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Knowledge and Preventive Practices Regarding Dental Erosion Associated with Energy Drink Consumption among Young Adults: A Questionnaire-Based Study

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ABSTRACT: Background: Erosive tooth wear (ETW) is a non-bacterial progressive destruction of tooth tissue by chemical means which leaves no residue. The explosive growth of energy drinks by young adults and students in the recent years has been an emerging extrinsic risk factor for dental enamel demineralization. While caries awareness is well promoted, the public health literacy and pre-emptive post-drinking protective practices against acid erosion is lacking.

Aim: To assess the prevalence of knowledge, attitudes, consumption and preventive practices towards dental erosion associated with the consumption of energy drinks among young adults (18-30 years old); and to determine the sociodemographic and behavioral predictors of high-risk consumption.

Design: Cross-sectional questionnaire survey in academic and community sample. Participants: 480 young adults (mean age 21.8±2.6 years). Materials and method: A validated, 28-item structured self-administered questionnaire was used to: (1) describe

sociodemographics; (2) quantify frequencies and practices of energy drinks consumption; (3) assess knowledge of dental erosion pathophysiology (0-10); and, (4) determine preventive measures in oral hygiene (0-8). Descriptive statistics, chi-squared, independent-samples t-test, Pearson's correlation and multivariable logistic regression analysis were used to analyse data using IBM SPSS Statistics v28.0 (α=0.05).

Results Participants revealed that 74.6% (n = 358) of respondents consumed energy drinks at least once a week, while 21.3% (n = 102) drank energy drinks daily. Despite 81.9% (n= 393) of respondents being exposed to the term dental erosion, only 34.2% (n= 164) of respondents could correctly discriminate acid erosion from bacterial caries induced by sugar, and only 28.5% (n= 137) agreed that sugar free energy drinks still caused erosion. Risky behaviors included slow sipping of energy drinks over more than 30 minutes (61.5%), consumption during or immediately following physical activity (44.8%), and mechanical brushing immediately post-consumption (38.1%) – a practice known to exacerbate mechanical damage to acid-softened enamel. Mean total knowledge scores were significantly higher among those in health-related majors (6.84 ± 2.11) versus non-health students (4.32 ± 2.05, $p < 0.001$). Low knowledge about erosion, male gender, having never been counseled by a dentist about oral health, and being in a non-health major were all independently associated with high-risk erosive consumption behaviors in multivariable analysis (aOR = 2.74, 95% CI: 1.81-4.15, $p < 0.001$; aOR = 1.92, 95% CI: 1.28-2.88, $p = 0.002$; aOR = 2.31, 95% CI: 1.52-3.51, $p < 0.001$; aOR = 1.78, 95% CI: 1.12-2.83, $p = 0.015$, respectively).

Conclusions: A significant knowledge-behavior gap was identified in energy drink-related dental erosion among young adults. The misunderstandings around sugar-free versions and the damaging act of brushing teeth immediately after energy drink consumption, call for chair side counseling by the oral health professionals and the implementation of an extensive university wide oral health awareness program.

1. INTRODUCTION

1.1 Background and Epidemiological Shift in Tooth Wear

In the last 20 years, clinical and preventive dentistry saw an important epidemiological change as regard to the cause and clinical expression of loss of dental hard tissues. Existing evidence shows that population water fluoridation, fluoridated toothpastes and targeted public health prevention programs have led to the apparent or actual stabilization and/or decline in the prevalence of dental caries in most industrialized and developing countries. There has been however a trend increase in the incidence of non-carious cervical lesions (NCCLs) and erosive tooth wear (ETW), and in particular among adolescents and young adults, which is silent but potentially disastrous for the long-term structure, esthetic, and occlusal function of dentition (Jaeggi & Lussi, 2014; Nijakowski et al., 2022; Gálvez-Bravo et al., 2025).

Dental erosion is conveniently and succinctly defined as the progressive and irreversible chemical dissolution of dental hard tissue that initially involves the outermost prismless and prismatic structure of the enamel, then proceeds to affect the underlying dentin and root cementum (Lussi & Carvalho, 2014; Silva et al., 2021; Martínez et al., 2024). In the complex nature of the intraoral environment, chemical demineralization seldom occurs as a sole etiological factor but rather interacts with other physical and/or mechanical processes such as attrition (tooth-to-tooth contact from mastication or bruxism), abrasion (wear from exogenous objects such as toothbrush bristles and coarse abrasive particles in dentifrice), and abfraction (microfracture of cervical fulcrum by eccentric occlusal loading) (Carvalho et al., 2015; Schmidt & Huang, 2022). This multifactorial clinical entity is appropriately described by the encompassing term of erosive tooth wear (ETW).

A fundamental pathophysiological difference which segregates dental erosion from other forms of dental destruction, often culminating in mineral loss, exists, even though similar processes exist. The etiology of dental caries has been described as an infectious, biolfilm-mediated disease in which acidogenic, aciduric microorganisms that harbor in dental plaque, mainly, Streptococcus mutans and Lactobacillus spp. Metabolize and ferment fermentable dietary carbohydrate resulting in the

production of weak organic acids, especially lactic, acetic, and propionic acids, leading to the development of localized subsurface demineralization underneath an intact zone that may be more readily demineralized in the early stage (Lussi & Carvalho, 2014).

Meanwhile, dental erosion directly acts on enamel and root surfaces, free from plaque, when erosion comes from the exposure to both extrinsic or intrinsic acid challenge. Instead of generating subsurface white-spot lesions, erosion acid dissolves in a centripetal, sequential manner of the surface mineralized tissue hydroxyapatite crystals, with a remarkable disruption of surface micro-hardness, and after both of the biological framework (protein+mineral) of superficial enamel has been disrupted, no biological regeneration process can be restored, requiring subsequent restorations for advanced acid destruction.

Pathologically, acids causing dental erosion are classified as either intrinsic or extrinsic. The intrinsic acids originate from high doses of recurrently ingested endogenous gastric hydrochloric acid (pH ~1.0-1.5), delivered into the oral cavity as a result of either gastroesophageal reflux disease (GERD), chronic pregnancy-related vomiting, alcoholism, or psychosomatic disorders including bulimia nervosa and anorexia nervosa (Reddy et al., 2016; Jaeggi & Lussi, 2014; Donovan et al., 2021). Acids of intrinsic origin predominantly attack the maxillary anterior teeth on the palatal or proximal dental surfaces and mandibular posterior teeth on the occlusal tooth surfaces, whereas extrinsic acids have been shown to be mainly derived from the widespread modern-day practice of frequently consuming acidic foods and beverages such as cord-grenate soft drinks, citrus fruit juices, dressing-thinned vinegar sauces, wines, pre-workout sports supplements, and commercial energy drinks (Gálvez-Bravo et al., 2025; Reddy et al., 2016; Martínez et al., 2024).

1.2 The Growing Popularity of Energy Drink for Young Adults

Commercial energy drinks comprise one of the fastest growing sectors of the global non-alcoholic beverage industry, with market growth rates exceeding those for traditional carbonated soft drinks (Visram et al., 2016). These beverages are consumed for their high levels of energy-boosting stimulant drugs and metabolic cofactors, which can range from 80 to 300 mg of caffeine per 8 oz dose, in addition to taurine, glucuronolactone, B-complex vitamins, herbal extracts (guarana, yerba mate, ginseng), sucrose and high-fructose corn syrup or non-nutritive artificial sweeteners, and are targeted toward young consumers in the 18-30 age bracket (Martínez et al., 2024; Clapp et al., 2019).

Advertisements often promote the use of energy drinks for producing increased mental energy, academic achievement, extreme sports performance, and lively nightlife. Thus, undergraduates, young professionals, shift workers, and novice athletes are prone to consume commercial energy drinks to make up for a lack of sleep, support concentration during exams, increase their physical endurance, or combat exhaustion in social venues by mixing their intake with alcohol (Visram et al., 2016; Schmidt & Huang, 2022; Gálvez-Bravo et al., 2025).

However, the physico-chemical constitution of commercially available energy drinks makes them potentially extremely damaging to mineralized dental tissue. Sound dental enamel is around 96% inorganic mineral (by weight), arranged as a calcium hydroxyapatite mineral crystal lattice substitution (Ca10(PO4)6(OH)2). Salivary calcium and phosphate ions are kept in a supersaturated solution at a physi-o-logical pH of 6.7-7.4, preventing mineral dissolution within the resting mouth (Hara & Zero, 2014). Enamel hydroxyapatite begins to undergo net mineral dissolution at a fluid pH of approximately 5.5. Conversely, exposed root dentine and cementum, which contains around 70% and 50% inorganic mineral, respectively, and are more heavily carbonate substituted, will undergo net mineral dissolution at a critical pH of around 6.2 to 6.5 (Lussi & Carvalho, 2014; Silva et al., 2021). In vitro testing of commercially available energy drinks reveals baseline pH values of between 2.36 and 3.80, effectively placing them significantly below the critical pH for enamel dissolution (Reddy et al., 2016; Silva et al., 2021; Martínez et al., 2024).

1.3 Chemical Factors Contributing to Erosive Capability

Although a low base pH triggers surface softening by delivering a large pool of free (H+) capable of protonating and dissolving PO4^3- and OH- groups within the hydroxyapatite crystal lattice, pH itself is not the sole determinant of erosive potential in vivo. Numerous in vitro profilometric, micro hardness and scanning electron microscopy (SEM) studies, as well as in situ intraoral appliance experiments, have indicated that various extrinsic chemical factors determine erosive potential (Shellis et al., 2014; Silva et al., 2021).

- Titratable acidity (TA) reflects the total pool of undissociated and dissociated acid molecules present in a beverage as expressed by the volume of an alkali (typically 0.1 M NaOH) needed to titrate the sample to pH 7.0 or above the critical pH of 5.5 (Reddy et al., 2016; Silva et al., 2021). Beverages with high titratable acidity and strong buffering capacities are anticipated to buffer the return to neutrality by salivary bicarbonate buffers, which can result in a greater length of intra-oral acidification following each sip.

- Acid and Calcium Chelation Power: Energy drink manufacturers for the last 50 years have been heavily focused on the use of acidulants, preservatives, and flavor enhancers. They tend to use either citric acid or phosphoric acid. Of the two citric acid is the only one that provides a dual leaching effect: 1) low pH results in ionization to release large amount of corrosive H+ ions that directly target enamel prisms; 2) as saliva gradually increases intraoral pH, the trivalent citrate anion becomes the strongest calcium chelator available and forms a strong soluble calcium complex by either chelating free Ca2+ ions directly from saliva or depleting calcium from the chloride infused enamel surface lattice (Shellis et al., 2014; Silva et al., 2021; Gálvez-Bravo et al., 2025).

- In general commercial energy drinks hardly contain calcium, phosphate and fluoride ions in contrast to dairy products or calcium enriched juices.

1.4 Behavioral Modifiers and Oral Health Literacy Gaps

The transition from Surface softening, microscopically, to pathology that can be clinically diagnosed (ie. Cupping of molar cusps, flattening of the occlusal form, translucent maxillary incisal edges, disappearance of perikymata and undesirably high dentinal hypersensitivity) is strongly influenced by individual intake habits and defense factors in host saliva (Hara & Zero, 2014; Carvalho et al., 2015). Some behavioral patterns have a great propensity to increase erosive risk:

- Slow consumption over long periods: Gradually consuming 1 can of energy drink over a prolonged 30-60 minutes period during study sessions or computer gaming subjects the dentition to continual acid challenges. Literature suggests, saliva takes about 20-30 minutes to neutralize dietary acids and restore the resting pH and therefore "sip in and out" throughout an hour-long period would delay restoration and sustain demineralization (Nijakowski et al., 2022; Chan et al., 2020).

- Swishing or retaining the beverage in the oral vestibule before swallowing seems to optimize the extent of contact and mechanically remove the acquired pellicle of protein film that forms over the bacteria (0.1-1.0 µm thick, innocuous protein film of salivary mucins and proline rich proteins that forms as a semi-permeable diffusion barrier for acid attack (Hara & Zero, 2014).

- Intoxication in heat and exercise-induced xerostomia. Activation of the sympathetic nervous system, dehydration, and mouth breathing during strenuous physical activity will significantly reduce unstimulated and stimulated salivary flow rates. When consumed during exercise-induced dry mouth, the non-neutralized acid energy drinks feed the enamel with no dilution, clearance, or bicarbonate buffering from the saliva, which further increases the rate of enamel dissolution (Nijakowski et al., 2022; Gálvez-Bravo et al., 2025).

- Before bedtime consumption: Drinking an energy drink just before bed day allows remaining acids to work on your teeth while you sleep because the flow of saliva during this time is minimal (nearly zero) (Donovan et al., 2021).

Timing of post-ingestion oral hygiene is also very important. After an acid challenge the outer 3 to 5um of enamel may become somewhat demineralized creating a weakened porous honeycomb matrix of compromised enamel prisms. If this demineralized zone is left alone in calcium and phosphate saturated saliva for 30 to 60 minutes this zone has a good chance to be partially re-hardened by precipitation of new mineral from the saliva. Brushing and abrasive cleaning of the surface immediately after an acid challenge may shear off this weakened layer before it has an opportunity to be re-hardened through mineral precipitation, causing irreversible cumulative tissue loss (Attin & Wegehaupt, 2014; Schmidt & Huang, 2022).

1.5 Study Rationale and Objectives

Translating laboratory research on the erosivity of energy drinks into preventative clinical practices entails a thorough awareness of the oral health literacy of young adults, their misconceptions, and actual practice habits. Knowledge of specific cognitive blind spots, such as the misconception that sugar-free energy drinks are detrimental to dental health, is crucial in designing appropriate clinical counseling protocols and public health messages (O'Toole et al., 2018; Manarte -Monteiro et al., 2025). Thus, the specific research aims of this cross-sectional questionnaire study were: 1. Consumption Epidemiology: To

measure and establish the extent, frequency, reasons, and behavioral consumption patterns of commercial energy drinks in young adults (ages 18-30 years). 2. Oral health literacy test: To assess the knowledge of non-bacterial dental erosion in terms of the etiology, clinical presentation, and chemical mechanisms, both "theoretical" and "functional". 3. Evaluate whether evidence-based preventive oral hygiene practices are being implemented by participants before, during and immediately following energy drink consumption.

4. To identify independent sociodemographic, academic, and clinical counseling predictors of low erosion knowledge and highrisk erosive consumption behaviors, using multivariable modeling.

2. MATERIALS AND METHODS

2.1 Study Design and Ethical Considerations

A descriptive, analytical, cross-sectional survey was conducted among Young Adults (YAs) that lives within an urban university district, for a period of 6 months (September 2024 to February 2025). The study protocol was developed, implemented and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cross-sectional studies. The Institutional Review Board (IRB) approval (DENT-2024-089) was granted before conducting data collection. All procedures were in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. An introductory consent page on the internet, has included information about the study's purpose, participation was voluntary, anonymity, confidentiality and lack of penalty for non-participation. Electronic forms of informed consent were made compulsory prior to providing access to the questionnaire items.

2.2 Study Population, Eligibility Criteria, and Sample Size Calculation

Inclusion criteria were young adults from 18 to 30 years of age who attended university campuses, student residences, sports centers or community facilities, sampled by Multi-stage Convenience and Stratified Snowball Sampling of convenience samples of health-science students from the universities and non-health-science students.

The inclusion criteria were: young people aged 18 to 30 years at the time of the survey, permanent residents of the study area, conversant in the language used for the questionnaire, having completed the electronic written informed consent form, and were willing to participate in the study. The exclusion criteria included young people younger than 18 and older than 30 years of age, duplicated records from the same IP address or device, and incomplete questionnaires having more than 10% core items missing.

Sample size calculation was carried out with Epi Info™ (version 7.2, Centers for Disease Control and Prevention, Atlanta, GA, USA). Assuming a confidence level of 95% ($Z = 1.96$) and a margin of error of 5% ($d = 0.05$), a conservative expected prevalence of high-risk consumption or erosion awareness of 50% was adopted to ensure maximum statistical power, with design effect of 1.15 to reflect variation in sampling units at the faculty level (cluster effect). The minimum sample size was estimated at 442. In order to compensate for loss of non-responses or incomplete data, invitations to participate in the survey were extended to 510 subjects, of which 480 completed questionnaires were included in the analysis (effective response rate: 94.1%).

2.3 Questionnaire Development, Structure, and Validation

The data were obtained via a structured 28-item self-administered digital questionnaire, adapted from previously validated tools that measured oral health literacy and erosive tooth wear (Schmidt & Huang, 2022; Manarte-Monteiro et al., 2025). Content and face validity were tested by the expert committee comprising three specialists in preventive and restorative dentistry and a biostatistician, who determined the importance, scientific accuracy, and linguistic accuracy of the items.

Before this whole scale was launched, a pilot study, in which 30 young people (not included in the final sample for analysis) participated, was performed to appraise the completion time, readability and psychometric properties of this scale. Internal consistency reliability was confirmed good to satisfactory by means of Cronbach's alpha coefficients for the 10 item knowledge scale and the preventive practices subscale respectively ($\alpha = 0.81$, $\alpha = 0.78$).

The validated questionnaire with 28 items was divided into four areas:

- Domain 1 – Sociodemographic and Baseline Oral Health Profile (Items 1-7): Domain 1 consisted of seven items assessing age, sex, academic or occupational discipline (health sciences versus non-health fields), regularity of dental appointments

(regular, i.e., within the previous 12 months, versus irregular or symptom-driven), history of chairside counsel regarding dental erosion from a dentist or dental professional, and self-perceived hypersensitivity to dental stimuli.

- Domain 2 - Energy Drink Consumption Behavior Domains (Items 8-15): contained 8 items related to if they are a consumer vs. a non-consumer, use frequency (daily [1 can/day], 3-6/week, 1-2/week, less than 1/week, never), main motive for consumption (school/work focus, sports/working out, social/nightlife, taste, other), use type (caffeinated or not (i.e., diet), regular/diet), and behaviors of concern (sip over 30 mins, intraoral swishing/holding prior to swallowing, use during or after sports/working out, and using within 30 mins of sleeping).

- Domain 3 - Dental erosion (Items 16-25): comprised of 10 objective (score 1 for correct answer and 0 for 'Don't Know' or incorrect answer) items of a 'True / False / Don't Know' format to avoid guessing bias. Items measured knowledge of the 'term' dental erosion, its difference from bacterial caries, relationship of low beverage pH and citric/phosphoric acid, impact of sugar free energy drinks, saliva's buffering and remineralisation activity, clinical signs of erosion (such as tooth sensitivity, yellowing of the teeth due to thinness of enamel, and incisal translucency and chipping), and the relationship of drinking acids and immediate tooth brushing to increased enamel erosion; after scoring of each item, a sum 0-10 Knowledge Score was derived from the sum of correct items, divided into Low (0-4), Moderate (5-7) and High (8-10) categories.

- Domain 4 – Preventive Oral Hygiene Practices (Items 26-28): These 3 sub items were measured on a Likert frequency scale (always/often = 2, sometimes = 1, rarely/never = 0; total score 0-8), which were designed to measure the implementation of evidence based protective practices by consumers, such as, consuming beverages by sipping through a straw that is kept away from anterior teeth, consuming plain water/milk immediately after consumption, leaving at least 30-60 minutes before brushing, and selecting fluoride/anti-erosive toothpaste.

2.4 Statistical analysis

Responses from all participants were coded, checked for completeness, and entered into the IBM SPSS Statistics for Windows, Version 28.0 (IBM Corp., Armonk, NY, USA) software program. Continuous variables, including age, knowledge scores, and preventive practice scores, were tested for normality assumptions using the Kolmogorov-Smirnov test and plotted in the Q-Q plot as well, and summarized with the means and standard deviation (Mean ± SD). Categorical variables are described in terms of absolute numbers (n) and relative frequencies (%)

Bivariate analysis was performed using Pearson's $\chi 2$ for dichotomous categorical variables and independent-samples t-tests for continuous scores. The relationship between erosion knowledge score and protective practice scores was examined by Pearson's linear correlation coefficient (r). A multivariable binary logistic regression model was developed, using the enter method, in order to identify the independent predictors of a binary outcome defined as 'high-risk erosive consumption behavior', in which the two combined criteria for high risk was fixed weekly energy drink consumption with at least one of three highly significant erosive modifiers: (a) slow sipping (>30 minute period); (b) peri-exercise, and; (c) consumption immediately before tooth brushing. These data were expressed as the adjusted odds ratio (aOR) with the 95% confidence interval (95% CI). Statistical significance was tested at the two-tailed alpha level of $p < 0.05$.

3. RESULTS

3.1 Sociodemographic profile and baseline oral health data

The survey was completed by 480 young adults, 254 female (52.9%) and 226 male (47.1%) with mean age of 21.8 ± 2.6 (Range 18–30), years. Two thirds of the sample population (66.3%; n = 318) fell within the age range of 18–22 years and 33.7% (n = 162) aged 23–30 years. Of the participants, 31.7% (n = 152) were studying in health-science areas while 68.3% (n = 328) were studying in non-health areas. In terms of baseline dental health practices, less than half of all participants (43.5%, n=209) reported routine attendance at preventive dental checkups at least annually. Only 24.4% (n=117) had received any advice regarding dental erosion by their dentist or dental hygienist. Self-reported tooth sensitivity was the most frequently reported dental condition among all participants (39.2%, n=188). Stratified analysis revealed that reported tooth sensitivity was almost twice as common among active consumers of EDs than among non-consumers (44.4% vs. 23.8%, χ 2 = 16.24, $p< 0.001$). A comparison of all socio-demographic and clinical variables (stratified by ED consumption status) are displayed in Table 1.

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Table 1. Sociodemographic and Baseline Oral Health Characteristics Stratified by Energy Drink Consumption Status (N = 480)

Variable	Total Sample (N = 480)	Consumers (n = 358)	Non-Consumers (n = 122)	χ^2 Value	p-Value
Male Sex	226 (47.1%)	187 (52.2%)	39 (32.0%)	14.82	<0.001*
Age 18–22 Years	318 (66.3%)	248 (69.3%)	70 (57.4%)	6.19	0.013*
Health Sciences Field	152 (31.7%)	98 (27.4%)	54 (44.3%)	11.45	0.001*
Regular Dental Checkups (≤12 mo)	209 (43.5%)	142 (39.7%)	67 (54.9%)	8.74	0.003*
Prior Erosion Counseling	117 (24.4%)	75 (20.9%)	42 (34.4%)	9.12	0.003*
Tooth Sensitivity Present	188 (39.2%)	159 (44.4%)	29 (23.8%)	16.24	<0.001*

**Statistically significant difference between consumers and non-consumers at a = 0.05 (Pearson's chi-square test).*

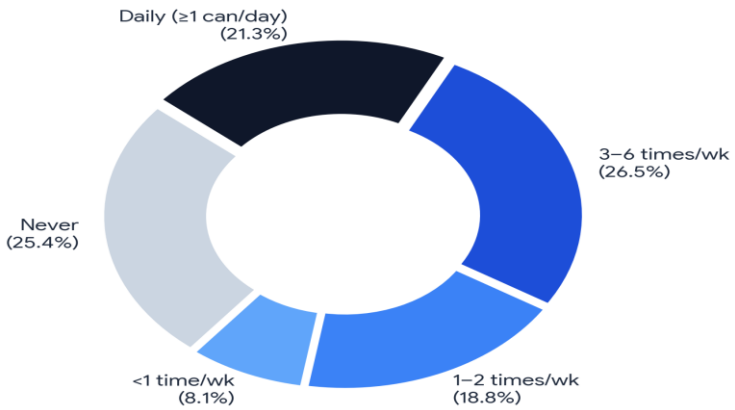
3.2 Energy Drink Consumption Frequency and Behavioral Patterns

Overall, three-quarters of the surveyed young adults (74.6%, n = 358) reported active consumption of commercial energy drinks, while 25.4% (n = 122) reported complete abstinence. As illustrated in Figure 1, 21.3% (n = 102) of all participants consumed energy drinks on a daily basis (≥1 can/day), 26.5% (n = 127) consumed them 3–6 times per week, 18.8% (n = 90) consumed them 1–2 times per week, and 8.1% (n = 39) consumed them less than once weekly. Motivations for Energy Drink Intake and Consumption Patterns

Among active consumers (n = 358) the leading reasons given for the use of energy drinks were for the feeling of mental alertness and focus when studying/ working (54.2% n=194), extra energy/endurance during sport/exercise in the gym (24.0% n=86), staying awake in clubs/parties during nights out (13.4% n=48), and due to taste (8.4% n=30). When choosing a product the majority of respondents chose the regular sugar-sweetened formulation (62.8% n=225) while the minority chose the sugar free or 'diet' formulation (37.2% n=133).

Behavioral analysis has shown that consumers displayed a significant drinking behavior that can significantly increase intraoral acidification (Figure 3). 61.5% (n = 220) consumed their energy drink by sipping it slowly while studying or working for more than 30 minutes. 44.8% (n= 160) of consumers had consumed their energy drink during or immediately following intense physical activity, 38.1% (n= 136) brushed their teeth immediately following the end of a drink and 22.9% (n= 82) swished or held in their mouth before swallowing.

Figure 1. Distribution of Energy Drink Consumption Frequency Among Young Adults (N = 480)



3.3 Knowledge Regarding Dental Erosion and Preventive Oral Hygiene Practices

In the whole sample, the average total Knowledge Score was 5.12 ± 2.38 (maximum 10), indicating on average a moderate-to-low level of knowledge about erosive tooth wear. The item-by-item analysis demonstrated a marked difference between knowledge of terminology versus mechanistic understanding of the phenomenon (Figure 2). Just under two-thirds (62.5%, n = 300) of participants responded correctly that erosion involves non-bacterial acid dissolution of enamel and dentine, in contrast to over four-fifths (81.9%, n = 393) who responded correctly that they had heard of the term dental erosion. In terms of mechanistic knowledge, about a third (34.2%, n = 164) of the subjects correctly identified non-bacterial acid dissolution as distinct from sugar metabolism of bacteria in producing caries, less than a third (28.5%, n = 137) knew that sugar-free energy drinks would be more likely to cause damage, and only just over a third (31.0%, n = 149) responded correctly to whether tooth brushing soon after the consumption of acidic drinks is likely to cause further damage to tooth enamel. Less than half (46.7%, n = 224) knew that saliva is able to neutralize and deposit minerals in enamel to prevent wear.

Figure 2. Assessment of Dental Erosion Knowledge Domains Across Participants

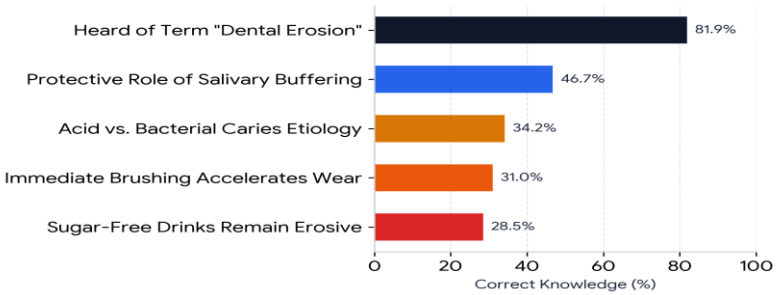
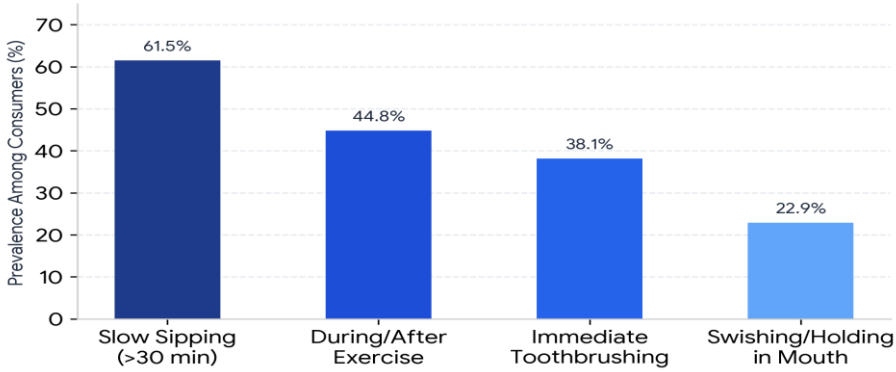


Figure 3. Prevalence of High-Risk Erosive Consumption Habits (n = 358)



Independent-samples t-test confirmed a highly significant educational gradient: health-science students achieved a mean Knowledge Score of 6.84 ± 2.11 compared to 4.32 ± 2.05 among non-health peers ($t = 12.41$, $p < 0.001$). Additionally, participants who had previously received erosion counseling from a dental professional scored significantly higher than those without prior counseling (7.15 ± 1.94 vs. 4.46 ± 2.18, $t = 11.88$, $p < 0.001$). Pearson's correlation demonstrated a significant positive association between Knowledge Scores and Preventive Practice Scores among consumers ($r = 0.48$, $p < 0.001$). Table 2 summarizes the distribution of specific preventive oral hygiene practices among active consumers.

Table 2. Adherence to Evidence-Based Preventive Oral Hygiene Practices Among Energy Drink Consumers (n = 358)

Preventive Oral Hygiene Practice	Always / Often n (%)	Sometimes n (%)	Rarely / Never n (%)	Clinical Risk Assessment
Using a straw to bypass anterior teeth	48 (13.4%)	89 (24.9%)	221 (61.7%)	Low Protective Adherence

Preventive Oral Hygiene Practice	Always / Often n (%)	Sometimes n (%)	Rarely / Never n (%)	Clinical Risk Assessment
Rinsing mouth with plain water immediately after intake	112 (31.3%)	134 (37.4%)	112 (31.3%)	Moderate Protective Adherence
Waiting ≥30–60 minutes before toothbrushing	109 (30.4%)	113 (31.6%)	136 (38.0%)*	High Abrasion Exposure
Chewing sugar-free xylitol gum to stimulate saliva	64 (17.9%)	102 (28.5%)	192 (53.6%)	Low Protective Adherence
Consuming drink alongside main meals rather than alone	81 (22.6%)	129 (36.0%)	148 (41.4%)	Elevated Acid Challenge

**Corresponds to the 38.1% (rounded across total consumer responses) who brushed immediately post-consumption.*

3.4 Multivariable Logistic Regression of High-Risk Consumption Predictors

A multivariable binary logistic regression analysis was performed to determine the independent predictors of high-risk erosive intake behavior, considering variables which may act as confounders (Table 3). The model was statistically significant (Omnibus $\chi 2 = 84.62$, df = 6, $p < 0.001$; Hosmer- Lemeshow goodness-of-fit $p = 0.642$) and explained 26.8% of the total variance (Nagelkerke R2 = 0.268).

Table 3. Multivariable Logistic Regression Model of Independent Predictors for High-Risk Erosive Consumption Behavior

Predictor Variable	Reference Category	Adjusted OR (aOR)	95% Confidence Interval (CI)	p-Value
Male Sex	Female Sex	1.92	1.28 – 2.88	0.002*
Age 18–22 Years	Age 23–30 Years	1.31	0.84 – 2.04	0.231
Non-Health Academic Field	Health Sciences Field	1.78	1.12 – 2.83	0.015*
Low Knowledge Score (0–4)	High Knowledge Score (8–10)	2.74	1.81 – 4.15	<0.001*
No Prior Dental Counseling	Received Prior Counseling	2.31	1.52 – 3.51	<0.001*
Irregular Dental Checkups	Regular Checkups (≤12 mo)	1.38	0.91 – 2.09	0.129

**Statistically significant independent predictor at a = 0.05. Model adjusted for all listed covariates.*

If the regression model is controlled for all covariates, then four parameters remain statistically significant in the model as independent explanatory variables of the consumptive behavior of high erosive risk:

- Those with the lowest tertile of knowledge (0-4 points) had almost three times the odds of performing erosive behaviors with high-risk erosion potential than the high tertile of knowledge (8-10 points) (aOR = 2.74, 95% CI: 1.81-4.15, $p < 0.001$).

- Lack of dental counseling: Participants who had not ever experienced chairside counseling for dental erosion by their dental professional had more than twice the odds of high risk behavior (aOR= 2.31, 95% CI: 1.52-3.51, $p < 0.001$).

- Male Sex: Male young adults were approximately twice as likely to be high risk consumers when compared to females (aOR = 1.92, 95% CI: 1.28-2.88, $p = 0.002$).

- Academic background: Compared to students and youth in health-science courses, those outside this field had significantly higher odds of engaging in risky consumptive behavior (aOR = 1.78, 95% CI: 1.12-2.83, $p=0.015$).

4. DISCUSSION

4.1 The Knowledge-Behavior Paradox and the Consumption Epidemiology

The results of the current study sample indicate that overall prevalence of commercial energy drinks (CED) consumption is high in young adults, with 74.6% reporting active weekly consumption, and 21.3% reporting daily consumption. These prevalence rates are comparable to those recently reported in European and international university samples by Martínez et al. (2024), Manarte- Monteiro et al. (2025), and Visram et al. (2016), all of whom reported high frequency consumption, associated with academic examination-related stress, sleep management and fitness culture.

Furthermore, the findings reveal a glaring 'knowledge-behaviour paradox' concerning oral health literacy. Superficial recognition of the term 'dental erosion' was high (81.9%), but the functional understanding of its underlying chemical pathophysiology was abysmally low (34.2% of participants distinguished between non-bacterial acid dissolution versus sugar-driven dental caries). When combined, the fundamentally conflated conceptual structures align with the notions espoused by Schmidt and Huang (2022) and O'Toole et al. (2018), providing reason behind why young adults rely on dental caries-preventative heuristics such as choosing sugar-free drinks or brushing immediately afterwards, which paradoxically does not prevent, but arguably accelerates acid-driven enamel dissolution.

4.2 The "Sugar-Free" fallacy and the physicochemical reality

What's particularly alarming is that more than 70% didn't know that sugarfree energy drinks have equally strong erosive potential, and a third of consumers even chose sugar-free energy drinks, likely under the false premise they were all-around safe for teeth. Physicochemical analyses by Martínez et al. (2024), Reddy et al. (2016), and Silva et al. (2021) indicate substituting sucrose with artificial sweeteners has no effect on initial pH (dangerously sour between 2.36 to 3.80) or treatable acidity.

Third, the use of citric acid in sugar-free energy drinks to mask taste differences of non-nutritive sweeteners. As discussed previously by Shellis et al. (2014), Silva et al. (2021), and Gálvez-Bravo et al. (2025) citrate anions continue to chelate salivary- and enamel-bound calcium ions as intraoral pH begins to recover, resulting in continued demineralization even if no carbohydrate consumption occurs. The 'sugar-free are safe for your teeth' myth also needs to be explicitly dispelled from a public health perspective, as proposed by Clapp et al. (2019).

4.3 Synergistic Behavioral Modifiers: Sipping, Exercise, and Immediate Brushing

Laboratory and clinical studies have repeatedly shown that the severity of erosive tooth wear is highly influenced by behavioral modifiers affecting acid exposure times and mechanical forces (Nijakowski et al., 2022; Chan et al., 2020). In the study participants' group, most consumers (61.5%) sipped their beverage, but at a slow rate for more than 30 min. In between the study sessions. This persistent sipping can continue to overwhelm the salivary bicarbonate buffers that would otherwise neutralize the intra-oral pH to above 5.5, the critical pH for enamel stability, leading to constant proton assault (Hara & Zero, 2014).

Furthermore, 44.8% ingested energy drinks during or immediately following exercise. As previously discussed in systematic reviews by Nijakowski et al. (2022) and Gálvez-Bravo et al. (2025) the effects of physical activity causing vasoconstriction of the salivary glands and dehydration were transient xerostomia and a compromised salivary buffer capacity. When a low-pH and high treatable acidity beverage is given in a dehydrated oral environment, there is maximized surface demineralization.

Perhaps the most counterproductive of the findings was the association of immediately brushing teeth after consumption (38.1%,), which has been known to prematurely erode enamel through disruption of the softened superficial 3-5 μm of the existing prism structure, endangering up to 30-50% micro hardness of the enamel surface (Silva et al., 2021). Prior brushing prior to salivary demineralization topples the softened layer thus exposed (Attin & Wegehaupt, 2014; Schmidt & Huang, 2022). Due to the synergistic nature of these factors, the clinical end point should be (and was) significantly increased dentin hypersensitivity among said cohort, 44.4% thereof in comparison to those not consuming energy drinks (23.8%, $p < 0.001$), heralding enamel surface reductions and open tubules (Donovan et al., 2021).

4.4 Sociodemographic Predictors and the Pivotal Role of Chairside Counseling

Multivariable logistic regression confirmed that being male was independently associated with double the odds of high-risk erosive consumption (aOR 1.92), consistent with previous work by Lind et al. (2025),Schlueter and Luka (2018) that young men consume more acidic sports and energy drinks and access fewer preventive dental services. For both knowledge and behavioral risk, non-health-science students reported more negative behaviors (aOR 1.78) and lower knowledge scores (mean of 6.75 out of 10) than healthstudents but still attained a barely average mean knowledge score, indicating that non-dental medical and nursing curriculums should strengthen the dental component.

However, routine dental attendance was not significantly associated with high-risk behaviors on its own in the adjusted model (aOR 1.38, $p=0.129$) with the lack of chairside counselling on dental erosion more than doubling high-risk behavior odds (aOR 2.31, $p<0.001$). When only 24.4% of those surveyed had ever received guidance on erosion from their dentist, there remains an enormous missed opportunity in the routine clinical setting (O'Toole et al., 2018; Manarte-Monteiro et al., 2025).

4.5 Recommendations for Clinical Practice and Public Health

In response to this silent epidemic of erosive tooth wear in young adults, a combined two-tier prevention strategy is suggested (Carvalho et al., 2015; Bartlett et al., 2019):

1. Standard BEWE testing: Dentists should perform Basic Erosive Wear Examination (BEWE) index as part of all the adolescents and young adult patients' routine check-ups so that loss of surface texture of enamel and cusps cupping can be identified prior to breakdown of dentin (Bartlett et al., 2019).

2. Individualized Risk Evaluation of the Diet: Dietary-specific questions about energy drinks, pre-workout supplements, and behaviors related to consumption should be added to routine health and dental history forms for the patient (Donovan et al., 2021).

3. The dental providers should provide simple, prioritized behavioral modifications instructions as detailed below:(a)no sipping slowly, (b) sipping quickly or drinking with meals, (c)use of a wide-bore straw, angled toward the palate to reduce contact of the labial enamel surface of the teeth, (d)allowing the consumption or drinking of acidic beverages, rinse with water, milk, or stannous-fluoride rinse immediately after consumption, and (e) delaying tooth brushing for at least 30-60 min, tooth brushing with low abrasively stannous fluoride or calcium-phosphate re-mineralizing dentifrice, as well as delaying tooth brushing for at least 30-60 min with the use of a soft-bristled toothbrush (Attin & Wegehaupt, 2014; Carvalho et al., 2015).

4. Campus-wide health literacy and labeling guidelines: Higher education institutions, campus gyms and community health resources should use campus-level targeted oral health literacy activities to clear up misconceptions about sugarfree acid drinks and post-acid fruit tooth brushing, as well as support higher readability pH and erosive risk labeling on energy drink commercial labels (Clapp et al, 2019; Inchingolo et al., 2023).

4.6 Strengths and Limitations

Strengths of the study are (a) sample size, (b) well-powered statistically (N=480; response rate= 94.1%) and (c) a psychometrically robustly developed assessment of mechanistic erosion literacy. Multivariable regression modelling provided for the assessment of potential independent behavioural predictors. Limitations include (a) cross-sectional design preventing causal inference of putative sequential progression from knowledge deficit to clinical tissue loss (b) survey data subject to recall and social desirability bias and (c) the lack of intra-oral clinical examination including BEWE scoring and salivary flow/buffering assessment which would permit an objective assessment of the correlation between self-reported symptoms

and actual physical erosion loss. The generation of longitudinal cohort studies utilizing validated literacy instruments, with digital clinical BEWE scoring and profilometric evaluation is desirable.

CONCLUSIONS

Commercial energy drink consumption is prevalent among young adults and has been linked to high-risk oral hygiene practices and behaviors that may hasten erosive tooth wear. Despite consensus on the concept of dental erosion, other erosive acid mechanisms not attributed to bacteria, the erosive nature of sugar-free energy drinks, and the inherent risks of immediate tooth brushing remain poorly understood. Given the independent deleterious effects of reduced oral health literacy, sex (male), non-health related education, and previous dental counseling on high-risk energy drink consumption behaviors, the authors should be encouraged to routinely incorporate BEWE screening and provide chairside counseling according to evidence-based protocols during young adult dental appointments. Campus-wide oral health literacy campaigns should be implemented to address this issue.

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