

# A Prediction Model for Chronic Kidney Disease Includes Periodontal Disease

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**Background:** An estimated 75% of the seven million Americans with moderate-to-severe chronic kidney disease are undiagnosed. Improved prediction models to identify high-risk subgroups for chronic kidney disease enhance the ability of health care providers to prevent or delay serious sequelae, including kidney failure, cardiovascular disease, and premature death.

**Methods:** We identified 11,955 adults  $\geq 18$  years of age in the Third National Health and Nutrition Examination Survey. Chronic kidney disease was defined as an estimated glomerular filtration rate of 15 to 59 ml/minute/1.73 m<sup>2</sup>. High-risk subgroups for chronic kidney disease were identified by estimating the individual probability using  $\beta$  coefficients from the model of traditional and non-traditional risk factors. To evaluate this model, we performed standard diagnostic analyses of sensitivity, specificity, positive predictive value, and negative predictive value using 5%, 10%, 15%, and 20% probability cutoff points.

**Results:** The estimated probability of chronic kidney disease ranged from virtually no probability (0%) for an individual with none of the 12 risk factors to very high probability (98%) for an older, non-Hispanic white edentulous former smoker, with diabetes  $\geq 10$  years, hypertension, macroalbuminuria, high cholesterol, low high-density lipoprotein, high C-reactive protein, lower income, and who was hospitalized in the past year. Evaluation of this model using an estimated 5% probability cutoff point resulted in 86% sensitivity, 85% specificity, 18% positive predictive value, and 99% negative predictive value.

**Conclusion:** This United States population-based study suggested the importance of considering multiple risk factors, including periodontal status, because this improves the identification of individuals at high risk for chronic kidney disease and may ultimately reduce its burden. *J Periodontol* 2009; 80:16-23.

## KEY WORDS

Glomerular filtration rate; hypertension; jaw, edentulous; kidney diseases; periodontal diseases; sensitivity and specificity.

Chronic kidney disease is a major public health problem related to serious sequelae, including end-stage kidney failure, cardiovascular disease, premature death, and increased health care expenditures.<sup>1,2</sup> The risk for these serious sequelae increases as the glomerular filtration rate (GFR) decreases below 60 ml/minute/1.73 m<sup>2</sup>,<sup>3-5</sup> corresponding to the National Kidney Foundation's Kidney Disease Outcomes Quality Initiative (K/DOQI) stage 3 and stage 4 chronic kidney disease defined as GFR 15 to 59 ml/minute/1.73 m<sup>2</sup>.<sup>1</sup> Fewer than 25% of the estimated seven million adults with chronic kidney disease reported ever being told that they had weak or failing kidneys,<sup>6</sup> suggesting that more than 75% of adults with chronic kidney disease are undiagnosed in the United States (U.S.).

The identification of high-risk individuals provides an opportunity for early detection and intervention to prevent or delay the onset of end-stage renal disease, cardiovascular events, premature death, and increased health care expenditures. Traditional risk factors for chronic kidney disease include age  $>60$  years,<sup>1,7-9</sup> hypertension,<sup>2,7,9-16</sup> diabetes,<sup>2,7-17</sup> poor glycemic control,<sup>1,7,12,13</sup> obesity,<sup>2,7,13-17</sup> macroalbuminuria,<sup>1,6,7,9,18</sup> smoking,<sup>1,7,10,13,15-17</sup> C-reactive protein (CRP),<sup>7,15,19</sup> elevated total cholesterol,<sup>1,7,13,15</sup> low levels of high-density lipoprotein (HDL) cholesterol,<sup>1,7,11,13,16</sup> elevated levels of low-density lipoprotein cholesterol,<sup>7,16</sup> race/ethnicity,<sup>1,7,12,14,15,17</sup>

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gender,<sup>1,7,8,10,13,15-17</sup> and income/poverty.<sup>1,7,14</sup> Non-traditional risk factors that may contribute to chronic kidney disease include periodontal disease,<sup>7,20-22</sup> education,<sup>7,14,17</sup> and access to medical care.<sup>7,14,23</sup>

The biologic plausibility for considering periodontal disease as a risk factor is derived from the potential role of the inflammatory response to periodontal disease in the chronic systemic inflammatory burden (e.g., increased CRP levels)<sup>15,19</sup> associated with chronic kidney disease. The local tissue destructive immunoinflammatory response to periodontal pathogens, their products (i.e., lipopolysaccharides), and inflammatory cytokines are believed to contribute to the chronic systemic inflammatory burden of periodontal disease.<sup>24,25</sup>

The objective of our study was two-fold: 1) to identify high-risk subgroups by estimating an individual's probability of chronic kidney disease by applying a multivariable model of traditional and non-traditional risk factors in a representative sample of the U.S. population using the Third National Health and Nutrition Examination Survey (NHANES III) dataset;<sup>26</sup> and 2) to validate the model using the standard diagnostic analyses of sensitivity, specificity, positive predictive value, and negative predictive value.

## MATERIALS AND METHODS

### Study Population

This cross-sectional study was deemed exempt by the institutional review board. NHANES III, conducted between 1988 and 1994, is a complex, multistage, stratified, clustered sample of the civilian, non-institutionalized U.S. population, which is representative of the U.S. population. We identified 11,955 adults  $\geq 18$  years of age in NHANES III, which represented 124.3 million Americans. The study population was randomly divided into two separate and distinct samples. Sample 1 ( $n = 5,978$ ) was used to develop the multivariable logistic regression model. To evaluate this model, we performed the standard diagnostic analyses of sensitivity, specificity, positive predictive value, and negative predictive value using 5%, 10%, 15%, and 20% probability cutoff points in the sample 2 dataset ( $n = 5,977$ ).

### Description of Main Outcome

The main outcome was moderate-to-severe chronic kidney disease defined as an estimated GFR of 15 to 59 ml/minute/1.73 m<sup>2</sup>.<sup>1</sup> This definition was reported to more precisely estimate decreased kidney function.<sup>6</sup> Henceforth, this moderately to severely decreased kidney function will be referred to as chronic kidney disease. The GFR was estimated using the simplified Modification of Diet in Renal Disease Study equation:  $GFR = 186.3 \times (\text{serum creatinine in mg/dl})^{-1.154} \times \text{age}^{-0.203} \times 0.742$  (if female)  $\times 1.21$  (if

black). The serum creatinine value was calibrated by subtracting the value of 0.23 to align the NHANES measures with creatinine assays in the aforementioned equation.<sup>27</sup>

### Description of Risk Factors

The model for chronic kidney disease includes the following 12 traditional and non-traditional risk factors.

**Health status.** Periodontal status was based on a clinical examination and categorized as no periodontal disease, periodontal disease, or edentulous. Periodontal disease was defined as having one or more sites with loss of attachment  $\geq 4$  mm and bleeding on the same tooth, where bleeding is an indicator of active inflammation.<sup>28</sup> Edentulous was defined as having lost all natural teeth. Periodontal disease is a major cause of edentulism in adults.<sup>29</sup> Systemic hypertension was defined as systolic pressure  $>140$  mm Hg, or diastolic pressure  $>90$  mm Hg, or the individual was told on two or more visits that he/she had hypertension. Diabetes was defined as fasting plasma glucose level  $\geq 126$  mg/dl, or  $\geq 200$  mg/dl after an oral glucose tolerance test, or self-reported physician diagnosed. Diabetes duration was dichotomized as  $\geq 10$  or  $<10$  years based on the K/DOQI report that diabetes duration of 10 to 15 years is a clinical feature of stage 1 or 2 chronic kidney disease.<sup>1</sup>

**Sociodemographic status.** These variables included: age, dichotomized as 18 to 59 years (referent) and  $\geq 60$  years; race/ethnicity, categorized as non-Hispanic white, non-Hispanic black, and Mexican American (referent); and low income, defined as  $< \$20,000$  annual household income.

**Health behavior and biomarkers.** Self-reported smoking status was current (referent), former, or never, excluding those who reported former or never smoking but were current smokers based on having serum cotinine levels  $\geq 15$  ng/ml, which is considered the gold standard to detect tobacco use.<sup>30</sup> Macroalbuminuria was defined as urinary albumin-to-creatinine excretion ratio  $\geq 300$  mg/g. High cholesterol was defined as total serum cholesterol  $\geq 240$  mg/dl. Low HDL cholesterol was  $\leq 35$  mg/dl. CRP was specified as a continuous variable in milligrams per deciliter.

**Health care use.** Health care use was defined as being hospitalized in the past year.

Additional risk factors that were considered in the multivariable modeling include gender, education, obesity, and having an annual physician visit.

### Statistical Analyses

Tests of the hypothesis that chronic kidney disease is associated with traditional and non-traditional risk factors used univariable (Table 1) and multivariable (Table 2) logistic regression modeling with statistical significance reported as a 95% confidence interval (CI). We

speculated that certain high-risk subgroups could be identified through the application of the most parsimonious model derived from sample 1 data to estimate an individual's probability of chronic kidney disease. Analyses were conducted on sample 2 data using statistical software packages<sup>†§</sup> to account for complex survey design and sample weights and to produce national estimates.<sup>31</sup> The estimated probability ( $\pi[x]$ ) that an individual with specific risk factors (covariates in multiple logistic regression model)<sup>32</sup> will have chronic kidney disease was calculated using the formula  $\pi(x) = e^{\beta_0 + \beta_1 X_1 + \dots + \beta_{12} X_{12}} / (1 + e^{\beta_0 + \beta_1 X_1 + \dots + \beta_{12} X_{12}})$ , where  $\beta_0$  is the intercept,  $\beta_1$  is the regression coefficient for the first independent variable ( $x_1$ ),  $\beta_2$  is the regression coefficient for the second independent variable ( $x_2$ ), and so forth for each of the 12 independent variables in the final model. The  $\beta$  coefficients derived in the multivariable logistic regression model were used to estimate the probability that individuals with specific characteristics had chronic kidney disease. To demonstrate the application of this model, we report the two extreme scenarios representing the very lowest risk individual with no risk factors and the very highest risk individual with all risk factors (Table 2), along with the successive addition of one to 12 risk factors (Figs. 1 and 2) based on the strength of their association. When the risk factor had more than two levels, the risk category with the largest coefficient (i.e., highest odds ratio [OR]) was incorporated in the cumulative risk factor estimation of the proportion of individuals with chronic kidney disease.

Furthermore, to evaluate this prediction model, we performed the standard diagnostic analyses of sensitivity, specificity, positive predictive value, and negative predictive value using 5%, 10%, 15%, and 20% probability cutoff points. Sensitivity and positive predictive values were calculated for those with a probability of having chronic kidney disease greater than or equal to the cutoff point. Specificity and negative predictive values were calculated for those with a probability of having chronic kidney disease less than the cutoff point.

## RESULTS

Table 1 presents important characteristics of the study population and the univariable logistic regression models ( $OR_{Crude}$ ) based on sample 1 data. Overall, 3.7% of adults had chronic kidney disease. The proportion of adults with chronic kidney disease varied according to risk factors. For example, adults  $\geq 60$  years of age (15.7%) were 27 times ( $OR_{Crude} = 26.79$ ; 95% CI: 16.47 to 43.60) more likely to have chronic kidney disease than younger adults; edentulous adults (15.7%) were 11 times ( $OR_{Crude} = 10.87$ ; 95% CI: 6.86 to 17.20) more likely to have chronic kidney disease, and adults with periodontal disease (7.2%) were 4.5 times ( $OR_{Crude} = 4.50$ ; 95% CI: 3.02

to 6.71) more likely to have chronic kidney disease than adults who did not have periodontal disease.

Table 2 (column 2) presents the most parsimonious final model of traditional and non-traditional risk factors for chronic kidney disease based on sample 1 data. Next, this most parsimonious final model was applied to sample 2 data using the resulting  $\beta$  coefficients reported in column 3 of Table 2. Thus, we report the model's estimate of the probability of chronic kidney disease for the lowest risk group (column 4: individuals with none of the model's risk factors [probability = 0.06%]) and for the highest risk group (column 5: individuals with all of the model's risk factors [probability = 98.3%]). This highest risk group was older ( $\geq 60$  years), non-Hispanic white edentulous former smokers, with diabetes  $\geq 10$  years, hypertension, macroalbuminuria, high cholesterol, low HDL cholesterol, CRP = 12.80 mg/dl, lower income, and hospitalization in the past year.

Twenty-two subgroups are displayed in Figures 1 and 2, ranging from having no risk factors to having all 12 risk factors based on the  $\beta$  coefficients listed in Table 2, along with the intercept ( $-7.39$ ). Figure 1 depicts the addition of one risk factor at a time as the cumulative risk factors, lowest to highest, beginning with the risk factor with the lowest  $\beta$  coefficient, i.e., high cholesterol (the last risk factor listed in Table 2), then the next lowest  $\beta$  coefficient, i.e., former smoker, and so forth. Figure 2 depicts the addition of one risk factor at a time as the cumulative risk factors, highest to lowest, beginning with the risk factor with the highest  $\beta$  coefficient, namely age  $\geq 60$  years, then the risk factor with the next highest  $\beta$  coefficient, i.e., macroalbuminuria, and so forth in the order listed in Table 2.

In Figure 1, the high-risk subgroup includes those with risk factors having the highest  $\beta$  coefficients, as indicated by the steep slope when an individual had one of the four strongest risk factors in addition to the other risk factors in the lowest-to-highest scenario. In the lowest-to-highest scenario, an estimated 3% of individuals with the eight weakest risk factors, but without the four strongest risk factors, have chronic kidney disease, i.e., edentulous, former smokers with diabetes  $\geq 10$  years, hypertension, low HDL cholesterol, high total cholesterol, low income, and hospitalization in the past year. In Figure 2, the highest-to-lowest scenario depicts that an estimated 21% of individuals with the three strongest risk factors, but not any of the other nine risk factors, have chronic kidney disease, i.e., an older ( $\geq 60$  years) non-Hispanic white adult with macroalbuminuria. The estimated probability of chronic kidney disease increased 33% for high CRP, 18% for hypertension, 12% for having diabetes  $\geq 10$  years, 6% for low income,

† SUDAAN release 9.0.1, Software for the Statistical Analysis of Correlated Data, Research Triangle Institute, Research Triangle Park, NC.  
§ SAS Systems for Windows, version 9.1, SAS Institute, Cary, NC.

**Table 1.**  
**Descriptive Summary and Association Between Risk Factors and Chronic Kidney Disease**

Risk Factor (n [%])	No Chronic Kidney Disease (96.3%)	Chronic Kidney Disease (3.7%)	OR <sub>Crude</sub> (95% CI)
Socioeconomic status			
Age (years)			
18 to 59 (4,396 [80.3])	99.3%	0.7%	1.00
≥60 (1,582 [19.7])	84.3%	15.7%	26.79 (16.47 to 43.60)*
Race/ethnicity			
Non-Hispanic white (2,446 [82.2])	96.0%	4.0%	4.60 (2.91 to 7.29)*
Non-Hispanic black (1,678 [11.5])	97.5%	2.5%	2.87 (1.67 to 4.93)*
Mexican American (1,854 [6.3])	99.1%	0.9%	1.00
Gender			
Female (3,123 [50.2])	95.5%	4.5%	1.64 (1.17 to 2.32)*
Male (2,855 [49.8])	97.2%	2.8%	1.00
Lower income			
Yes (2,808 [31.8])	93.4%	6.6%	3.05 (2.24 to 4.14)*
No (3,170 [68.2])	97.7%	2.3%	1.00
High school graduate			
Yes (3,649 [78.1])	97.3%	2.7%	1.00
No (2,299 [21.9])	92.8%	7.2%	2.84 (2.06 to 3.91)*
Health status and health behavior			
Periodontal status			
Edentulous (787 [11.6])	84.3%	15.7%	10.87 (6.86 to 17.20)*
Periodontal disease (589 [6.1])	92.8%	7.2%	4.50 (3.02 to 6.71)*
No periodontal disease (4,602 [82.3])	98.3%	1.7%	1.00
Diabetes duration			
≥10 years (1,677 [1.6])	77.0%	23.0%	8.65 (5.09 to 14.70)*
<10 years (5,811 [98.4])	96.7%	3.3%	1.00
Hypertension			
Yes (1,742 [25.0])	89.3%	10.7%	8.95 (6.31 to 12.70)*
No (4,236 [75.0])	98.7%	1.3%	1.00
Macroalbuminuria			
Yes (108 [1.1])	80.1%	19.9%	6.91 (3.48 to 13.72)*
No (5,870 [98.9])	96.5%	3.5%	1.00
Obesity			
Yes (2,557 [36.9])	95.4%	4.6%	1.50 (1.09 to 2.08)*
No (3,412 [63.1])	96.9%	3.1%	1.00
High cholesterol			
Yes (1,098 [17.9])	91.2%	8.8%	3.74 (2.67 to 5.24)*
No (4,880 [82.1])	97.5%	2.5%	1.00
Low HDL			
Yes (709 [12.8])	94.5%	5.5%	1.68 (1.13 to 2.49)*
No (5,269 [87.2])	96.6%	3.4%	1.00
Smoking status			
Never (3,047 [45.8])	96.4%	3.6%	2.86 (1.69 to 4.83)*
Former (1,300 [23.3])	93.1%	6.9%	5.68 (3.55 to 9.09)*
Current (1,631 [30.9])	98.7%	1.3%	1.00

**Table 1. (continued)****Descriptive Summary and Association Between Risk Factors and Chronic Kidney Disease**

Risk Factor (n [%])	No Chronic Kidney Disease (96.3%)	Chronic Kidney Disease (3.7%)	OR <sub>Crude</sub> (95% CI)
Hospitalized in past year			
Yes (773 [10.7])	91.8%	8.2%	2.79 (1.92 to 4.05)*
No (5,205 [89.3])	96.9%	3.1%	1.00
Annual physician visit			
Yes (4,736 [80.1])	95.8%	4.2%	2.53 (1.40 to 4.56)*
No (1,242 [19.9])	98.3%	1.7%	1.00
CRP (mg/dl)	NA	NA	1.40 (1.23 to 1.59)*

Unweighted number with weighted percent. Excluded those who reported never or former smoking with serum cotinine level indicating current smoker. Inclusion criterion: periodontal examination or edentulous.

OR<sub>Crude</sub> = Unadjusted odds ratio for the association between chronic kidney disease and the suspected/recognized risk factors in sample 1; NA = not applicable. \*  $P < 0.05$ .

**Table 2.****Multivariable Logistic Regression Model of Independent Risk Factors for Chronic Kidney Disease in Descending Order of  $\beta$  Coefficients, Low-Risk and High-Risk Subgroups**

Risk Factor	Final Model OR <sub>Adj</sub> (95% CI)	Final Model $\beta$ Coefficient (intercept = -7.39)	Low Risk (0.06%)	High Risk (98.3%)
Age $\geq 60$ years	9.03 (5.52 to 14.77)*	2.46	Age <60 years	Age $\geq 60$ years
Macroalbuminuria	3.41 (1.82 to 6.41)*	1.93	No macroalbuminuria	Macroalbuminuria
Race/ethnicity				
Non-Hispanic white	3.08 (2.00 to 4.75)*	1.63	Mexican American	Non-Hispanic white
Non-Hispanic black	2.36 (1.33 to 4.21)*	0.99		
CRP (mg/dl)	1.19 (1.01 to 1.41)*	0.12	0.21	12.80
Hypertension	2.21 (1.61 to 3.03)*	0.76	No hypertension	Hypertension
Diabetes duration	1.52 (0.93 to 2.49)	0.69	Diabetes <10 years	Diabetes $\geq 10$ years
Low income	1.57 (1.09 to 2.25)*	0.54	Not low income	Low income
Hospitalized in past year	1.90 (1.26 to 2.87)*	0.46	Not hospitalized in past year	Hospitalized in past year
Periodontal status				
Edentulous	2.03 (1.31 to 3.14)*	0.44	No periodontal disease	Edentulous
Periodontal disease	1.60 (1.07 to 2.39)*	0.38		
Low HDL cholesterol	1.69 (1.07 to 2.65)*	0.43	Not low HDL cholesterol	Low HDL cholesterol
Smoking status				
Former smoker	2.47 (1.52 to 4.02)*	0.40	Current smoker	Former smoker
Never smoker	2.16 (1.27 to 3.66)*	0.32		
High cholesterol	1.93 (1.33 to 2.79)*	0.16	Not high cholesterol	High cholesterol

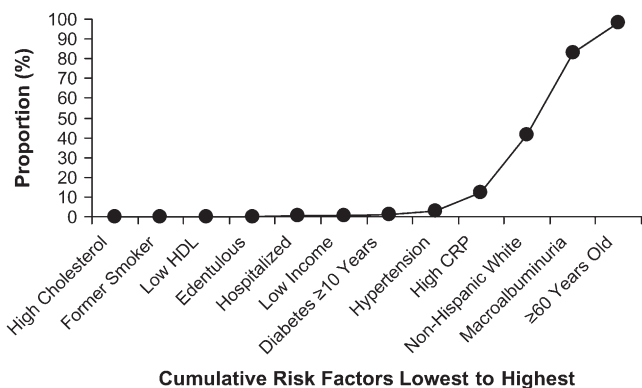
Excluded those who reported never or former smoking with serum cotinine level indicating a current smoker.

OR<sub>Adj</sub> = OR for the association between chronic kidney disease, simultaneously taking into account all the listed potential or recognized risk factors.

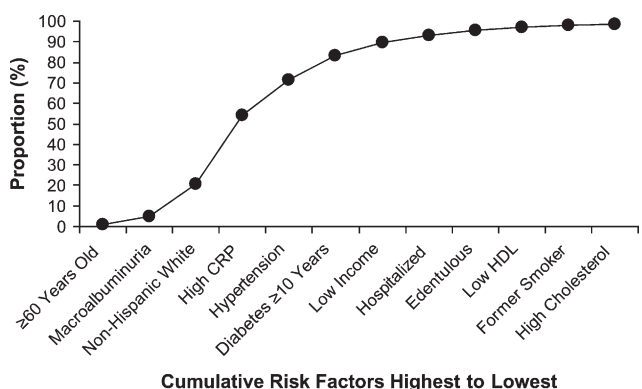
\*  $P < 0.05$ .

4% for being hospitalized in the past year, 2% for edentulism or periodontal disease, 1% for low HDL cholesterol, 1% for former smoking, and 0.3% for high cholesterol (Fig. 2).

Evaluation of this prediction model using the standard diagnostic analysis<sup>33</sup> of sample 2 is shown in Table 3, depicting the changing sensitivity, specificity, positive predictive value, and negative predictive value with



**Figure 1.** Proportion of individuals with chronic kidney disease. Cumulative risk factors lowest to highest.



**Figure 2.** Proportion of individuals with chronic kidney disease. Cumulative risk factors highest to lowest.

**Table 3.** Evaluation of Prediction Model for Chronic Kidney Disease, U.S. Adults

Cutoff Point (probability)	Sensitivity (%)*	Specificity (%)†	Positive Predictive Value (%)*	Negative Predictive Value (%)†
5%	86	85	18	99
10%	68	90	20	99
15%	58	94	26	98
20%	46	96	32	98

\* Sensitivity and positive predictive value were calculated for those with probability greater than or equal to the cutoff point.

† Specificity and negative predictive value were calculated for those with probability less than the cutoff point.

increasing probability of having chronic kidney disease. As the cutoff point was changed from 5% to 10% to 15% to 20%, the sensitivity decreased, the specificity and positive predictive value increased, and there was little

change in the high negative predictive value. Sensitivity ranged from 46% to 86%, specificity was 85% to 96%, positive predictive value was 18% to 32%, and negative predictive value was 98% to 99%. Evaluation of this model using a 5% probability cutoff point resulted in 86% sensitivity, 85% specificity, 18% positive predictive value, and 99% negative predictive value.

**DISCUSSION**

Our population-based study estimated the probability of chronic kidney disease using the  $\beta$  coefficients in the most parsimonious final model with 12 recognized and suspected risk factors for chronic kidney disease. Subgroups were identified ranging from virtually no probability (0.06%) to very high probability (98%). Any individual’s risk can be estimated as the probability that individuals with the same 12 specific characteristics have chronic kidney disease using the formula in the Statistical Analyses section and the  $\beta$  coefficients reported in Table 2.

The impact of the strongest risk factors on the estimated probability of chronic kidney disease is evident by the steep slope in Figure 1 when the four strongest risk factors were added in the lowest-to-highest scenario. For those with the eight lowest risk factors, the estimated probability of chronic kidney disease was 3%, the addition of high CRP quadrupled the estimated probability to 12%. The addition of the next risk factor, race/ethnicity, more than tripled the estimated probability of chronic kidney disease to 41% for non-Hispanic white adults with the same nine risk factors. Next, having macroalbuminuria doubled the estimated probability of chronic kidney disease to 83%. Finally, when adding the risk factor age  $\geq 60$  years, the estimated probability of chronic kidney disease increased to 98% (Table 2, column 5; Fig. 1).

Conversely, if an individual’s only risk factor was the strongest risk factor, age  $\geq 60$  years, the estimated probability of chronic kidney disease was only 0.7% (Fig. 2). The estimated probability of chronic kidney disease was 5% for adults with the two strongest risk factors, age  $\geq 60$  years and macroalbuminuria. The addition of the next strongest risk factor, non-Hispanic white race/ethnicity, quadrupled the estimated probability to 21%. The addition of high CRP more than doubled the estimated probability of chronic kidney disease to 54%. The addition of having hypertension increased the probability of chronic kidney disease by 18% to 72%. The addition of each of the remaining seven risk factors resulted in a smaller increase in the probability than the previous risk factor (except for being a former smoker), such that the addition of having diabetes  $\geq 10$  years, having low income, being hospitalized in the past year, being edentulous or having periodontal

disease, having low HDL cholesterol, being a former smoker, and having high cholesterol increased the probability of having chronic kidney disease by 12%, 6%, 4%, 2%, 1%, 1%, and 0.3%, respectively, to 98.3% (Fig. 2).

Evaluation of our final model using a cutoff point of 5% probability for chronic kidney disease resulted in 86% sensitivity, 85% specificity, 18% positive predictive value, and 99% negative predictive value. The diagnostic characteristics of our model (age, macroalbuminuria, race/ethnicity, CRP, hypertension, diabetes duration, low income, being hospitalized in the past year, periodontal status, HDL cholesterol, smoking status, and cholesterol) are similar to the 92% sensitivity, 68% specificity, 18% positive predictive value, and 99% negative predictive value reported for a model with age, gender, hypertension, proteinuria, anemia, diabetes, peripheral vascular disease, history of cardiovascular disease, and congestive heart failure.<sup>8</sup> Including periodontal status improved the fit of our model compared to the model without periodontal status, based on the Satterthwaite-adjusted F statistic  $P$  value = 0.0031.

A limitation of this study is that it was cross-sectional; thus, the temporal association is unknown. A major strength of our study is that the most parsimonious multivariable model was developed using a random half-sample (sample 1) of the U.S. population-based dataset, which was separate and distinct from the other random half-sample (sample 2) that was used for validation. The screening cutoff point of 5% probability had very good sensitivity, specificity, and negative predictive value. The sensitivity indicates an estimated 86% of adults with chronic kidney disease would be identified using this model, and the specificity indicates that 85% of adults without chronic kidney disease would be identified as not having chronic kidney disease. However, the positive predictive value indicates that only 18% of those identified by the model are estimated to have chronic kidney disease. Our findings exemplify the general epidemiologic premise that the rarer or lower the disease prevalence, the better the negative predictive value, whereas better positive predictive values are found for more prevalent conditions.<sup>33</sup> This is evident in Table 3; as the cutoff point increased (higher probability of having chronic kidney disease) the positive predictive value increased. An additional strength of this study is that these findings can be generalized to the U.S. population because the NHANES III sampling methodology was designed to represent the U.S. population.<sup>26</sup>

## CONCLUSIONS

This U.S. population-based study suggested the importance of considering multiple risk factors, includ-

ing periodontal status, because this improves the identification of individuals at high risk for chronic kidney disease and may ultimately reduce its burden. Further research is needed to simultaneously assess the role of multiple risk factors and to validate this model in other populations.

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