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Effectiveness of nutrition counseling on reducing sugar intake amount and frequency: A randomized clinical trial

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Abstract:

BACKGROUND: Dental caries is a widespread oral health issue with significant medical and socioeconomic consequences. Despite preventive measures, nearly 90% of US adults have experienced caries, disproportionately affecting lower-income and minority populations. While fluoride use and oral hygiene practices help mitigate caries development, dietary sugar remains a primary driver. However, nutrition counseling in dental settings remains underutilized.

MATERIALS AND METHODS: This randomized, single-center, two-group clinical study assessed the impact of Stephan's curve-based nutrition counseling on snacking frequency and added sugar consumption over 2 weeks. One hundred adult participants were randomized into an intervention group receiving personalized nutrition counseling or a control group receiving no counseling. The nutrition counseling focused on reducing both the frequency of snacking and the amount of added sugar consumed during snacks. Participants used an app that calculates the amount of added sugar consumed. Additionally, the Stephan's curve was utilized as a visual tool to demonstrate how sugar or carbohydrate intake causes a drop in pH below the critical threshold. Examiners assessed the caries experiences expressed as decayed, missing, or filled teeth (DMFT) of participants at baseline and at the 2-week follow-up visit. Participants logged their snacking frequency and sugar consumption daily. Statistical analysis compared pre- and post-intervention data using t-tests and Random Forest modeling.

RESULTS: The intervention group significantly reduced snacking frequency by 26.1% ($P = 0.006$) and sugar intake by 50.8% ($P = 0.001$), while the control group showed non-significant reductions of 9.5% ($P = 0.09$) and 5.2% ($P = 0.67$), respectively. Random forest modeling identified younger participants as more responsive to the intervention.

CONCLUSION: Stephan's curve-based nutrition counseling effectively reduced sugar intake and, to a lesser extent, snacking frequency. These findings support incorporating dietary education into routine dental care.

Keywords:

Dental caries, dietary sucrose, nutrition counseling

Introduction

Dental caries is a multifactorial disease with significant medical, social, and economic implications.^[1] Despite methods preventing its occurrence have been widely investigated and practiced, dental caries still impacts individuals and communities,

causing pain, suffering, impairment of function, and reduced quality of life. The National Health and Nutrition Examination Survey reveals distressing statistics: nearly 90% of US adults aged 20 to 64 have experienced dental caries, with one in four having untreated dental caries. The burden is disproportionately higher among black and Mexican American adults, younger adults, those with lower incomes and

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education, and smokers. On average, adults had 9.3 decayed, missing, or filled teeth (DMFT) between 2011 and 2016.^[2] These findings reveal that there is an urgent need for better preventive measures and interventions.

The pathogenesis of dental caries is a well-known process, and traditional strategies for managing cariogenic biofilm have relied on Keyes' diagram, which denotes three prerequisites for caries development: bacteria, food, and the tooth.^[3] The most effective approaches to controlling caries development target these factors directly by focusing on biofilm removal, reducing the intake of fermentable carbohydrates, and strengthening the tooth's resistance to acid attack through fluoride supplementation.^[4,5] Brushing and flossing to remove biofilm, community water fluoridation, and in-office fluoride treatments that prevent demineralization are actively promoted by the American Dental Association.^[6] However, extensive evidence consistently points to dietary sugars as the main cause of dental caries. This connection is supported by a breadth of studies, from key animal studies involving germ-free rats fed a cariogenic diet to long-term observational cohort studies that tracked the relationship between sugar consumption and concurrent caries development.^[7-9] Clinical trials and systematic reviews further demonstrate that both the frequency and amount of sugar intake play a significant role in forming dental caries.^[10,11] To reduce the risk of noncommunicable diseases, with a particular focus on the prevention and control of unhealthy weight gain and dental caries, the World Health Organization (WHO) recommends reducing the intake of free sugars to less than 10% of total energy intake.^[12] In addition, the American Heart Association (AHA) specifically differentiates between *naturally-occurring* sugars—like those in fruits and milk—and *added* sugars, which are added during food preparation or processing. To maintain a healthy diet, the AHA advises that added sugars should account for less than 6% of daily calories—about 25 g for women and 36 g for men.^[13] Despite the clear link between sugar intake and dental caries as well as other chronic diseases, most dental professionals do not include nutrition counseling and caries risk assessment in their services.^[4] This highlights a major lack in acknowledging the role of dentists in educating and promoting healthier nutrition habits, such as reducing fermentable carbohydrates.^[14]

The American Dental Association introduced a billable code for nutrition counseling (D1310), which addresses dietary habits that affect oral health.^[6] Our preliminary study (IRB#5230385) used the BigMouth Dental Repository, a comprehensive database of electronic health records from 11 US dental schools affiliated with the Consortium of Oral Health Research and Informatics (COHRI). This database encompasses

information from over 3 million patients representing diverse demographics, which provided us with important insights.^[15] Between July 2022 and August 2023, there were 65,974 patient records with completed comprehensive or periodic oral evaluations. Only 1,307 of these records—about 2%—included documentation of nutrition counseling through the D1310 code, revealing the significant underuse of such counseling by dental institutions to actively prevent oral diseases. Furthermore, there is limited information on the effectiveness of nutrition counseling and its impact on dietary choices and subsequent dental caries prevention.

The purpose of the study was to evaluate the effectiveness of nutrition counseling in reducing the frequency and amount of added sugar consumption during snacking. We focused on snacking because a previous study found that one in three individuals in this community was classified as a frequent snacker, consuming snacks more than three times a day.^[16] Specifically, the study used Stephan's^[17] curve to educate participants on the impact of sugar and snack consumption as well as its timing on oral pH and caries risk. This curve illustrates that pH drops significantly within 30 minutes after a meal, creating an environment conducive to tooth demineralization. Consuming additional sugar *within* this 30-minute window is less detrimental compared to consuming sugar *after* the 30-minute window. We hypothesized that participants receiving Stephan's curve-based nutrition counseling would show a significant reduction in the amount and frequency of snacking compared to those without this intervention. In this way, this study seeks to fill the gap in evidence regarding the use of nutrition counseling in dental settings and its potential to create healthier dietary behaviors, therefore contributing to more comprehensive strategies that target dental caries and other chronic diseases.

Materials and Methods

Study design and setting

A randomized, single-center, two-cell, and parallel-group clinical study, conducted in California, evaluated the effectiveness of Stephan's curve-based nutrition counseling on the frequency and amount of added sugar consumption during snacking in adults over a 2-week time frame. A theoretical framework of the study is illustrated in Figure 1.

Study participants and sampling

Inclusion and exclusion criteria

The study assessed the effectiveness of nutrition counseling in reducing both the frequency of snacking and the amount of added sugar consumed during snacks, compared to a control group that did not receive any counseling. The research was conducted at Loma Linda

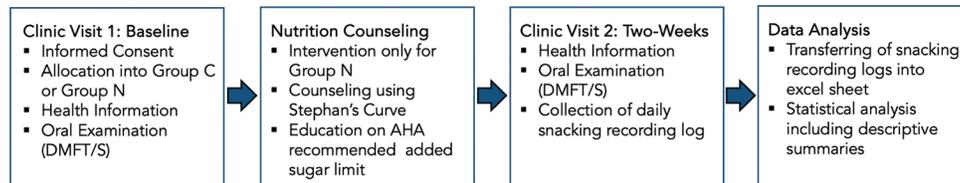


Figure 1: Theoretical framework of study

University School of Dentistry in Loma Linda, California. The study included participants who were 18 years or older, willing to comply with the study protocol, able to read and speak English, and available throughout the study period. Exclusion criteria consisted of individuals under the age of 18 and those with fewer than 20 teeth. A flyer was posted on the School of Dentistry student lounge board to recruit subjects.

Randomization of treatments

Eligible participants who met the inclusion and exclusion criteria were randomly assigned to either the control group or the nutrition counseling intervention group. Blinding of the examiner or the participants was not feasible. Each participant was assigned a unique identification number sequentially, from 001 to 100, and randomization to the study groups was determined by a coin toss.

Interventions

During the nutrition counseling session, the examiner used Stephan's curve as a personalized, interactive visual aid to explain how participants' snacking habits impact their oral health [Figure 2]. Each session lasted approximately 10 minutes, and all examiners received training on how to deliver the counseling effectively. The counseling began with a detailed discussion of the participant's dietary intake throughout the day, including meals, snacks, and beverages. For each reported snack or meal containing sugar or carbohydrates, the examiner marked corresponding drops on the Stephan's curve to demonstrate how these foods caused the oral pH to fall below the critical threshold (approximately 5.5). The examiner also illustrated the time it typically takes—around 30 minutes—for the pH to recover to a neutral state, emphasizing how frequent snacking could prolong the acidic environment and increase the risk of dental caries. Additionally, the examiner introduced the "Sugar Intake" app [Figure 3]. The examiner helped each participant download the app onto their smartphone and provided a step-by-step demonstration on how to input food items and calculate the total added sugar consumed. Participants were provided a daily log to record their sugar intake with the use of the app, with the goal of staying within the American Heart Association's recommended limits (25 g for women and 36 g for men). To reinforce this guidance, participants were given a printed handout summarizing the AHA's recommendations, along with

practical tips to reduce added sugar consumption and make healthier snack choices.

Recording

All participants were provided with a log to record both the frequency of snacking and the amount of added sugar consumed during snacking for 2 weeks.

Sample size

The sample size of 100 participants was based on detecting an effect size (Cohen's $w = 0.56$) with 80% power and a significance level of 0.05, using a t -test for group differences.

Scoring criteria

At Visit 1, participants' demographic information and health history were recorded. To calculate the DMFT score, the examiners conducted a comprehensive oral examination to assess the number of decayed (D), missing due to caries (M), and filled teeth (F) for each participant. The DMFT score was calculated by adding the counts of decayed, missing, and filled teeth, providing a cumulative measure of caries experience. All teeth were assessed except for third molars. For an adult, the possible DMFT score ranged from 0 (indicating no dental caries experience) to 28 (reflecting caries-related conditions affecting all eligible teeth). Sugar intake (grams/day) and snacking frequency (episodes/day) were assessed. At the 2-week follow-up, the baseline assessments were repeated. The dental examiners visually examined the oral cavity and perioral area using a dental light and dental mirror.

Intra- and inter-examiner calibration

All dental examiners received a 4-hour training on nutrition counseling and the use of the sugar intake app so that the same sequence and wording were used for the intervention group. Calibration on the reporting of DMFT scores was performed before the initiation of the study using a set of clinical photographs. The intraclass correlation coefficient values of the stratified reliability results were 0.978, 0.997, 0.986, 0.994, and 0.995 for AR, AP, CG, CN, and SK, respectively. Inter-examiner correlation coefficients with SK as the gold standard were AR: 0.907, AP: 0.936, CG: 0.914, and CN: 0.936.

Adverse events assessment

Adverse events were obtained from an interview with the participants and from a dental examination by the investigators.

Data collection tool and technique

The nutrition counseling focused on reducing both the frequency of snacking and the amount of added sugar consumed during snacks. Participants used the free “Sugar Intake” app, which calculates the amount of added sugar consumed and compares it to the AHA guidelines [Figure 3]. Additionally, the Stephan’s curve was utilized as a visual tool to demonstrate how sugar or carbohydrate intake causes a drop in pH below the critical threshold, and how it takes approximately 30 minutes for pH levels to return to neutral. Participants were asked to recall their daily diet, beginning with breakfast, and list the snacks they consumed throughout the day. The operator then plotted this information on Stephan’s curve, illustrating the pH drop and the time

required for it to return to a neutral level. Periods of vulnerability to caries were highlighted in red to serve as a visual warning prompt [Figure 2]. A printed handout summarizing the AHA recommended daily sugar limits was also provided to reinforce the counseling.

Ethical considerations

This protocol was reviewed and approved by the Loma Linda University Institutional Review Board, located in Loma Linda, California (IRB # 5240464). The purpose of the study was explained to the participants, and they were assured that their information would remain confidential. Moreover, the intervention was initiated after participants signed the informed consent form.

Statistical analysis method

Responses from 100 participants were included in the final analysis. The statistical analysis included descriptive statistics, hypothesis testing, and predictive modeling to evaluate the effectiveness of nutrition counseling in reducing snacking frequency and sugar consumption. Descriptive statistics were compared between the baseline and post-intervention values for key variables between the nutrition counseling intervention group (Group N) and the control group (Group C). The primary outcome of change in sugar intake amount and frequency was assessed within and between the groups. Paired t-tests examined changes within each group while independent t-tests assessed differences

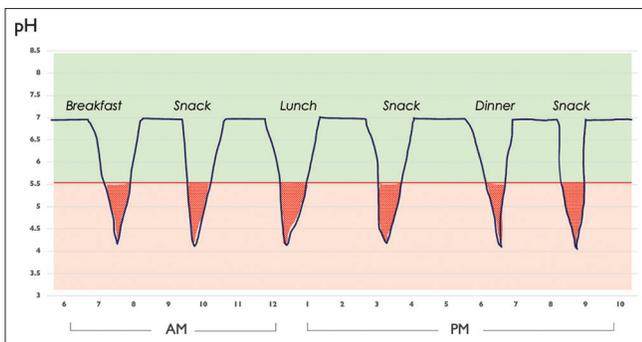


Figure 2: The use of the Stephan’s curve during nutrition counseling

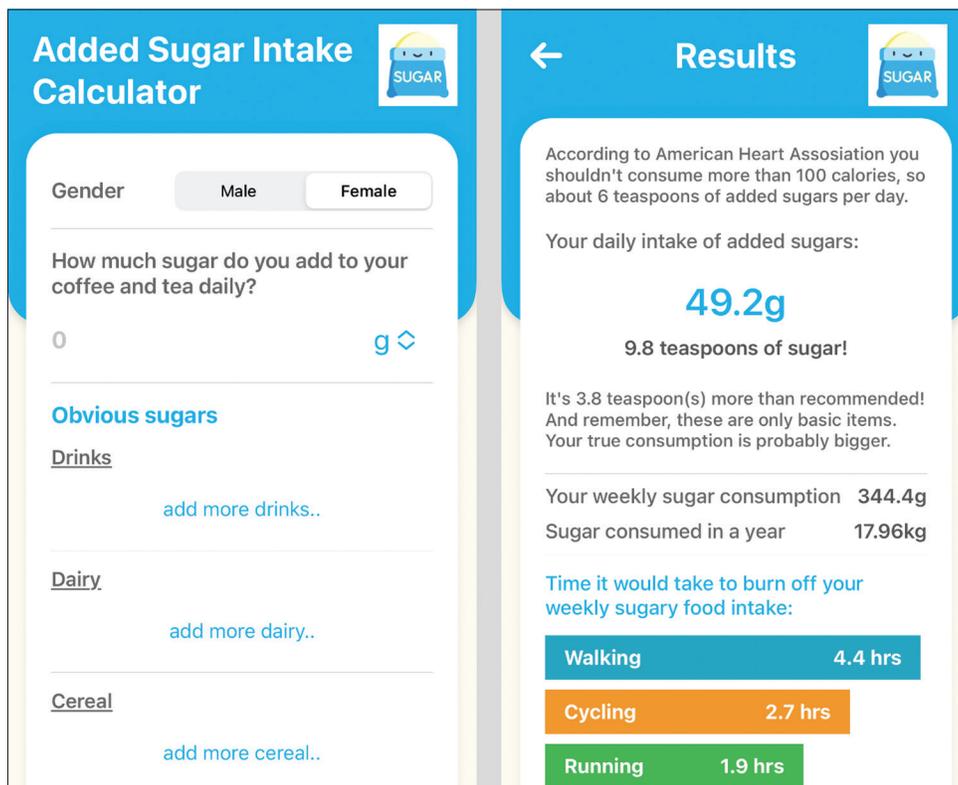


Figure 3: Sugar intake app: From calculation to results generation

between the groups. Random forest models were used for the secondary outcome related to predicting factors associated with frequent snacking, high sugar consumption, and reductions in both behaviors. Analysis was accomplished using Jamovi 2.6.23.^[18] All statistical tests of hypotheses were two-sided and used a level of significance of alpha = 0.05.

Results

Study reporting and baseline demographics

The population enrolled and who completed the study is presented in the Consolidated Standards of Reporting Trials diagram [Figure 4]. A total of 100 participants completed the 2-week clinical study. The 100 participants entered the clinical study and were randomized into one of the two treatment groups. The Intention-to-treat analysis was performed. The baseline demographics and caries experiences (DMFT) by groups are summarized in Table 1. The average age of participants in Group C was 38.7 years (± 17.6), while Group N had a slightly higher average age of 40.8 years (± 15.5). This difference

was not statistically significant ($P = 0.517$). In terms of caries experiences, Group C had a higher mean number of decayed teeth (D), with an average of 0.6 (± 1.5), compared to 0.1 (± 0.4) in Group N. This difference was statistically significant ($P = 0.046$). For missing teeth (M), both groups showed similar values: 0.8 (± 2.0) in Group C and 0.6 (± 1.4) in Group N, with no statistically significant difference ($P = 0.564$). The number of filled teeth (F) was also comparable between the groups—5.8 (± 5.5) in Group C and 5.4 (± 5.4) in Group N ($P = 0.686$). Overall, the total DMFT score (Decayed, Missing, and Filled Teeth) was slightly higher in Group C (7.2 ± 6.6) than in Group N (6.1 ± 6.0), but this difference was not statistically significant ($P = 0.394$).

Throughout the study, no adverse effects on the oral hard or soft tissues were observed by the clinical investigator or reported by the study participants when questioned.

Changes in snacking frequency

Table 2 summarizes the changes in snacking frequency over a 2-week period for participants who completed the clinical study, comparing results within each group and between the two groups (Group C and Group N). At baseline, the average snacking frequency was 2.1 (± 1.2) times per day in Group C and 2.3 (± 1.6) in Group N. Within-group analysis showed that Group C experienced a 9.5% reduction in snacking frequency after 2 weeks, but this change was not statistically significant ($P = 0.090$). In contrast, Group N demonstrated a significant 26.1% reduction in snacking frequency ($P = 0.006$), suggesting

Table 1: Summary of independent variables at baseline by group

| Variable | Group C (Mean \pm SD) | Group N (Mean \pm SD) | P |
|-------------|-------------------------|-------------------------|-------|
| Age (years) | 38.7 \pm 17.6 | 40.8 \pm 15.5 | 0.517 |
| D | 0.6 \pm 1.5 | 0.1 \pm 0.4 | 0.046 |
| M | 0.8 \pm 2.0 | 0.6 \pm 1.4 | 0.564 |
| F | 5.8 \pm 5.5 | 5.4 \pm 5.4 | 0.686 |
| DMFT | 7.2 \pm 6.6 | 6.1 \pm 6.0 | 0.394 |

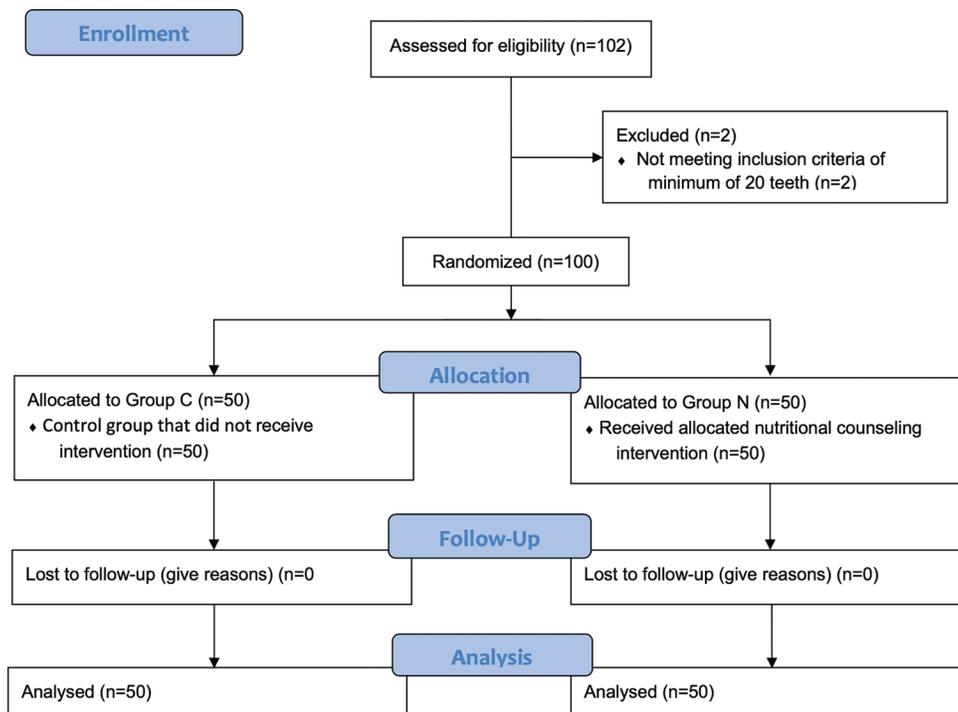


Figure 4: Consolidated standards of reporting trials diagram for the 2-week nutrition counseling clinical study

that the intervention had a meaningful impact on this group. Between-group analysis compared the overall effectiveness of the nutrition counseling intervention between the two groups. Group N had a 16.6% greater reduction in snacking frequency compared to Group C, although this difference was not statistically significant ($P = 0.129$).

Changes in amount of added sugar consumption

Table 3 presents the changes in the amount of added sugar consumed during snacking over a 2-week period for participants in Group C and Group N who completed the clinical study. At baseline, participants in Group C consumed an average of 13.5 g of added sugar (± 12.9), with a 95% confidence interval of 9.9 to 17.1 g. In Group N, the baseline average was substantially higher at 26.4 g (± 36.3), with a 95% confidence interval of 16.3 to 36.5 g. Within-group analysis revealed a 5.2% reduction in added sugar intake for Group C after 2 weeks, but this change was not statistically significant ($P = 0.670$). In contrast, Group N showed a significant 50.8% reduction ($P = 0.001$), indicating a meaningful improvement in dietary behavior within that group. Between-group analysis showed a 45.6% greater reduction in added sugar intake in Group N compared to Group C, and this difference was statistically significant ($P = 0.003$).

Random forest modeling

The impact of age was notable, with younger participants responding more effectively to the intervention. Predictive modeling revealed that age was the most influential factor, with younger individuals showing larger reductions in both snacking frequency and added sugar consumption. While the intervention was broadly effective, it showed variability in impact, particularly

among older participants, where reductions were less pronounced.

Discussion

The risk of dental caries is strongly influenced by dietary choices and eating habits. Diets that are low in added sugars and consist of minimally processed foods are associated with a lower risk of caries, whereas frequent consumption of sugary, ultra-processed foods significantly increases the likelihood of dental decay.^[11,19-21] Given this, dentists and healthcare providers play a vital role in identifying patients’ risk factors and conducting comprehensive assessments for those at risk or already experiencing dental decay. One widely recognized concept in dental education is Stephan’s^[17] curve, which graphically illustrates fluctuations in pH levels in response to food and beverage consumption. It is primarily used to educate dental students about the effects of dietary habits on oral health. However, despite its effectiveness as a teaching tool, it has not been extensively employed in patient education.

Our study is novel in that it introduces the use of Stephan’s curve as an interactive visual aid to illustrate the impact of snacking frequency and sugar intake on dental caries. Studies have shown that visual and interactive tools are highly effective in improving patient understanding and engagement in health education.^[22,23] Visual aids enhance comprehension, particularly for individuals with lower health literacy, by simplifying complex information into clear and memorable formats.^[23] Furthermore, interactive tools, such as drawing and engaging discussions, have been demonstrated to increase patient participation and adherence to preventive behaviors.^[23] By drawing the curve alongside participants, we provided a tangible

Table 2: Within and between-treatment analysis for snacking frequency at the 2-week examinations for participants who completed the 2-week clinical study

| Group | No. of participants | Baseline snacking frequency | 95% confidence interval | Within-treatment analysis | | Between-treatment analysis | |
|-------|---------------------|-----------------------------|-------------------------|---------------------------|----------------|----------------------------|----------------|
| | | | | % Change [†] | P [‡] | % Change [§] | P [*] |
| C | 50 | 2.1 (1.2) | 1.8 to 2.4 | 9.5 | 0.090 | 16.6 | 0.129 |
| N | 50 | 2.3 (1.6) | 1.9 to 2.7 | 26.1 | 0.006 | – | – |

[†]Percentage change exhibited by after 2-week mean relative to the baseline mean. A positive value indicates a reduction in snacking frequency. [‡]Significance of paired t-test comparing the baseline and after-treatment examinations. [§]Difference between the baseline means of the control and intervention group expressed as percentage. A positive value indicates a greater reduction in the snacking frequency for the intervention group relative to the control group. ^{*}Significance of Independent t-tests of baseline to after 2-week mean between the control and intervention group. –: Not applicable

Table 3: Within and between-treatment analysis for amount of added sugar consumption during snacking at the 2-week examinations for participants who completed the 2-week clinical study

| Group | No. of participants | Baseline added sugar amount | 95% confidence interval | Within-treatment analysis | | Between-treatment analysis | |
|-------|---------------------|-----------------------------|-------------------------|---------------------------|----------------|----------------------------|----------------|
| | | | | % Change [†] | P [‡] | % Change [§] | P [*] |
| C | 50 | 13.5 (12.9) | 9.9 to 17.1 | 5.2 | 0.670 | 45.6 | 0.003 |
| N | 50 | 26.4 (36.3) | 16.3 to 36.5 | 50.8 | 0.001 | – | – |

[†]Percentage change exhibited by after 2-week mean relative to the baseline mean. A positive value indicates a reduction in amount of added sugar during snacking. [‡]Significance of paired t-test comparing the baseline and after-treatment examinations. [§]Difference between the baseline means of the control and intervention group expressed as percentage. A positive value indicates a greater reduction in the amount of added sugar during snacking for the intervention group relative to the control group. ^{*}Significance of Independent t-tests of baseline to after 2-week mean between the control and intervention group. –: Not applicable

representation of the vulnerability of teeth to acid attacks following sugar consumption, thereby reinforcing the importance of dietary choices and snacking in caries prevention.

Many different types of studies have captured information on nutrition counseling practices related to oral health; however, there are limited data available on the specific details of the counseling provided and how it affected a diet change.^[24] Our findings highlight the effectiveness of Stephan's curve-based nutrition counseling in reducing both snacking frequency and added sugar consumption among adult participants over a 2-week period. Furthermore, it supports the use of apps that become increasingly popular for nutrition education.^[25,26] The findings support the hypothesis that providing visual and interactive education about sugar consumption and its impact on oral pH can positively influence dietary behaviors. These reductions suggest that educational interventions focused on the biological mechanisms of caries formation can effectively promote behavioral changes. In contrast, the control group showed only a minor reduction in snacking frequency (9.5%), which was notably significant and may be due to a placebo effect, as participants became more aware of their snacking behavior simply by taking part in the study. Random Forest modeling identified age as a key determinant of intervention effectiveness, with younger participants exhibiting greater reductions in both snacking frequency and sugar intake. This finding aligns with previous studies suggesting that younger individuals may be more receptive to dietary modifications when provided with clear educational tools.^[27]

Although nutrition counseling may require additional time, a recent study has shown that simply enhancing the caries risk assessment form with targeted dietary questions could help better identify patients who would benefit from such counseling.^[21] Notably, the study consistently found links between dietary sugar intake—particularly from sugar-sweetened beverages—and planned restorative treatments. Additionally, unstructured eating patterns were also associated with a higher need for restorative care.^[21]

While our study highlights the effectiveness of nutrition counseling, several limitations must be noted. First, the reliance on self-reported dietary logs introduces potential reporting bias. Second, the study did not track how frequently participants used the recommended app to monitor sugar intake. Third, the short duration of the study (2 weeks) restricts the ability to evaluate long-term behavioral changes and the effect on caries experiences. Lastly, the study was carried out at one center, creating a potential for information contamination. To determine the sustainability of the observed dietary modifications,

longitudinal studies with extended follow-up periods are necessary. Moreover, examining the influence of socioeconomic factors, health literacy, and pre-existing dietary habits could help refine intervention strategies further.

Conclusion

This study provides compelling evidence that nutrition counseling using Stephan's curve effectively supports health policy benchmarks established by the World Health Organization (WHO) and AHA by reducing added sugar intake to below recommended thresholds and decreasing snacking frequency. Integrating such dietary education into routine dental practice aligns with current public health recommendations in promoting comprehensive oral and overall health improvement.

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Institutional Review Board

Loma Linda University Institutional Review Board approved the study, IRB # 5240464.

Clinical Trial registration information

ClinicalTrials.gov: NCT06673342

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Conflicts of interest

The authors have no conflict of interest to disclose.

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