Tohoku J. Exp. Med., 2018, **246**, 81-86

Simplified Prediction Model for Accurate Assessment of Dental Caries Risk among Participants Aged 10-18 Years

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Dental caries assessment needs to be targeted at specific age groups, as many risk factors are related to patient age. Pre-teen and teenage patients, who are still at risk of occurrence of new carious lesions, need more individualized caries management strategies. Therefore, this study aimed to identify caries-related risk factors and develop a simplified risk prediction model for dental caries. Risk factors for caries were assessed in 171 participants aged 10-18 years, based on a questionnaire survey, previous history of caries, oral hygiene, microorganism colonization, saliva secretion, saliva buffer capacity examinations, and the acidogenicity of dental biofilms. These risk factors were entered into a computer-based risk assessment program (the Cariogram), and correlations between these factors and Cariogram scores were investigated. Significant risk predictors were used to develop a simplified risk prediction model. The performance of this model in predicting dental caries incidence was evaluated using receiver operating characteristic analysis, to determine its applicability to the management of caries. Our simplified prediction model included three predictors that were significantly associated with caries incidence: use of fluoride-containing toothpaste, the acidogenicity of dental biofilms, and saliva secretion ($p < 0.001$). The resulting model had a sensitivity and specificity of 60.5 and 85.0%, respectively, with a cut-off value of 69.41 as the threshold. The area under the curve of this model was 0.782 (95% confidence interval = 0.681-0.884, $p < 0.001$). Our new caries risk prediction model is expected to allow clinicians to accurately and easily predict patients' risk of occurrence of new caries.

Keywords: acidogenicity; caries risk assessment; dental biofilm; fluoride; saliva
Tohoku J. Exp. Med., 2018 October, **246** (2), 81-86.

Introduction

Recently, there has been significant evolution in the field of personalized healthcare services, which combine scientific technology and medical services. These programs collect and analyze various data on individual patients' health to provide personalized healthcare strategies. This approach has been extended to oral healthcare strategies, with an emphasis on the need for early diagnosis and management of dental caries. Various oral care strategies for dental caries are being introduced; however, determining and managing caries risk at the individual patient level is challenging because of the many etiologies that lead to dental caries.

The occurrence of dental caries is influenced by multiple factors, ranging from oral microflora, and saliva production and composition, to factors related to a patient's systemic health and lifestyle, such as the use of fluoride-containing toothpaste and diet (Fejerskov et al. 1994; Gibson and Williams 1999; Leone and Oppenheim 2001; Marsh 2010). Therefore, it is essential to establish oral care strategies based on an individuals' unique combination of risk factors. Hence, many oral practitioners recommend the use of objective assessment methods to predict the risk of caries, such as the Cariogram, a computer-based risk assessment tool (Petersson et al. 1998). This software can be used to illustrate interactions between caries-related risk factors, such as a patient's history of caries, related diseases, diet, amount of plaque, mutans streptococci (MS) colonization, fluoride program, saliva secretion, and saliva buffer capacity (Bratthall and Hänsel Petersson 2005). By graphically representing these interactions, the Cariogram evaluates the risk of new caries occurrence, in addition to helping identify intervention strategies for preventing caries in at-risk patients (Fig. 1).

However, the Cariogram has some limitations in evaluating patients' risk for developing new caries. First, a previous history of dental caries, which predisposes patients to new caries occurrence, is evaluated using the Decayed Missing Filled Teeth (DMFT) or Surface (DMFS) indices.

Received May 21, 2018; revised and accepted September 26, 2018. Published online October 17, 2018; doi: 10.1620/tjem.246.81.
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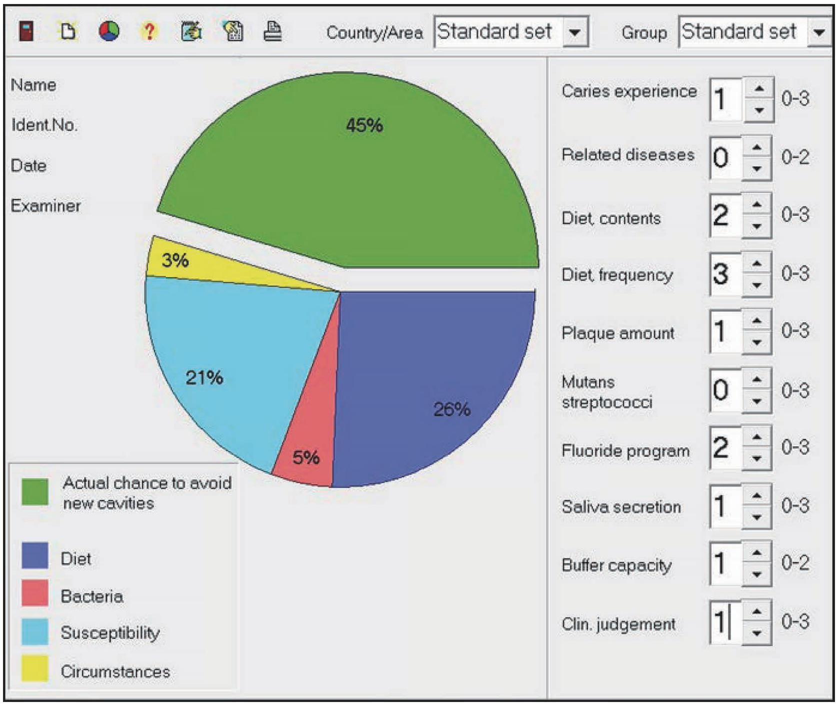

Fig. 1. One example for dental caries risk assessment of patients with the Cariogram.
This example indicates that the probability of the participant avoiding dental caries is 45%.

These indices are designed to detect late stages of caries progression, whereas current clinical practice emphasizes the detection of early caries lesions with a focus on the prevention and management of early stage disease. Second, only the contributions of closely related species of MS are identified as microbiological factors that contribute to the occurrence of caries. Therefore, this model cannot reflect the ecological characteristics of various species that might be related to oral disease in an individual. Third, Cariogram analysis requires evaluation of 10 factors, including the judgement of the clinician. Hence, this program is time consuming and costly for both the examiner and patient.

Given the limitations of existing predictive models, the identification and evaluation of alternative evidence-based models is necessary. Therefore, we aimed to identify caries-related risk factors and develop an accurate and simplified risk prediction model for dental caries, which can be practically utilized in clinical dental practice.

Materials and Methods

Ethical aspects of this study

The protocol for this cross-sectional study was approved by the Institutional Review Board committee of Gachon University (IRB No. 1044396-201612-HR-107-01). All procedures were conducted in accordance with the ethical principles for medical research involving human participants as stipulated in the Declaration of Helsinki (2013 version) by the World Medical Association. This study was also conducted in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (von Elm et al. 2007). The objectives and procedures of this study were explained to all participants and the parents or legal caregivers of children prior to the onset of the study. Informed consent was obtained from parents or legal caregivers, and written consent was obtained from all children before inclusion in the study. The general eligibility of each volunteer was determined through the screening procedure described below.

Participants

Participants aged 10 to 18 (mean age = 13.99 ± 3.91) years were recruited between January and April 2017. Among a total of 176 volunteers, 171 (70 males, 101 females) were selected in accordance with a screening test. During the screening test, participants were excluded based on the following criteria: (1) suffering from periodontal disease or other oral diseases, (2) undergoing active orthodontic treatment, (3) taking medication such as antibiotics, (4) suffering from any systemic disease.

Oral examination and data collection

All examinations were performed by a single qualified dental hygienist. Participants were advised to avoid eating, drinking, smoking, chewing gum, brushing teeth, or using mouthwash for 4 h prior to their appointment. During their first visit, participants underwent a caries risk assessment. First, each participant completed a questionnaire regarding their medical and dental history, medication, diet composition, food frequency, and fluoride exposure. Second, the existence of any DMFT was assessed by visual inspection to determine patients' history of dental caries. The DMFT range for "normal" caries experience was calculated as the mean DMFT score ± standard deviation reported for the target age group in the Republic of Korea 2010 Korea National Oral Health Survey. The mean 2010 survey DMFT indices of 2.08 at 12 years, 3.57 at 15 years, and 6.06 at 18-24 years were used for comparison with results in the present study, for participant age groups 11-13, 14-17, and 18-19 years, respectively.

To assess oral hygiene status, the amount of dental biofilm was estimated according to the Silness-Löe Plaque Index (PI): each of the four surfaces of the teeth (buccal, lingual, mesial, and distal) was given a score from 0-3 and PI calculated as the mean of these four scores.

To measure the stimulated whole saliva secretion rate (S-SSR), saliva was collected while participants chewed a piece of paraffin wax for 5 min. Participants with an S-SSR of > 0.7 mL/min were considered normal, whereas participants with a very low S-SSR (< 0.7 mL/min) were defined as having hyposalivation (Axelsson 2000). The buffer capacity of stimulated saliva was determined using the CRT® buffer kit (Ivoclar-Vivadent Ltd., Schaan, Liechtenstein). The test zone of the buffer strip was saturated with stimulated saliva using a pipette. After 5 min of reaction, a color chart provided by the manufacturer was used to record the buffer capacity as high (> pH 5.5, blue), moderate (pH 4.5 to 5.5, green), or low (< pH 4.5, yellow).

The levels of MS and lactobacilli (LB) were examined using the CRT® bacteria test (Ivoclar-Vivadent Ltd., Schaan, Liechtenstein). The agar surfaces were entirely wetted with stimulated saliva and incubated at 37°C for 48 h, after which media bacteria counts were compared to the model charts provided by the manufacturer. MS and LB counts were scored in two categories: $< 10^5$ or $\geq 10^5$ CFU/mL saliva. LB counts were utilized for evaluation, instead of diet composition (Bratthall et al. 2004).

The acidogenicity of participants' dental biofilms was measured using the Cariview® test (AIOBIO™, Seoul, Republic of Korea). Samples of dental biofilm on the buccal surfaces of participants' teeth were obtained using sterilized swabs and immediately inoculated into a culture medium for cultivation at 37°C for 48 h. Cariview® scores were calculated using the accompanying analysis software and participants divided into three risk groups: Cariview® scores 0-40 = low risk; 41-70 = moderate risk; and 71-100 = high risk. Then, all tooth surfaces were cleaned with a toothbrush by a trained dental hygienist and the caries status of participants' sound teeth re-evaluated using the International Caries Detection and Assessment System (ICDAS) II classification criteria. Early carious lesions were assigned ICDAS codes 1 or 2. Code 1 lesions can present as carious opacities in the enamel after air-drying for 5 s, whereas code 2 lesions involve a more extensive, distinct visual change, which presents as a white spot that is visible both when wet and dry.

Caries risk assessment using the Cariogram

The Cariogram program (English version) was downloaded from https://www.mah.se/fakulteter-och-omraden/Odontologiska-fakulteten/Avdelning-och-kansli/Cariologi/Cariogram/. Cariograms were generated using nine variables, entered into the computer program (Fig. 1) (Bratthall and Hänsel Petersson 2005). The clinical judgement, which is the last variable of the Cariogram, was automatically set at the pre-set score of 1. More detail on the scoring method for the remaining nine variables is available from the Cariogram manual (Internet version 2) (Bratthall et al. 2004). Based on this model, participants were divided into three groups according to their chance of avoiding new cavities (dental caries): high risk = 0-20% chance of avoiding new cavities, moderate risk = 21-80% chance of avoiding new cavities, and low risk = 81-100% chance of avoiding new cavities.

Statistical analyses

Correlations between caries-related risk factors and Cariogram scores were evaluated using the χ^2-test. The relevant risk factors with Cariogram scores were then selected to include significant covariates in the logistic model. Binary logistic regression analysis was performed to develop a simplified caries risk prediction model and identify the relative importance of various risk factors for dental caries. After selecting the four initial models, adequacy of inferred logistic models was assessed using predicted probability with log likelihood (L), $-2\ln L$, and the Nagelkerke R^2, and was compared in terms of the percentage of participants classified correctly and Hosmer-Lemeshow test using the usual chi-square goodness-of-fit test to determine the most suitable model. Next, after selecting the final logistic model (Model 4), the logistic regression formula was calculated with three predictors and the probability of occurrence of dental caries was inferred. Receiver operating characteristic (ROC) curve was then constructed with the given tested variable and the probability of occurrence of dental caries; the area under the ROC curve (AUROC), sensitivity, and specificity were then calculated to determine efficacy of the final logistic model for accurately predicting dental caries risk. Finally, we evaluated the validity of the final model (Model 4) by establishing a cut-off value equal to the sum of the sensitivity and specificity values. All statistical analyses were performed using SPSS version 23 statistics software (IBM Chicago, IL, USA). P values < 0.05 were considered statistically significant.

Results

Factors that had a significant association with caries occurrence are summarized in Table 1. These included the use of fluoride-containing toothpaste ($p < 0.001$), DMFT index ($p < 0.001$), MS and LB counts ($p < 0.001$), S-SSR ($p = 0.006$), saliva buffer capacity ($p = 0.004$), and Cariview® score ($p = 0.037$).

Based on these findings, four initial models for caries risk prediction were constructed by combining three to five predictors related to caries occurrence (Table 2). Notably, participants who did not use fluoride-containing toothpaste or had Cariview® scores > 50 had 12.434 and 1.804-fold higher chances, respectively, of developing new caries (both $p < 0.001$). Furthermore, participants with an S-SSR < 0.7 mL/min had a 3.916-fold increase in the risk for developing new caries ($p < 0.001$). After comparing the number of covariates, predicted probabilities, and model appropriateness, Model 4 was selected as the most appropriate for predicting caries risk. The formula of the Model 4 was constructed as follows:

$$\ln(p/1-p) = -2.775 + 2.520 \times [\text{the use of fluoride toothpaste}] + 0.590 \times [\text{Cariview® score}] + 1.365 \times [\text{S-SSR}]$$

(p is the probability of occurrence of dental caries).

Hence, this final model (Model 4), the simplified caries risk prediction model, included three caries-related predictors: the use of fluoride-containing toothpaste, the acidogenic ability of plaque bacteria, and S-SSR.

Using receiver operating characteristic (ROC) analysis,

Table 1. Cariogram scores according to caries-related factors.

Factors	Classification	†Cariogram scores, N (%)			‡*p* value
		0-20 (N = 18)	21-80 (N = 122)	81-100 (N = 31)	
Food frequency	≤ 3 meals per day	2 (11.1%)	16 (13.1%)	2 (6.4%)	0.760
	> 3 meals Per day	16 (88.9%)	106 (86.9%)	29 (93.6%)	
Fluoride toothpaste	Use	3 (17.6%)	88 (72.1%)	31 (100%)	< 0.001
	Not use	15 (82.4%)	34 (27.9%)	0 (0%)	
DMFT index	≤ Mean	5 (27.8%)	83 (68.1%)	28 (90.3%)	< 0.001
	> Mean	13 (72.2%)	39 (23.9%)	3 (9.7%)	
Plaque index	≤ 1	1 (5.6%)	18 (14.8%)	2 (6.5%)	0.443
	> 1	17 (94.4%)	104 (85.2%)	29 (93.5%)	
MS counts	$< 10^5$	2 (11.1%)	78 (63.9%)	30 (96.8%)	< 0.001
	$\geq 10^5$	16 (88.9%)	44 (36.1%)	1 (3.2%)	
LB counts	$< 10^5$	8 (44.4%)	101 (82.8%)	31 (100%)	< 0.001
	$\geq 10^5$	10 (55.6%)	21 (17.2%)	0 (0%)	
S-SSR	> 0.7	13 (72.2%)	112 (91.8%)	31 (100%)	0.006
	≤ 0.7	5 (27.8%)	10 (8.2%)	0 (0%)	
Buffer capacity	High	11 (61.1%)	84 (68.9%)	20 (64.5%)	0.004
	Medium	3 (16.7%)	37 (30.3%)	11 (35.5%)	
	Low	4 (22.2%)	1 (0.8%)	0 (0%)	
Cariview® score	0-39.9	6 (33.3%)	59 (48.4%)	19 (61.3%)	0.037
	40-69.9	7 (38.9%)	48 (39.3%)	12 (38.7%)	
	70-100	5 (27.8%)	15 (12.3%)	0 (0%)	

†Cariogram scores correspond to chance of avoiding caries.
‡*p* values denote differences between groups determined by χ^2-test.
MS, mutans streptococci (CFU/mL saliva); LB, *lactobacillus* (CFU/mL saliva);
S-SSR, stimulated saliva secretion rate (mL/min).

we defined a cut-off caries risk prediction value of 69.41% for the positive prediction of new caries occurrence (Fig. 2), at which our model had a sensitivity and specificity of 60.5 and 85.0%, respectively. Hence, participants with calculated risk scores above this cut-off (> 69.41) had a higher risk of developing new caries, compared to those with scores below this threshold. Area under the ROC curve (AUC) for exact analysis of the simplified caries risk prediction model was 0.782 (95% confidence interval = 0.681-0.884; $p < 0.001$).

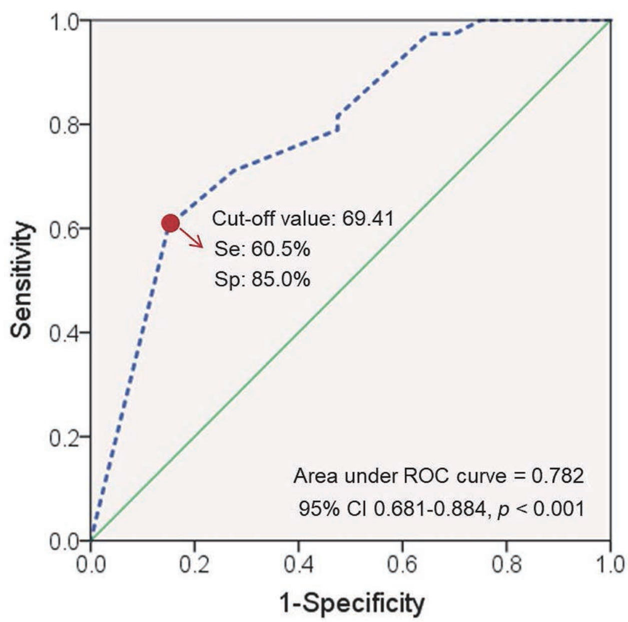

Fig. 2. Receiver Operating Characteristic curve for the simplified caries risk prediction model.
Se, sensitivity; Sp, specificity; CI, confidence interval.

Discussion

Caries risk assessment is an essential component in the clinical decision-making process. The main goal of caries risk assessment is to determine the appropriate level of patient care based on their caries risk status. However, the time and cost constraints of this approach limit its utilization. Therefore, the aim of this study was to develop a model that is both simple and accurate for predicting the risk of caries occurrence in individuals.

This study developed a simplified caries risk prediction model (Model 4), which includes the use of fluoride-containing toothpaste, acidogenic ability of dental biofilm (Cariview® score), and S-SSR (Table 2). The use of these predictors is supported by the findings of this study, in addition to evidence from previous reports. For example, fluoride is the most significant protective factor against mineral loss in the hard tissues of teeth (Petersson et al. 1998). Continuous exposure to low concentrations of fluoride (1,000 ppm F) promotes the formation of calcium fluoride (CaF_2)-containing globules on the tooth surface (Featherstone 1999). These deposits could form a protective coating on the enamel, by incorporating pellicle proteins and secondary phosphate at neutral pH, and additionally provide a reservoir for fluoride ions. Exposure to the low pH of the oral environment gradually dissolves these deposits, and the resulting release of fluoride ions and subsequent adsorption onto enamel surfaces could increase the rate of remineralization (Jeng et al. 2008). Hence, the use of fluoride-containing toothpaste is one of the most effective and convenient self-care methods for remineralization of dental hard tissues (Twetman et al. 2003). Several previous studies have already reported the use of fluoride-containing toothpaste having a clear protective effect against caries of permanent teeth in children, when compared to regular toothpaste (Heidmann and Poulsen 1997; Twetman et al. 2003; Marthaler 2004). These reports are consistent with the results of this study, in which we found that the probability of caries occurrence was significantly greater (12.434-fold) in children who did not use fluoride-containing toothpaste (Table 2).

We also found that the acidogenic ability of dental biofilms was a significant predictor for caries occurrence. This study showed participants with higher Cariview® scores had a significantly higher (1.804-fold) probability of developing new caries, which therefore suggests that biofilms with higher acidogenic ability could accelerate caries occurrence. A recent study found that predicting the effects of microbiological factors on the occurrence of caries requires an assessment of the oral microbial environment, beyond the analysis of single or limited species of bacteria (Marsh and Bradshaw 1995). Dental biofilms change depending on the various environmental conditions within the oral cavity; this is presumed to play a critical role in the occurrence of oral diseases. Therefore, it is argued that the microbiological causes of the onset of dental caries should be determined by analyzing dental biofilms based on overall changes in the microbial ecosystem, in addition to other characteristics of biofilm structure (Takahashi and Nyvad 2008; Marsh 2010). Thus, instead of conducting analyses based on the ratio of specific species, such as MS or LB, identifying kinetic changes in tooth minerals in response to the acidogenic ability of dental microflora would provide a more comprehensive approach for predicting caries formation. Our prediction model includes a covariate that evaluates the pH levels produced by microorganisms in dental biofilms, in contrast to the less predictive quantification of MS used by the Cariogram.

The final predictor incorporated in our new prediction model was S-SSR. The rate of secretion, composition, and physical and chemical characteristics of saliva differ

Table 2. Caries risk prediction models in the logistic regression.

Covariates	Model 1		Model 2		Model 3		Model 4	
	Odds Ratio	95% CI	Odds Ratio	95% CI	Odds Ratio	95% CI	Odds Ratio	95% CI
Constant	0.091	–	0.337	–	0.062	–	0.064	–
Fluoride exposure	11.363	4.811-26.838	10.588	4.566-24.553	11.777	5.012-27.674	12.434	5.557-28.025
Cariview® score	2.059	1.219-4.562	2.065	1.945-4.510	2.063	1.220-4.539	1.804	1.220-3.813
S-SSR	4.679	1.171-18.702	–	–	3.949	1.035-15.069	3.916	2.147-13.371
Saliva buffer capacity	1.486	1.181-2.302	1.577	1.225-2.480	–	–	–	–
Previous caries	1.126	1.498-3.548	1.146	1.511-3.572	1.024	1.461-3.275	–	–
Nagelkerke R^2	0.367		0.335		0.353		0.348	
Classification Accuracy (%)	79.7		77.8		79.1		79.1	
Hosmer-Lemeshow test	4.453 ($p = 0.814$)		6.752 ($p = 0.455$)		2.298 ($p = 0.890$)		2.118 ($p = 0.580$)	

CI, confidence interval; S-SSR, stimulated saliva secretion rate (mL/min).

between individuals. Therefore, saliva is considered a critical factor in determining individual differences in susceptibility to dental caries (Piotrowski et al. 1992). Previous studies have confirmed the high possibility of caries occurrence in participants with abnormally low S-SSRs (Spak et al. 1994; Lenander-Lumikari and Loimaranta 2000). In addition, Axelsson identified lower S-SSR as a major factor contributing to caries lesion progression and reported that participants with S-SSR < 0.7 mL/min have an increased risk of caries occurrence (Axelsson 2000). Likewise, the present study found that participants with S-SSR < 0.7 mL/min had a significantly higher (3.916-fold) probability of developing new caries, compared to those with higher S-SSR (Table 2).

We determined the most appropriate cut-off value for our new model (Model 4) with the lowest rates of false negative and false positive results for diagnosing the risk of caries occurrence was 69.41 (sensitivity = 0.605; specificity = 0.850; Fig. 2). In addition, this cut-off value had a specificity ≥ 85%, which was higher than the sensitivity. These findings indicate that rate of false positives (1-specificity) can be minimized by using our thresholds. Furthermore, a high AUC of 0.782 (95% CI = 0.681-0.884, $p < 0.001$) provides evidence for the validity of this model and the factors we used to assess caries risk. Based on our findings, it might be possible to quantitatively determine whether or not the patient is at risk for dental caries.

Because this study is limited by its cross-sectional design, it will be necessary to analyze the predictive value this new risk model using caries prevalence data collected over a longer period. However, based on our preliminary findings, this new model could be a promising tool for predicting dental caries.

In conclusion, we developed a new simplified caries risk model based on the use of fluoride-containing toothpaste, Cariview® score, and S-SSR. This new model is expected to enable rapid and accurate analysis of caries risk in patients. Furthermore, because this new model consists of only three factors, compared to the 10 factors commonly assessed by the Cariogram, it is expected to greatly contribute to the cost-effectiveness of predictive model utilization in clinical settings.

Acknowledgments

This study was supported by the Basic Science Research Program of the National Research Foundation of Korea (NRF) and funded by the Ministry of Education [grant number 2016R1D1A1B03934754].

Conflict of Interest

The authors declare no conflict of interest.

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