES Index was initially described using US Census data from 2000, before the study period; however, we compared the AHRQ SES Index to updated US Census data from 2007 to 2011, and we found excellent concordance in predicting neighborhood socioeconomic index (Supplemental Figure 3).

Despite the fact that 30% of dialysis centers and 33.7% of patients receiving dialysis in our study were located within geographic regions with either no access or low access to healthy food, neighborhood food environment and socioeconomic environment did not affect serum phosphorus control. These results suggest that the main determinants of phosphorus control may instead be food choice, access to effective educational tools, and medication adherence. Understanding a patient’s income, food availability near where they live, and their personal preferences can help develop personalized dietary plans to reduce dietary phosphorus intake. Future remedies to improve phosphorus control may require addressing these issues as well as the pervasive problem of inadequate labeling.

**DISCLOSURES**

P. Reese is an associate editor for the *American Journal of Kidney Disease*. All remaining authors have nothing to disclose.

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**Figure 3.** Increasing proportion of patients are on a phosphorus binder over time, after starting dialysis.
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Dr. Vishnu S. Potluri, Dr. Deirdre Sawinski, and Dr. Peter P. Reese designed the study. Dr. Vishnu S. Potluri, Vicky Tam, Dr. Justine Shults, Dr. Deirdre Sawinski, Dr. Jordana B. Cohen, and Dr. Peter P. Reese were involved in analyzing the data. Dr. Vishnu S. Potluri and Dr. Peter P. Reese drafted and revised the manuscript. All authors were involved in the interpretation of the results and approved the final version of the manuscript.

SUPPLEMENTAL MATERIAL

This article contains the following supplemental material online at http://jasn.asnjournals.org/lookup/suppl/doi:10.1681/ASN.2020030290/-/DCSupplemental.

Supplemental Appendix 1. Methodology for estimating the number of healthy and less-healthy food outlets within patient residential zip code and dialysis unit neighborhood.

Supplemental Appendix 2. Components of the AHRQ SES Index.

Supplemental Figure 1. Geographic distribution of dialysis units included in the final cohort.

Supplemental Figure 2. The proportion of patients with serum phosphorus >5.5 mg/dl or >6.5 mg/dl is greater among patients who are younger.

Supplemental Figure 3. Correlation between AHRQ SES Index from US Census data from 2000 and SES Index calculated using US Census data from 2007 to 2011.

Supplemental Table 1. Availability of healthy and less-healthy food outlets in the neighborhood of the dialysis unit.

Supplemental Table 2. Correlation between zip code SES for dialysis unit and patient home location.

Supplemental Table 3. Individual components of the mixed-effects linear model demonstrating the relationship between availability of healthy food outlets and serum phosphorus levels.

Supplemental Table 4. Individual components of the mixed-effects linear model examining the relationship between neighborhood SES index and serum phosphorus levels.

Supplemental Table 5. Mixed-effects linear model examining the relationship between availability of healthy food outlets within 0.6 miles (1 km) of a dialysis unit on serum phosphorus level.

Supplemental Table 6. Mixed effects linear model examining the relationship between availability of less-healthy food within 0.6 miles (1 km) of a dialysis unit on serum phosphorus level.

REFERENCES


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