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Comparative Analysis of the Erosive Effects of Carbonated and Energy Drinks on Dental Enamel InVitro

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Abstract

Background: The global consumption of soft and energy drinks has increased markedly, especially among younger individuals. These beverages adversely affect general health and also contribute significantly to dental enamel erosion due to their high acidity.

Objective: This study aimed to evaluate and compare the surface-level erosive effects of Coca-Cola®, Pepsi®, Sting®, and Red Bull® on dental enamel using Scanning Electron Microscopy.

Materials and Methods: An in-vitro experimental study was conducted on forty extracted human third molars at Sardar Begum Dental College, Gandhara University, Peshawar. The samples were divided into four groups (n=10), each immersed in one of four beverages: Coca-Cola®, Pepsi®, Sting®, and Red Bull®. The pH of each drink was measured using a pH meter. Scanning electron microscopy (SEM) images were obtained before and after immersion to observe surface enamel changes. Data were analyzed using SPSS (Version 23) with Tests of Normality and Fisher's Exact Test to evaluate erosive effects.

Results: All the teeth showed normal appearing enamel before immersion in their respective drinks. After 10 minutes immersion, SEM images revealed varying degrees of enamel etching with a statistically significant change in the appearance of enamel ($p = 0.004$). Coca Cola® and Pepsi groups caused more pronounced and deeper etching patterns compared to Energy drinks.

Conclusion: Short-term exposure to acidic beverages produces significant microscopic alterations in enamel surface morphology, with Coca Cola® and Pepsi® causing the most pronounced etching patterns. These findings emphasize the role of acidic beverages in enamel erosion and the importance of preventive strategies for dental health.

Keywords: Tooth enamel, Erosion, Carbonated drinks, Energy/Sports drinks, Acidic pH

Introduction

Dental erosion is a widespread phenomenon that has received increasing attention in recent years.[1-3] Dental erosion is defined as the irreversible, pathological loss of enamel and dentin caused by chemical dissolution from non-bacterial acids of either extrinsic or intrinsic origin.[4-6] This phenomenon has become a global concern due to changes in dietary habits, including the increasing consumption of acidic beverages such as fizzy and energy drinks.[7,8]

Studies indicate that the prevalence of erosive tooth wear is increasing among children and young adults.[9, 10] The global consumption of energy drinks has risen sharply, surpassing 5.8 billion litres across 160 countries in 2013. Their popularity, particularly among children and adolescents is driven by their caffeine and sugar-based stimulant effects combined with a sweet, appealing taste.[11] Moreover, exercise induced dehydration reduces salivary flow, and the consumption of fizzy or sports drinks to meet energy demands during this time, creates an ideal environment for dental erosion.[12, 13] These beverages, frequently consumed both post exercise and recreationally, further exacerbate enamel demineralization among the youth.[14] Thus, it is needed to quantify and compare the effects of those fizzy/sports drinks on dental enamel erosion.

The structural integrity of enamel is crucial for maintaining oral health. Once eroded, enamel cannot regenerate, leaving teeth vulnerable to further damage.[15] Enamel loss results in increased tooth sensitivity, heightened susceptibility to caries, and aesthetic concerns such as discoloration and surface roughness.[16,17] Over time, severe erosion can lead to exposure of the underlying dentin, impairing oral function and causing significant discomfort.[18]

Early detection of enamel erosion is essential for timely intervention. Scanning electron microscopy (SEM), a powerful imaging technique, offers detailed visualization of enamel surface, enabling researchers to detect surface changes at the microscopic level. SEM is particularly effective in studying the etching patterns caused by acidic beverages, providing valuable insights into their erosive potential.[19,20]

This study aimed to compare the erosive potential of carbonated and energy drinks, assessed the severity of enamel damage due to carbonated and energy drinks using SEM imaging and scoring, and investigated the influence of beverage acidity on enamel erosion.

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Materials and Methods

An in-vitro laboratory-based experimental study was conducted at Sardar Begum Dental College, Gandhara University, Peshawar, KP, and the Department of Industrial Engineering, University of Engineering and Technology (UET), Peshawar. Ethical approval for the study was obtained from the Ethical Review Committee of Sardar Begum Dental College prior to commencement of the experiment. A total of 40 caries-free human third molars were collected and used for the study. Soft tissue remnants attached to the extracted teeth were carefully removed. The teeth were sterilized and stored in formalin solution until further use.

Before the experimental procedure, all teeth were rinsed with tap water, cleaned using a brush, and air-dried. Each tooth was then mounted in acrylic resin blocks to facilitate handling during the experimental procedures.

Four beverages were selected based on their high consumption rates and differing acidic compositions. The beverages included two carbonated soft drinks (Coca Cola® and Pepsi®) and two energy drinks (Sting® and Red Bull®).

The pH of each beverage was measured at the beginning of the experiment using a Sartorius pH meter (Figure S1). Each measurement was performed three times, and the mean pH value along with the standard deviation was calculated for each beverage.

Figure S1: Sartorius pH meter 21

Experimental Grouping

The teeth were randomly allocated into four groups (n = 10 per group) according to the beverage used for immersion:

Group A: Coca-Cola®
Group B: Pepsi®
Group C: Sting®
Group D: Red Bull®

Immersion Procedure

Each group of teeth was immersed in its designated beverage for 10 minutes, simulating short-term exposure during beverage consumption. After immersion, the teeth were rinsed with distilled water to remove any residual beverage and subsequently air-dried.

Scanning Electron Microscopy (SEM) Analysis

Surface morphological changes of enamel were evaluated using Scanning Electron Microscopy (SEM) (Oxford Instruments). High-resolution images were captured before and after beverage immersion.

Enamel surface morphology was examined at 1000× magnification to identify etching patterns and surface damage.

Enamel Surface Scoring

SEM images were analyzed using a scoring system modified from Seow and Thong[22] to assess enamel surface changes:

Score 0: Normal enamel with no visible changes
Score 1: Mildly etched enamel with minimal frostiness
Score 2: Moderately etched enamel with distinct frostiness
Score 3: Deeply etched enamel with severe frostiness

Statistical Analysis

Data were analyzed using Statistical Package for Social Sciences (SPSS), Version 23. Fisher's Exact Test was applied to determine differences in enamel surface changes among the study groups. A p-value < 0.05 was considered statistically significant.

Results

Among the tested beverages, Coca Cola® exhibited the lowest pH as measured by pH meter readings as sown in Table 1. Total sample size of the study was 40 teeth, which were divided into 4 groups of 10 teeth each. Tests of normality were applied on the appearance of enamel after 10 minutes immersion in respective drinks, which shows a p value (Kolmogorov-Smirnov test) of 0.001 for mildly etched enamel surface with minimal frostiness, exhibiting normal distribution. Enamel Surface Scoring Before Immersion in their respective drinks is shown in Table 3. Enamel Surface Scoring after Immersion in their respective drinks (p-value = 0.004) is demonstrated in Table 4. Scanning electron micrographs displayed distinct morphologies alterations of the enamel surfaces of teeth for Coca Cola®, Pepsi® groups, as compared to the Red bull® and Sting® groups and non-treated enamel surfaces as shown in Figure 2a, b, c, d & e.

Table S1: pH of Various Beverages Used in the Study

S. No.	Beverage Name	pH ± SD, n=3
1	Coca Cola®	2.37 ± 0.01
2	Pepsi®	2.39± 0.01
3	Sting®	3.41± 0.01
4	Red Bull®	3.81 ± 0.01

Table S2: Enamel Surface Scoring of Teeth in Each Group Before Immersion

Score	0	1	2	3
Groups	No. of Teeth with Normal Appearing Enamel	No. of Teeth with Mildly Etched Enamel	No. of Teeth with Moderately Etched Enamel	No. of Teeth with Deeply Etched Enamel
Coca-Cola®	10	0	0	0
Pepsi®	10	0	0	0
Sting®	10	0	0	0
Red Bull®	10	0	0	0

Table S3: Enamel Surface Scoring of Teeth in Each Group After Immersion

Score	0	1	2	3
Groups	No. of Teeth with Normal Appearing Enamel	No. of Teeth with Mildly Etched Enamel	No. of Teeth with Moderately Etched Enamel	No. of Teeth with Deeply Etched Enamel
Coca-Cola®	0	4	6	0
Pepsi®	0	5	5	0
Sting®	0	9	1	0
Red Bull®	0	10	0	0

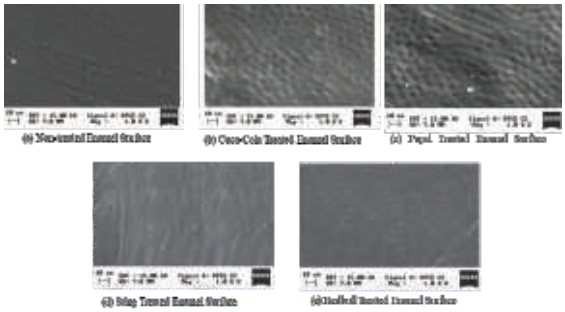

Figure S2: Enamel Surface Scoring of Teeth in Each Group After Immersion

Discussion

This study was conducted to evaluate the changes in enamel surface morphology following 10-minute immersion in four commonly consumed beverages, using Scanning Electron Microscopy (SEM) for characterization. Forty extracted teeth were divided into four groups (n=10 each) and analyzed microscopically before and after exposure to their respective beverages. All the teeth in the 4 groups had normal appearing enamel before immersion in their respective drinks. However, post-immersion analysis revealed statistically significant surface alterations ($p = 0.004$). In the Coca Cola® group, most specimens exhibited moderate etching with distinct surface frostiness, while in the Pepsi® group, equal numbers of teeth showed mild and moderate etching. The Sting® group displayed predominantly mild etching with minimal frostiness, whereas all samples in the Red Bull® group demonstrated only mild surface changes. Among the tested beverages, Coca Cola® exhibited the lowest pH as determined by pH meter readings and caused the greatest enamel erosion, demonstrating a direct relationship between beverage acidity and the extent of enamel demineralization.

The results of this study are in accordance with previous literature. A study performed by Shah, A., et al [23] demonstrated that the erosive and demineralization potential of Coca-Cola® was highest among the tested beverages i.e. wine and green tea. The low pH and high acidic content of Coca Cola® were major contributing factors to this pronounced demineralization. These findings showed the strong association between beverage acidity and enamel erosion, emphasizing the need for preventive measures and public awareness regarding the frequent consumption of highly acidic soft drinks like Coca-Cola®. Similarly, Jameel et al. [20] confirmed that acidic, low-fluoride beverages such as Pepsi® and Coca Cola® caused substantial enamel erosion, with evident surface morphological alterations, while beverages containing fluoride or neutral pH (e.g., tea and mineral water) resulted in minimal demineralization of surface enamel.

Barac et al. [24] and Jensdottir et al. [25] also demonstrated that cola drinks possess greater immediate erosive potential compared to fruit juices such as orange juice. Another study conducted by Razak FA et al. [26], reported that sports drinks exhibited lower erosive potential due to the presence of calcium ions, which act as buffers against acidity. Seow and Thong [22], showed that the most acidic drinks such as Coca Cola® and Pepsi® had statistically significant erosive effects on the tooth enamel surface. But all the erosive effects were reversed when the teeth were exposed to saliva. However large quantities of saliva are required to completely reverse the effects of erosion on tooth enamel surface. Recently, Kumar, N., et al. [19] further demonstrated that exposure to acidic beverages caused identifiable enamel surface erosion of varying severity under SEM analysis, although the reductions in calcium and phosphorus content were not statistically significant. These findings suggest that beverage acidity primarily affects surface morphology rather than causing substantial elemental loss in enamel composition.

Collectively, these findings reinforce that the erosive potential of beverages is strongly influenced by their acidity, composition, and exposure duration. Frequent consumption of highly acidic soft drinks, particularly colas, poses a significant risk to enamel integrity and underscores the importance of preventive strategies and public education on dietary habits affecting dental health.

Conclusion

This study demonstrated the erosive effects of acidic beverages on dental enamel, with cola-based drinks causing the most severe etching and surface degradation. SEM analysis confirmed significant morphological changes and emphasized the role of beverage acidity and composition in enamel erosion. Preventive measures and public health campaigns are essential to reduce their consumption and protect dental health.

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1. Samar Kamran: Conception, Study Design, Fundings, Materials, Data Collection, Data Analysis, literature Review, Manuscript Writing, Critical Review.
2. Shafqat Ali Shah: Study Design, Supervision, Data Analysis, literature Review, Manuscript Writing, Critical Review.
3. Murad Ali Shah: Study Design, Supervision, Data Analysis, literature Review, Manuscript Writing, Critical Review.