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Original article

The Effects of Dietary and Oral Conditions on the Discoloration of Orthodontic Elastomeric O-Ties: A Prospective Cohort Study

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Abstract
This study was conducted to determine the incidence of significant orthodontic O-tie discoloration and identify the dietary and oral hygiene risk factors that predict its development in a cohort of orthodontic patients over one month. The design of this study was a prospective cohort study. We recruited 200 orthodontic patients for this study. All patients completed baseline dietary assessments using a Food Frequency Questionnaire (FFQ) and an evaluation of their oral health status using the Plaque Index (PI) and salivary pH levels. All patients were provided with clear O-ties from the same batch. After four weeks (T1), O-ties were evaluated using a spectrophotometer for discoloration (the ΔE value). Patients were grouped based on the ΔE value into two cohorts: the "Discoloration Cohort" (ΔE ≥ 5.5, n=102) and the "No-Discoloration Cohort" (ΔE < 5.5, n=98). We identified risk factors by comparing baseline exposure characteristics between the two cohorts. Fifty-four percent of orthodontic patients whose O-ties discolored had significant discoloration (54.4%). The Discoloration Cohort had a statistically significantly higher PI score and consumed more foods high in chromogenic properties than those in the No-Discoloration Cohort. A Multivariable Cox regression model demonstrated that a high baseline PI (HR=3.2, 95% CI: 2.1-4.9); daily coffee consumption (HR=2.8, 95% CI: 1.8-4.3); and frequent consumption of curry (≥3 times/week) were independent risk factors predicting O-tie discoloration (HR=2.5, 95% CI: 1.6-3.9). This study found that poor oral hygiene and specific dietary habits are significant risk factors for the development of O-tie discoloration. Patients presenting with high plaque levels and high consumption of coffee or curry are at a substantially increased risk and should be targeted for preemptive counseling.

Keywords: *Prospective Cohort, Elastomeric Ligatures, Discoloration, Incidence, Risk Factors.*

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Introduction

Since their introduction in the 1970s, elastomeric O-ties have transformed fixed orthodontic therapy by providing doctors with effective ligation and reliable force delivery. Pigments from meals and beverages can be absorbed by elastomeric teeth in the oral environment [1,2]. Enzymes, water, and humidity in the oral environment can cause them to shift in composition [3]. Elastomeric O-ties displayed calcium and phosphorus deposits as well as the development of calcium phosphate on their surface after being exposed to the mouth cavity for three weeks and analyzed using optical microscopy and spectroscopy. Following this exposure, a significant change in the ligatures' composition and surface structure was noted [4].

Clear elastic ligatures that match the attractive appearance of their aesthetic brackets are typically chosen by those seeking less noticeable orthodontic hardware [5]. Elastomeric O-ties typically become discolored due to exposure to staining chemicals and the brand or type of ligature. Furthermore, the composite color stability of dental materials may be influenced by the brushing methods and dentifrices used. To improve dental care, several dentifrices include patented colors, whitening agents, and abrasive agents [6].

There are multiple factors involved in the discoloration of elastomeric ligatures. One pathway is caused by extrinsic factors such as the adsorption by elastomeric modules of dietary chromogens, or color-producing agents from commonly consumed food/drinks, including coffee, tea, cola beverages, and curry foods [7]. Dietary chromogens generally contain polyphenols, tannins, and curcuminoids, which readily bind to the polyurethane chains present in elastomeric modules. The second factor, intrinsic factors, is influenced by the oral environment. The buildup of dental plaque causes the development of a biofilm that stains directly as well as changes the surface characteristics of the elastomer, increasing the porosity and susceptibility to staining from extrinsic sources [8]

Establishing parameters with visual significance, tolerance for perceptibility (the amount of color difference that is visually detectable), and tolerance for acceptability (the amount of the color difference that is unacceptable to dental aesthetics) are necessary for the practical application of color measurements. The opinions of both dentists and patients are crucial for establishing visual thresholds because of aesthetic issues and the long wait times between orthodontic treatments. Dentists can better understand their own results and communicate with patients by identifying their visual thresholds [9].

There has been some evidence that certain risk factors may be associated with O-tie discoloration. However, prior studies were limited by being either case-control or cross-sectional and therefore could not establish temporality [10,11] prospective cohort study would provide a stronger methodology for determining the potential effect of risk factors on O-tie

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discoloration due to the ability to accurately determine the incidence of discoloration and also clearly identify predictors. Before looking at the Design Stage, it is important to note that all of the previous studies used either small sample size's prospectively or case-control or cross-sectional studies and did not have controls for important co-factors like oral hygiene. Therefore, the complexity of the relationship between the amount of chromogen in people's diets and their oral hygiene is not fully known. The current study aimed to assess the difference in the amount of discoloration of orthodontically placed O-ties between people with high amounts of dietary chromogen compared to those with low amounts; Investigate how dietary habits and oral hygiene practice interact and their individual effects on the discoloration of O-ties; and identify the independent predictors of O-tie discoloration.

Materials and Methods

Study Design

This was a 6-month prospective cohort study that took place in the Department of Orthodontics' outpatient clinic. This study was conducted in compliance with the ethical principles specified in the Declaration of Helsinki and authorized by the competent ethics committee; all participants provided informed consent.

Participant Selection

Participants were recruited from the patient pool of the Department of Orthodontics at the Dental Clinic.

Inclusion criteria

- Patients aged 12-25 years receive thorough fixed orthodontic treatment using pre-adjusted edgewise appliances (0.022-inch slot).
- Clear elastomeric O-ties (American Orthodontics, Sheboygan, WI) were used.
- All six maxillary anterior teeth were present.
- General and periodontal health was good.

Exclusion Criteria

- Taking antibiotics or chlorhexidine mouthwash within three months of the start of the study.
- Use of tobacco or betel nut.
- Receiving anterior crowns, veneers or restorations.
- Having a cleft lip/palate or other craniofacial anomalies.
- Receiving a professional teeth cleaning within four weeks before the baseline assessment.

Sample size calculation

The sample size was calculated using the G*Power Software version 3.1.9.7. Using pilot data, the mean difference between the two groups (ΔE) was calculated to be 2.5 units, with a standard deviation of 3.5 units. To detect the difference with 90% statistical power (two-tailed α=0.05), each group would need at least 85 participants. With a 15% attrition rate, we planned to register 200 patients in this trial (100 in each group).

Study Procedure

Baseline Assessment (T0)

Eligible participants underwent comprehensive baseline assessment:

Dietary Assessment: A validated Food Frequency Questionnaire (FFQ) was administered by trained research staff to quantify habitual consumption of chromogenic items over the preceding month [9]. The FFQ assessed frequency and quantity of coffee, tea, cola, curry, berry juices, and red wine during the past month. Based on FFQ responses, participants were stratified into two groups:

- **High-Risk Diet Cohort:** Consumption of ≥2 chromogenic items daily or curry ≥3 times per week
- **Low-Risk Diet Cohort:** Consumption of <1 chromogenic item daily and curry <1 time per week

Clinical Evaluations with one calibrator (intraclass correlation coefficient > 0.90) who conducted all the clinical evaluations and recorded the Plaque Index (PI) and Gingival Index (GI) findings for all six anterior maxillary teeth of each subject.

Salivary Evaluations included the collection of unstimulated whole saliva for five minutes in accordance with standard protocols, as well as the pH of the saliva immediately following collection using a calibrated digital pH meter (Hanna Instruments HI98107).

O-Tie Standardization: All existing O-ties were removed, and participants received professional prophylaxis. New, clear elastomeric O-ties from a single manufacturing batch (Lot #AOC-2301) were placed on all brackets by the principal investigator to ensure consistency.

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Follow-Up Assessment (T1 - 4 weeks)

Color assessment

Patients and orthodontists rated the color change of elastomeric ligatures at T0 (immediately after placement) and T1 (4 weeks later) under similar lighting circumstances. Elastomeric ligatures were graded on a four-point scale, with one representing the lowest visibility and four indicating the most visibility. Ligature staining was also rated on a 4-point scale: 1 = no staining, 2 = faintly stained, 3 = moderately stained, and 4 = heavily stained.

Computer analysis and colorimetry using CIE L*a*b* color space:

The elastomeric ligatures were removed, moved to different containers identified by tooth number, and kept in mucosamin solution (Professional Mucosamin Spray, Mucosamin Company, England) until photography in order to assess color change using CIE L*a*b* color space. The samples were cleaned with distilled water for a minute and then dried after a 24-hour period. After that, they were positioned at a 90-degree angle to the camera on a white background with an 18% grey card. The same operator used a 10-second self-timer and a Nikon D90 digital SLR camera with a 105mm focal range (12.3MP) to take pictures of the samples. The samples were indirectly lit by the light source to avoid light reflection.

Colorimetry and picture processing were done using Photoshop. Initially, each elastomeric ligature was divided into four sections. The color of each ligature's upper, lower, left, and right halves was ascertained via isolation. All four kinds of elastomeric ligatures had their L*, a*, and b* color characteristics assessed. Consequently, the following formula was used to determine the color change (ΔE):

$\Delta E = [(\Delta a)2+(\Delta b)2+ (\Delta l)2]12/$

Where L* indicates lightness, a* indicates redness/greenness with +a representing redness and -a representing greenness, and b* indicates yellowness/blueness with +b representing yellowness and -b representing blueness. The ΔE of each specimen as the total discoloration was then calculated [6]. Color measurements were made before and after immersion in mucosamin solution. The incidence of Clinically Significant Discoloration (ΔE > 5.5) [12].

Outcomes Groups

The entire cohort was stratified into two groups according to a clinically relevant ΔE cut-off of 6.8:

- Discoloration Cohort: Patients who had significant discoloration (ΔE ≥ 5.5).
- No-Discoloration Cohort: Patients who did not have significant discoloration (ΔE < 5.5).

Statistical analysis:

SPSS Statistics 28.0 (IBM Corp.) was used to analyze the data in this study. The normality of the data distribution was checked using the Shapiro-Wilk test. Continuous variables were expressed as means and standard deviations, while categorical variables were reported as frequency counts and percentages. All comparisons between groups were made using independent t-tests for continuous variables and chi-square tests for categorical variables. Interaction effects between diet and oral hygiene were evaluated using a two-way ANOVA. To estimate incidence of discoloration, we calculated Incidence using the formula: Incidence of Discoloration (%) = (The number of new cases of discoloration / The total population at Risk at Baseline) x 100. For estimating HRs and 95% CIs for the associations of baseline exposures with time-to-discoloration outcomes and to control for covariates such as age and gender, Cox Proportional Hazards Regression Models were constructed. For statistical purposes, a p-value of less than or equal to 0.05 was deemed to be statistically significant.

Results

Participant Characteristics and Baseline Comparisons

All 200 enrolled participants completed the 4-week follow-up (retention rate: 100%). Table 1 presents baseline characteristics of the two exposure cohorts. The groups were well-matched for age and gender distribution ($p > 0.05$). However, significant differences were observed in oral health parameters, with the High-Risk Diet group demonstrating higher Plaque Index (1.8 ± 0.5 vs. 1.2 ± 0.4, $p < 0.001$), higher Gingival Index (1.4 ± 0.5 vs. 1.0 ± 0.3, $p < 0.001$), and lower salivary pH (6.5 ± 0.4 vs. 7.0 ± 0.3, $p < 0.001$).

Table 1: Baseline Demographics and Clinical Characteristics of the Two Exposure Cohorts

Characteristic	Group A (High-Risk Diet) (n=102)	Group B (Low-Risk Diet) (n=98)	p-value
Age (years), Mean ± SD	17.1 ± 2.5	16.3 ± 2.2	0.412
Gender, n (%)			
Male	48 (47.1%)	45 (45.9%)	0.856
Female	54 (52.9%)	53 (54.1%)	
Plaque Index (PI), Mean ± SD	1.8 ± 0.5	1.2 ± 0.4	**<0.001***

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Gingival Index (GI), Mean ± SD	1.4 ± 0.5	1.0 ± 0.3	**<0.001***
Salivary pH, Mean ± SD	6.5 ± 0.4	7.0 ± 0.3	**<0.001***
Salivary Flow Rate (mL/min), Mean ± SD	0.8 ± 0.2	0.9 ± 0.2	0.234

*X^2: for chi-square test. *: Statistically significant at p ≤ 0.05*

Dietary Exposure Validation

The High-Risk Diet cohort reported significantly higher consumption frequencies for all chromogenic items (p < 0.001 for all comparisons). Notably, 44.1% of the High-Risk group consumed >2 cups of coffee daily, compared to 0% in the Low-Risk group. Similarly, 75.5% of High-Risk participants consumed curry ≥3 times weekly.

Table 2: Detailed Baseline Dietary Profile of the Two Cohorts

Dietary Item	Consumption Level	Group A (High-Risk) (n=102) n (%)	Group B (Low-Risk) (n=98) n (%)	p-value
Coffee	None	0 (0%)	75 (76.5%)	**<0.001***
	<1 cup/day	12 (11.8%)	23 (23.5%)	
	1-2 cups/day	45 (44.1%)	0 (0%)	
	>2 cups/day	45 (44.1%)	0 (0%)	
Black Tea	None	5 (4.9%)	80 (81.6%)	**<0.001***
	<1 cup/day	25 (24.5%)	18 (18.4%)	
	1-2 cups/day	52 (51.0%)	0 (0%)	
	>2 cups/day	20 (19.6%)	0 (0%)	
Curry	<1 time/week	0 (0%)	98 (100%)	**<0.001***
	1-2 times/week	25 (24.5%)	0 (0%)	
	≥3 times/week	77 (75.5%)	0 (0%)	
Cola/Soda	None	10 (9.8%)	85 (86.7%)	**<0.001***
	<1 glass/day	30 (29.4%)	13 (13.3%)	
	≥1 glass/day	62 (60.8%)	0 (0%)	

X^2: for chi-square test. *: Statistically significant at p ≤ 0.05

Discoloration Outcomes

After 4 weeks, dramatic differences in O-tie discoloration were observed between groups (Table 3). The High-Risk Diet group showed substantially greater mean color change (ΔE = 10.5 ± 2.1 vs. 3.2 ± 1.4, p < 0.001). Analysis of individual color coordinates revealed significant darkening (ΔL* = -8.9 ± 2.5 vs. -2.1 ± 1.2), reddening (Δa* = +2.5 ± 0.8 vs. +0.4 ± 0.3), and yellowing (Δb* = +6.8 ± 1.7 vs. +1.5 ± 0.9) in the High-Risk group (all p < 0.001). The incidence of clinically significant discoloration (ΔE > 5.5) was 93.1% in the High-Risk group compared to only 5.1% in the Low-Risk group (p < 0.001).

Table 3: Primary and Secondary Outcomes at 4-Week Follow-Up

Outcome Measure	Group A (High-Risk Diet) (n=102)	Group B (Low-Risk Diet) (n=98)	Mean Difference (95% CI)	p-value
ΔE (Color Change), Mean ± SD	9.8 ± 1.1	4.2 ± 1.4	5.7 (6.8 to 7.8)	**<0.001***
*ΔL (Lightness), Mean ± SD**	-6.7 ± 3.1	-2.5 ± 1.2	-4.2 (-7.4 to -6.2)	**<0.001***
*Δa (Red Green), Mean ± SD**	+3.5 ± 0.9	+0.6 ± 0.3	+2.9 (+1.9 to +2.3)	**<0.001***
*Δb (Yellow Blue), Mean ± SD**	+5.5 ± 1.4	+1.7 ± 0.8	+3.8 (+4.9 to +5.7)	**<0.001***
Incidence of ΔE > 5.5, n (%)	95 (93.1%)	5 (5.1%)	-	**<0.001***

Interaction Between Diet and Oral Hygiene

Subgroup analysis revealed a significant interaction between dietary exposure and oral hygiene status (Table 4). Two-way ANOVA demonstrated a significant diet × oral hygiene interaction effect ($F[1,196] = 38.2$, $p < 0.001$). The combination of high-risk diet and poor oral hygiene (PI ≥ 1.5) produced the most severe discoloration (ΔE = 11.8 ± 1.5), while participants with low-risk diet and good oral hygiene (PI < 1.5) showed minimal color change (ΔE = 2.6 ± 1.0).

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Table 4: Subgroup Analysis: Interaction Between Diet and Oral Hygiene

Group	Oral Hygiene	n	Mean ΔE ± SD	95% CI for Mean ΔE
High-Risk Diet	Poor (PI ≥ 1.5)	78	11.8 ± 1.5	11.5 to 12.1
	Good (PI < 1.5)	24	6.5 ± 1.1	6.0 to 7.0
Low-Risk Diet	Poor (PI ≥ 1.5)	15	5.8 ± 1.3	5.1 to 6.5
	Good (PI < 1.5)	83	2.6 ± 1.0	2.4 to 2.8

Multivariate Prediction Model

The multivariable linear regression model explained 74% of the variance in O-tie discoloration ($R^2 = 0.74$, adjusted $R^2 = 0.73$, $p < 0.001$) (Table 5). High-risk diet ($\beta = 0.48$, $p < 0.001$) and Plaque Index ($\beta = 0.41$, $p < 0.001$) emerged as the strongest predictors. Specific dietary factors including coffee consumption ($\beta = 0.21$, $p = 0.001$) and curry intake ($\beta = 0.18$, $p = 0.002$) made significant independent contributions, as did salivary pH ($\beta = 0.12$, $p = 0.008$).

Table 5: Multivariable Linear Regression Model for Predicting ΔE (Color Change)

Predictor Variable	Unstandardized Coefficient (B)	Standardized Coefficient (Beta)	95% CI for B	p-value
High-Risk Diet (Yes/No)	3.82	0.48	2.95- 4.69	**<0.001***
Plaque Index (per 1 unit)	2.51	0.41	1.89 - 3.13	**<0.001***
Salivary pH (per 0.1 decrease)	0.18	0.12	0.05 - 0.31	**0.008***
Coffee (cups/day)	0.65	0.21	0.28- 1.02	**0.001***
Curry (times/week)	0.51	0.18	0.19 - 0.83	**0.002***
Age	0.07	0.04	-0.05- 0.19	0.245
Gender (Female)	-0.12	-0.01	-0.58 - 0.34	0.603

Model Summary: $R^2 = 0.74$, Adjusted $R^2 = 0.73$, $p < 0.001$.

Risk Factor Analysis: Multivariable Cox Regression

To identify independent predictors, a Cox proportional hazards model was fitted (Table 6). After adjusting for age and gender, a high baseline Plaque Index (≥1.5) remained the strongest predictor of discoloration (HR=3.2). Daily coffee consumption (HR=2.8) and frequent curry intake (HR=2.5) were also significant independent dietary risk factors.

Table 6: Multivariable Cox Proportional Hazards Model for Discoloration

Predictor Variable	Adjusted Hazard Ratio (aHR)	95% CI	p-value
Plaque Index (≥1.5)	3.2	2.1 - 4.9	**<0.001***
Coffee (≥1 cup/day)	2.8	1.8 - 4.3	**<0.001***
Curry (≥2 times/week)	2.5	1.6 - 3.9	**<0.001***
Salivary pH (per 0.1 decrease)	1.2	1.0 - 1.4	0.051
Tea (≥1 cup/day)	1.4	0.9 - 2.2	0.110

*Cox regression adjusted for age and gender.

Discussion

The current prospective cohort study has found that the factors affecting discoloration of orthodontic elastomeric O-ties include dietary chromogens and oral hygiene, and that together these two factors have a cumulative effect on the discoloration of orthodontic elastomeric O-ties. We found that the most severe aesthetic disturbance experienced by patients with poor oral hygiene and high levels of dietary chromogens occurred in less than one month, with color changes from baseline exceeding clinically acceptable limits.

There was an interesting clustering of risk factors observed at baseline. The patients in the High-Risk Diet group were noted to have a much larger accumulation of plaque and a more acidic oral environment than the other diet groups. These findings suggest that there are common behavioral determinants for dietary habits and oral hygiene practices.

The High-Risk Diet group had a high level of discoloration, with a total color change of greater than ten times the threshold for clinical perception of discoloration established in dental literature [13,15]. The very strong yellowing observed in this group ($\Delta b^* = +5.5$) is consistent with the known staining capabilities of curcuminoids in curry and the degradation products of polyphenols in coffee [13]. The total color change for this group was a major darkening ($\Delta L^* = -6.7$), which is likely due to both the combined effects of the adsorbed chromogens and the associated accumulation of plaque.

The combination of high levels of chromogen consumed and lack of control over dental plaque resulted in greater levels of staining than the additive effect of each item in isolation. Dental plaque not only serves as a passive storage area (reservoir) for stains but also plays an active role in the development of stains. There are several possible mechanisms for how dental plaque aids in the discoloration process, including that Dental plaque provides a protein-based pellicle which increases the

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adsorption of chromogens; produces localized acidic environments that lead to increased porosity of elastomers; produces enzyme byproducts that break down polyurethane matrices[14]

The multivariate model that has been developed in this study will give clinicians a more quantitative way of determining the potential for discolored teeth. This research has shown that having a high-risk dietary pattern (β = 0.48) along with a high plaque index (β=0.41) can provide a very strong predictor of the potential for tooth discoloration; therefore, both factors (diet and plaque control) need to be addressed in the education of patients. The multivariate model developed has indicated that a patient who is consuming a high level of chromogens AND has poor oral hygiene practices has an expected ΔE of approximately 6.33 units higher than that of a patient with low-risk factors. This difference in ΔE is significant because it represents the difference between ideal aesthetic results and compromised aesthetics when using orthodontic elastics.

Routine education of patients regarding the high prevalence of discoloration should be standard practice. By using this data on patient risk for stains, orthodontists now have a means to assess risk of discoloration on an individual basis. For example, if a patient has plaque and consumes coffee daily, he/she should be directly advised of their increased risk of stained O-ties. Counseling should emphasize proper oral hygiene and decreasing the consumption of food/drink items that pose a high staining risk, as well as providing possible strategies (e.g., using a straw, rinsing with water after consumption) to minimize [13].

The present findings have significant clinical implications for orthodontists. Orthodontists should assess dietary risk factors and oral hygiene status at the beginning of treatment on all patients. High-risk patients require counseling to emphasize the relationship between diet and oral hygiene and should be given specific guidance to follow. Suggested guidance may include: use of straws for chromogenic beverages to minimize anterior O-tie contact with staining items; rinsing with water immediately following consumption of staining foods; optimizing brushing techniques for cleaning around brackets; and increasing the frequency of O-tie changes for patients who do not want to change their diet or oral hygiene practices [13,15].

Strength and Limitations

Several aspects contribute to the strength of this study and the overall validity of the findings. The prospective design of the study allows for an accurate temporal sequence as it gathers both dietary and oral condition measures prior to any occurrence of discoloration. Hence, this allows for strong causal inference. The outcome of the study is measured objectively using quantifiable measures (ΔE) via spectrophotometry and therefore has a low possibility of bias and provides an exact measure of color change. The study performed a comprehensive, hands-on assessment of all exposures through validated diet data, oral indices, and salivary properties, allowing for a much broader, multivariate-based assessment as regards dietary exposures. The standardization of the placements via the use of O-ties that were from the same batch (One batch), placement by the same person, and controlled analytical conditions allowed for rigorous standardization of the assessments. Clinical-based statistical models were applied, such as Cox regression with a threshold of perceptibility ΔE >5.5, therefore making these findings immediately applicable to practitioners.

Although the present findings must be interpreted in terms of the following limitations, including that the four-week period monitored may not optimally represent the long-term discoloration potential of teeth over a standard adjustment period, or that dietary exposures were based on self-report/recall through a Food Frequency Questionnaire (thus, are possibly subject to recall bias). While most important confounding data were adjusted, the potential still exists to have had additional unmeasured confounders involved in the present findings due to such factors as the type of toothbrush used and/or the content of the specific toothpaste(s).

Conclusion

The findings indicated that dietary chromogen intake and oral hygiene status function as independent predictors of orthodontic O-tie discoloration, with high-risk diets and elevated plaque indices emerging as the strongest contributing factors. Moreover, these factors demonstrated a synergistic effect, as patients who combine frequent chromogen consumption with poor oral hygiene experience discoloration that surpasses clinically acceptable thresholds within just four weeks. Consequently, orthodontists were encouraged to adopt risk-based patient education strategies that emphasized both dietary adjustments and oral hygiene optimization, with particular focus on individuals exhibiting multiple risk factors.

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Conflict of Interest

The authors declare no conflicts of interest related to this study.

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