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THE IMPACT OF SUGAR-SWEETENED AND SUGAR-FREE CARBONATED BEVERAGES ON DENTAL ENAMEL EROSION - LITERATURE REVIEW

Michalina Pastuszka *(Corresponding Author, Email: michalina.pastuszka10@wp.pl)*
Medical University of Lublin, Lublin, Poland
ORCID ID: 0009-0006-6531-5021

Kamil Nieroda
Medical University of Lublin, Lublin, Poland
ORCID ID: 0009-0004-0923-2630

Szymon Malec
Medical University of Lublin, Lublin, Poland
ORCID ID: 0009-0000-4344-5286

Hanna Praczyk
Medical University of Lublin, Lublin, Poland
ORCID ID: 0009-0004-2588-2035

Weronika Partyka
Medical University of Lublin, Lublin, Poland
ORCID ID: 0009-0004-2129-4199

Dominika Brożyna
Jan Kochanowski University, Kielce, Świętokrzyskie, Poland
ORCID ID: 0009-0002-1542-6904

Bartłomiej Andrzej Sałapski
Jan Kochanowski University, Kielce, Świętokrzyskie, Poland
ORCID ID: 0009-0008-8366-1272

Mateusz Wnęk
Wojewódzki Szpital Specjalistyczny im. św. Rafała w Czerwonej Górze, ul. Czerwona Góra 10, 26-060 Chęciny, Poland
ORCID ID: 0009-0008-1087-973X

Natalia Julia Szafraniec
Szpital Kielecki Św. Aleksandra, Kielce, Poland
ORCID ID: 0009-0001-7544-4007

Katarzyna Anna Sobczyk
Szpital Kielecki Św. Aleksandra, Kielce, Poland
ORCID ID: 0009-0000-8740-5016

ABSTRACT

Introduction and Aim: Dental erosion is defined as a non-carious loss of mineralized tooth structure caused by acids that do not originate from bacterial activity. Acidic carbonated beverages, including both sugar-sweetened and sugar-free products, represent important extrinsic factors that may contribute to enamel demineralization, surface softening, and erosive tooth wear. Although sugar-free drinks are commonly regarded as healthier alternatives to conventional soft drinks, their acidic composition may still have a harmful effect on dental tissues. The aim of this review is to compare the impact of sugar-sweetened carbonated beverages and their sugar-free equivalents on dental enamel and general health.
Materials and Methods: A narrative review of the literature was performed using advanced searches in the PubMed and Google Scholar databases. English-language articles published within the last twenty years were included. The analyzed literature comprised clinical and observational studies, systematic reviews, and meta-analyses.
Conclusions: Although non-caloric sweeteners may reduce sugar intake and lower the risk of dental caries associated with fermentable carbohydrates, beverages containing these sweeteners may still promote dental enamel erosion due to their acidic composition. Therefore, replacing sucrose with artificial or natural low-calorie sweeteners does not fully eliminate the potential adverse effects of soft drinks on dental hard tissues.

KEYWORDS

Erosion, Beverage, Drinks, Tooth Erosion, Cola Zero

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Introduction

Dental erosion, also known as erosive tooth wear, is a type of non-carious tooth surface loss resulting from the chemical dissolution of mineralized dental tissues. Unlike dental caries, which develops as a consequence of acids produced by bacterial fermentation of dietary carbohydrates, dental erosion is caused by acids of non-bacterial origin. These acids may be divided into intrinsic and extrinsic sources. Intrinsic acids are primarily related to gastric acid exposure, for example in individuals with gastroesophageal reflux disease, recurrent vomiting, or eating disorders. Extrinsic acids are mainly associated with environmental and dietary factors, especially frequent intake of acidic foods and beverages. This distinction is clinically relevant because erosion and caries differ in their etiology, mechanism of development, and pattern of tissue destruction. While caries is a biofilm-dependent process, erosion is primarily a chemical phenomenon and may occur even without bacterial involvement.[1] The development of dental erosion is multifactorial and depends on the interaction of several chemical, biological, and behavioral factors. Although low pH is one of the key factors initiating enamel and dentin dissolution, pH alone is not sufficient to determine the erosive potential of a given substance. Other physicochemical properties, including titratable acidity, buffering capacity, mineral saturation, and the presence of calcium, phosphate, and fluoride ions, may substantially influence the extent of mineral loss.[5] Individual susceptibility is also modified by salivary flow rate, salivary buffering capacity, tooth structure, dietary patterns, frequency and duration of acid exposure, and oral hygiene habits. Therefore, dental erosion should not be interpreted as the result of a single causative factor, but rather as a consequence of complex interactions between chemical, biological, and behavioral determinants.[2] Enamel is the most highly mineralized tissue in the human body and provides protection for the underlying dentin and pulp. It consists mainly of inorganic material, especially hydroxyapatite crystals, which are responsible for its hardness, mechanical resistance, and relative tolerance to acidic challenges. However, this protective capacity is limited. When the oral environment becomes sufficiently acidic, enamel minerals may dissolve, leading to surface softening and gradual loss of dental tissue. The critical pH for enamel dissolution is generally estimated to be approximately 4.5–5.5, although the real erosive effect depends on the complete chemical composition of the substance. In recent years, dental erosion has become an increasingly important clinical problem, particularly

among children and adolescents. This trend may be related to lifestyle changes and dietary habits, especially the growing consumption of acidic, industrially processed beverages. Carbonated soft drinks are considered an important extrinsic factor in the development of erosive tooth wear. Exposure to these beverages may cause quantitative changes in enamel mineral composition, including calcium and phosphorus loss, as well as qualitative alterations in surface morphology, such as increased roughness and dissolution of highly mineralized areas. As a result, frequent consumption of acidic carbonated beverages may weaken enamel integrity and contribute to progressive erosive tooth wear.[3] Commercial low-calorie and non-caloric sweeteners have become increasingly popular as sucrose substitutes in food and beverage products. Their widespread use is associated with efforts to reduce sugar intake, obesity, and dental caries. Sweeteners such as aspartame, stevia, and erythritol are now commonly used in commercial soft drinks. Aspartame is approximately 200 times sweeter than sucrose, which allows its use in very small amounts with minimal caloric contribution. Stevia, obtained from Stevia rebaudiana, is a natural sweetener approximately 200–300 times sweeter than sucrose and does not support bacterial acid production because it does not contain fermentable carbohydrates.[4] Erosive tooth wear affects approximately 30% of the global population, with adolescents and males considered groups at higher risk. This increased susceptibility is strongly associated with lifestyle factors, particularly frequent consumption of acidic beverages. Fruit juices, carbonated soft drinks, and energy drinks are among the main dietary contributors to erosive tooth wear. Adolescents are especially vulnerable, as they are frequent consumers of energy drinks due to their perceived stimulating effects. Moreover, carbonated beverages contain acids such as carbonic, citric, phosphoric, and tartaric acids, which are important contributors to enamel erosion.[6]

The aim of this study is to compare the effects of sugar-sweetened carbonated beverages and sugar-free alternatives on human health. The analysis is based on scientific literature indexed in PubMed, with particular emphasis on metabolic, physiological, and oral health consequences related to the consumption of these beverages. Although sugar-free soft drinks are often considered healthier than sugar-containing beverages, current evidence suggests that both types may have adverse effects not only on dental tissues but also on general physiological function. Through a critical review of available literature, this paper aims to provide a comprehensive assessment of the health implications associated with regular consumption of carbonated soft drinks, regardless of sugar content.

Results

Carbonated soft drinks are linked to several negative oral health outcomes, particularly dental caries and enamel erosion. Sugar-containing beverages may promote caries development due to frequent sugar exposure and inadequate oral hygiene. However, sugar-free and low-calorie drinks should not be regarded as harmless to dental hard tissues. Despite lacking fermentable sugars, many of these beverages exhibit erosive properties similar to conventional sugar-containing soft drinks. This indicates that the erosive potential of a beverage is determined not only by sugar content, but mainly by its acidic composition and physicochemical characteristics. Research on carbonated beverages, particularly cola-based drinks, has shown that both regular and sugar-free variants may have pH values below the critical threshold for enamel dissolution. Coca-Cola Original, Coke Zero, Diet Coke, and Coca-Cola Light have all been reported to possess acidic pH levels capable of contributing to enamel demineralization. Nevertheless, the literature does not provide consistent conclusions regarding whether regular or sugar-free cola produces greater enamel damage. Some studies report more pronounced enamel changes after exposure to regular Coca-Cola, whereas others indicate greater enamel loss after exposure to diet or light cola formulations. These differences may result from variations in beverage composition, exposure protocols, enamel type, and methods used to assess erosion. The erosive action of cola beverages is mainly associated with the presence of acids, especially phosphoric acid and carbonic acid. Phosphoric acid is particularly important because of its strong acidic nature and ability to release multiple protons, which may intensify enamel surface dissolution. Carbonic acid is weaker and less stable, decomposing into carbon dioxide and water after exposure to air, which may explain minor pH changes after opening the beverage container.[10] Available evidence also shows that the erosive potential of acidic beverages and food products varies considerably depending on chemical composition. In one study, Gatorade produced greater enamel lesion depths than Red Bull and Coca-Cola, while all three beverages were more erosive than Diet Coke and apple juice. On root surfaces, the greatest lesion depths were also observed after exposure to Gatorade, followed by Red Bull, Coca-Cola, apple juice, and Diet Coke. These findings suggest that different dental tissues may respond differently to acidic exposure, with root surfaces often being more susceptible to

erosive damage than enamel.[12] The analyzed findings also indicate that acidic sweets may, in certain cases, cause greater erosive enamel wear than carbonated soft drinks. This may be associated with the presence of various organic acids, such as citric, lactic, and maleic acids, as well as the viscous consistency of sweets, which allows them to adhere to tooth surfaces and prolong acid exposure. Therefore, assessment of erosive risk should include not only beverages but also acidic food products, their composition, and the duration of their contact with dental tissues. Dental enamel is highly vulnerable to structural changes after contact with acidic beverages, which may result in surface softening and early demineralization. In one of the reviewed studies, optical profilometry and FTIR spectroscopy were used to assess enamel surface and chemical changes after exposure to erosive drinks. All tested beverages caused a statistically significant increase in enamel surface roughness, indicating an early stage of erosive tooth wear. These findings are consistent with previous studies showing increased enamel roughness after exposure to carbonated and energy drinks. In contrast to studies involving prolonged exposure, this investigation assessed only a single 5-minute contact period, reflecting the initial phase of erosion rather than advanced irreversible tissue loss. The erosive potential of beverages was shown to depend not only on pH, but also on titratable acidity, buffering capacity, and acid composition. Although Coca-Cola® had the lowest pH, energy drinks such as Red Bull® and Sugar-Free Red Bull® produced more pronounced chemical changes in enamel structure, suggesting greater mineral dissolution. Importantly, the study confirmed that sugar-free beverages are not neutral toward dental tissues. Sugar-Free Red Bull® caused substantial chemical and structural enamel changes despite the absence of sugar, emphasizing the dominant role of acidity in the erosion process.[6] The study by Khamverdi et al. (2013) compared the erosive effects of regular Coca-Cola and Diet Coca-Cola on dental enamel. The results showed that Diet Coke caused a greater decrease in enamel microhardness (266.8 HV) than regular Coca-Cola (304.2 HV). These findings suggest that some sugar-free carbonated beverages may demonstrate even higher erosive potential than sugar-sweetened beverages, most likely due to their acidic composition rather than sugar content alone.[7] In the study conducted by Brent L. Gravelle, sugar-free beverages were also found to have greater erosive potential than sugar-sweetened drinks.[8] Rios et al. (2018) assessed enamel loss after exposure to regular cola and light cola beverages. The study demonstrated measurable enamel erosion in both groups, with regular cola causing 6.69 μm of enamel loss and light cola causing 4.80 μm. The authors concluded that the low pH of soft drinks plays an important role in enamel demineralization regardless of sugar content, although sugar-sweetened beverages showed slightly greater erosive effects.[9] In another study, light cola caused significantly lower enamel wear than regular cola. Although both beverages reduced enamel microhardness, the regular cola drink showed a stronger erosive effect. These findings suggest that sugar-free cola beverages may be less harmful to enamel than sugar-sweetened soft drinks in some cases; however, they still retain the ability to contribute to enamel erosion due to their acidic composition.[11] The observations reported by Kitchens and Owens are consistent with the findings obtained by Daniel Rios.[13]

Table 1 presents a summarized overview of the effect of sugared and sugar-free soft drinks on dental enamel erosion. It highlights the beverages tested, the main findings, and the conclusions of the studies included in this review.

Table 1. Effect of Sugared and Sugar-Free Soft Drinks on Dental Enamel Erosion

Study	Beverages	Main Findings	Conclusion
Khamverdi et al., 2013	Coca-Cola vs Diet Coca-Cola	Diet Coke: 266.8 HV Regular Coke: 304.2 HV	Diet Coke showed greater erosive potential.
Rios et al., 2018	Regular cola vs Light cola	Regular cola: 6.69 μm enamel loss Light cola: 4.80 μm	Low pH increased enamel erosion.
Korte et al., 2019	Classic Coke, Diet Coke, Zevia Cola	All beverages caused enamel surface alterations.	Sugar-free beverages retain erosive potential.
AlHelal et al., 2025	Coca-Cola, Coke Light, Red Bull, Sugar-Free Red Bull	All beverages increased enamel roughness after 5 min exposure.	Sugar-free drinks may induce early-stage enamel erosion.
Annupiya et al., 2016	Regular vs Diet soft drinks	All beverages reduced plaque pH below 5.5.	Regular and diet drinks showed similar erosive risk.
Kitchens & Owens, 2007	Coca-Cola Classic vs Diet Coke	Both drinks increased enamel surface roughness.	Both beverages contributed to enamel erosion.

In addition to carbonated beverages, acidic sweets have also been identified as potential contributors to dental enamel erosion. Because they contain organic acids, especially citric acid, these products may promote enamel demineralization. One study assessed the erosive potential of selected acidic sweets and compared their effects with Coca-Cola® and citric acid solutions. The study showed that all tested acidic sweets caused enamel erosion, although the degree of damage varied between products. The highest erosive potential was observed for Fini® Diet and Fini® Regaliz Acid Tubes, whose effects were comparable to 0.1% citric acid and greater than those of Coca-Cola®. In contrast, Fini® Kisses and Fini® Bubblegum Fruit Salad produced lower enamel wear, similar to that observed after exposure to Coca-Cola®. The study also found that sweets containing citric acid combined with other acids, such as lactic or maleic acid, caused greater enamel erosion than products containing only one type of acid. The authors emphasized that acidic sweets may be more damaging than carbonated beverages because of their sticky consistency, which prolongs contact with the tooth surface and increases enamel exposure to acids. Importantly, the study confirmed that "diet" or sugar-free products are not necessarily safe for enamel. Despite the lack of sugar, they may still cause significant enamel erosion because of their high acidity.[12]

Discussion

The findings of this review suggest that both sugar-sweetened and sugar-free carbonated beverages may contribute to dental erosion. Although sugar-free drinks reduce exposure to fermentable carbohydrates and may therefore lower the risk of dental caries, they should not be considered completely safe for enamel. Their erosive potential is mainly associated with low pH, titratable acidity, buffering capacity, and the presence of acids such as phosphoric, citric, and carbonic acid, rather than sugar content alone.[1][5][6] This distinction is important because dental caries and dental erosion are caused by different mechanisms. Caries develops as a result of bacterial metabolism of sugars, while erosion occurs through direct chemical dissolution of dental tissues by acids of non-bacterial origin.[1] Consequently, replacing sugar with artificial or natural sweeteners may reduce cariogenic potential, but it does not remove the risk of enamel demineralization. The reviewed studies demonstrate that both regular and sugar-free cola beverages can cause enamel surface alterations, including reduced microhardness, increased surface roughness, and mineral loss. However, the results are not entirely consistent. Some studies found greater enamel damage after exposure to regular Coca-Cola, whereas others reported stronger erosive effects for diet or sugar-free variants.[7][8][9][11] These discrepancies may be related to differences in beverage formulation, exposure time, enamel sample characteristics, and research methodology. It is also important that erosive changes may appear even after short contact with acidic beverages. Studies using optical profilometry and FTIR spectroscopy detected measurable enamel alterations after brief exposure, indicating that repeated intake may gradually contribute to erosive tooth wear.[6] Furthermore, energy drinks, sports drinks, and acidic sweets may also demonstrate high erosive potential. Acidic sweets may be particularly harmful because their sticky structure extends their contact time with dental surfaces.[12] From a clinical point of view, patients should be informed that "sugar-free" does not necessarily mean "safe for teeth." Preventive advice should include reducing the frequency of acidic beverage intake, avoiding prolonged sipping, drinking water after acid exposure, and avoiding toothbrushing immediately after consuming acidic products. Further studies, especially in vivo and in situ investigations, are needed to compare the erosive potential of different beverages under conditions that more closely reflect the oral environment. Overall, the available evidence indicates that both sugar-sweetened and sugar-free carbonated beverages may adversely affect enamel when consumed frequently. The main factor responsible for this effect is acidity, not only the presence or absence of sugar.

Conclusions

Based on the analyzed studies, both sugar-sweetened and sugar-free carbonated beverages show significant erosive potential toward dental enamel. The reviewed literature indicates that the erosive effect of soft drinks is primarily related to their acidic composition and low pH rather than sugar content alone. Frequent exposure to acidic beverages may result in enamel demineralization, increased surface roughness, reduced enamel microhardness, and progressive dental erosion. Several studies, including those by Khamverdi et al. and Brent L. Gravelle, showed that certain sugar-free beverages may have erosive effects comparable to or even greater than sugar-sweetened beverages. This suggests that replacing sugar with artificial sweeteners does not eliminate the harmful influence of soft drinks on dental tissues. Acids such as phosphoric and citric acid appear to play a key role in the erosion process. In contrast, the study conducted by Daniel Rios indicated that

light cola beverages caused less enamel wear than regular cola drinks. Nevertheless, despite their lower erosive effect, sugar-free beverages still contributed to enamel softening and demineralization. Similar findings were reported by Kitchens and Owens, who confirmed that both regular and diet soft drinks negatively affected enamel surface integrity. Moreover, the reviewed evidence suggests that the adverse effects of carbonated beverages are not limited to oral health. Regular consumption of both sugar-containing and sugar-free soft drinks has also been associated with negative systemic effects, including metabolic disturbances, obesity, diabetes risk, and changes in gastrointestinal and overall physiological function. In conclusion, both sugar-sweetened and sugar-free carbonated beverages should be considered potentially harmful to dental enamel and general health when consumed frequently and over long periods of time.

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