The Abrasive Effect of a Porcelain and a Nickel–Chromium Alloy on the Wear of Human Enamel and the Influence of a Carbonated Beverage on the Rate of Wear

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Abstract

Purpose: This study was conducted to determine the abrasive effect of a porcelain and an Ni–Cr alloy on the wear of human enamel, and the influence of a carbonated beverage on the rate of wear.
Materials and Methods: Tooth specimens were prepared by embedding 48 freshly extracted mandibular first premolars in acrylic. Twenty-four of these specimens were abraded against Ni–Cr, and the remaining 24 against porcelain in artificial saliva and carbonated beverage media, respectively ($n = 12$), on a specially designed abrasive testing machine at a constant load of 40 N with 6 mm amplitude for 15,000 cycles. The cusp heights of the tooth specimens were measured both before and after abrasion using a profile projector. The abraded cast specimens were subjected to profilometry for computing the surface roughness; the abrading media was subjected to atomic absorption spectrophotometry for analyzing Ni and Cr ion levels. Data obtained were statistically analyzed.
Results: Porcelain specimens in a medium of carbonated beverage caused the highest wear of tooth specimens. The lowest wear of tooth specimens was Ni–Cr specimens in artificial saliva medium. Carbonated beverage caused significantly higher wear of tooth specimens when abraded against Ni–Cr and porcelain specimens than did artificial saliva. The mean quantitative surface roughness of porcelain specimens was significantly higher than that of Ni–Cr specimens, irrespective of the medium in which abrasion testing was conducted. There was no statistically significant difference between the concentrations of Ni ions released in artificial saliva and carbonated beverage media. Also, there was no statistically significant difference between the concentrations of Cr ions released in artificial saliva and carbonated beverage media.
Conclusions: The wear of human enamel was significantly higher in the presence of carbonated beverage than artificial saliva and against porcelain when compared with Ni–Cr. The surface roughness of porcelain in the presence of carbonated beverage was found to be highest, and the release of Ni and Cr was not affected by carbonated beverage.

Wear is the progressive loss of substance from the surface of a body brought about by mechanical action like rubbing, impact, scraping, and erosion.[1] Dental erosion is defined as irreversible loss of dental hard tissue by a chemical process that does not involve bacteria. Dissolution of mineralized tooth structure occurs upon contact with acids introduced into the oral cavity from intrinsic or extrinsic sources. This form of tooth surface loss is part of a larger picture of tooth wear, which also consists of attrition and abrasion. Causes of dental erosion may be extrinsic or intrinsic. Extrinsic causes may include contact with acidic media either by way of foodstuff or by iatrogenic exposure. Examples of extrinsic acids are acidic beverages, foods, medications, or environmental acids. The most common of these are dietary acids in the form of fruits, fruit juices, carbonated beverages, and sports drinks. The suspected erosive potential of beverages does not depend on pH alone. Other components of

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beverages such as calcium, phosphates, and fluoride may affect erosive potential. Also, factors such as frequency and method of intake of acidic beverages and tooth brushing frequency after intake may influence susceptibility to erosion.[2-6]

Intrinsic causes include gastric acid regurgitated into the esophagus and the mouth. Causes include gastroesophageal reflux disease and chronic excessive vomiting seen in patients with eating disorders such as anorexia nervosa or bulimia, peptic ulcers, pregnancy, drug side effects, diabetes, and nervous system disorders.[7,8]

The rate of wear may be affected (accelerated) by the introduction of a prosthesis with wear properties differing from those of the natural teeth. The sequelae include unacceptable damage to the occluding surfaces, alteration of the functional path of masticatory movement, supraeruption of occluding teeth, exposure of prepared tooth structures, loss of anterior tooth guidance, and esthetics, resulting in increased horizontal stresses on the masticatory system and associated temporomandibular joint remodeling.[9] Hence, the proper selection of restorative material is critical for preserving normal function and occlusal harmony.

Porcelain is the most used esthetic fixed prosthodontic restorative material.[10] It is rather unfortunate and of concern that dental porcelain is being used injudiciously on occlusal surfaces, many times just to fulfill patient demand for esthetics. The abrasiveness of ceramics against enamel is well known.[10-15] It would be an oversimplification if abrasion were solely attributed to the difference in the surface hardness of porcelain and enamel. The abrasiveness of ceramics is multifactorial and may be attributed to differences in hardness, tensile strength, composition, surface finishing of the ceramic, and frequent exposure to corrosive agents such as acidic beverages.[16]

On the other hand, Ni–Cr alloy can be routinely used on the occlusal surfaces, as its hardness and wear properties are comparable to that of enamel; however, the disadvantage of this material, apart from esthetics, is the concern regarding Ni hypersensitivity and its potential as a carcinogen.[17] The biologic release of this element in vivo and in an artificial environment and also its biocompatibility and side effects have been studied,[18-20] but the concentration of Ni and Cr in artificially simulated masticatory conditions (loading) in the presence of decreased pH (due to intake of acidic beverages) has seldom been studied.

One of the other processes reported, but not extensively studied, is the role of the oral chemical environment in the wear process. In modern society, many soft drinks with pH values less than 4 are consumed. Excessive consumption of drinks with low pH values is hypothesized to cause tooth wear. The acid in these drinks apparently demineralizes and softens the tooth surface, and the effect could be intensified by superimposed abrasion or attrition.[15] Thus, all acidic beverages are of potential concern. This study aimed to investigate the effects of these by using one carbonated beverage (Pepsi) as a representative of all acidic beverages.

This study was conducted with the following objectives: to compare the amount of tooth wear caused by porcelain restorative material with that caused by Ni–Cr alloy, when abraded against natural teeth, in artificial saliva and carbonated beverage media; to compare the surface roughness of porcelain restorative material against that of Ni–Cr alloy, when abraded against natural teeth, in artificial saliva, and carbonated beverage media; and to compare the release of Ni and Cr when abraded against natural teeth, in artificial saliva with that released in carbonated beverage medium.

Materials and methods

The study was divided into the following sections:

Section 1

Fabrication of tooth specimens

Forty-eight freshly extracted mandibular first premolars were procured. All were cleaned with hydrogen peroxide to remove debris and tissue tags and stored in normal saline. The teeth were embedded in acrylic blocks fabricated from putty impressions of a block of aluminum ($2 \times 2 \times 3$ cm^3) (Fig 1).

Fabrication of Ni–Cr and porcelain test specimens

Forty-eight wax patterns (S-U-Modeling-Wax, blue; Schuller, Ulm, Germany), circular in shape (6-cm diameter, 3-mm height) with four extensions on the sides measuring $5 \times 2 \times 1$ mm^3 were fabricated and stored in water to minimize dimensional changes. All 48 patterns were sequentially sprued and invested in groups of ten each in a 6x-casting ring (Degussa, Hanau, Germany) using Bellavest (graphite-free, phosphate-bonded precision investment; Degussa) and Begosol investment powder and liquid, respectively. The castings were retrieved. Twenty-four of these specimens were finished according to standard procedures (Fig 1). The remaining 24 specimens were then sandblasted, and a uniform thickness of porcelain of shade 1M1 was built up and glazed using VMK-95 Metall Keramik (Vita Zahnfabrik, Bad Sackingen, Germany) (Fig 1) in a ceramic furnace (Vita 90; Vita Zahnfabrik).

Artificial saliva and carbonated beverage used

One liter of Meyer's artificial saliva (pH 7.04) was prepared according to established technique, and three 200 ml bottles of Pepsi (Pepsico India Ltd., Haryana, India; batch no. 24) were used as the prototype for carbonated beverage. Meyer's artificial saliva contains KCl, NaCl, $Na_2HPO_4 \cdot H_2O$, Na_2S, Urea,

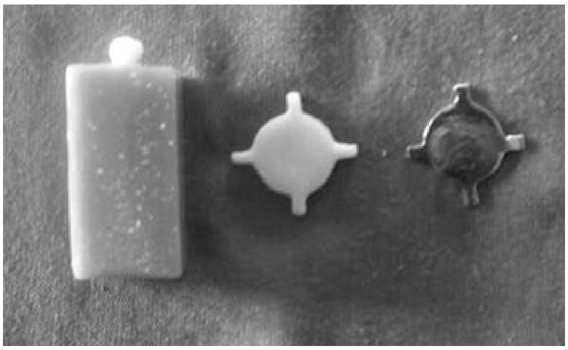

Figure 1 A tooth, a porcelain, and a Ni–Cr specimen.

$CaCl_2{\cdot}H_2O$, and distilled water. Temperature was maintained at 37.5°C, and the solutions were changed after abrasion testing of each specimen.

Forty-eight tooth specimens were abraded against 24 Ni–Cr and 24 porcelain-fused-to-metal specimens as follows

A total of 12 tooth/alloy and 12 tooth/porcelain specimens were abraded against 12 alloy/saliva and 12 porcelain/saliva specimens, respectively, in a medium of artificial saliva. Similarly, 12 tooth/alloy and 12 tooth/porcelain specimens were abraded against 12 alloy/beverage and 12 porcelain/beverage specimens, respectively, in a medium of carbonated beverage.

Tooth/alloy: Tooth specimens to be abraded against Ni–Cr alloy

Tooth/porcelain: Tooth specimens to be abraded against porcelain

Alloy/saliva: Ni–Cr specimens to be abraded against tooth specimens in a medium of artificial saliva.

Porcelain/saliva: Porcelain specimens to be abraded against tooth specimens in a medium of artificial saliva.

Alloy/beverage: Ni–Cr specimens to be abraded against tooth specimens in a medium of carbonated beverage.

Porcelain/beverage: Porcelain specimens to be abraded against tooth specimens in a medium of carbonated beverage.

The abrasion testing machine

The abrasion testing machine is specifically designed to simulate the masticatory process. It is electrically operated and consists of an upper and a lower member to which the specimens were attached with the help of screws. The tooth specimens were attached to the upper member, which is fixed. The Ni–Cr and porcelain specimens were attached to the lower member, which oscillates with a 6-mm amplitude. This amplitude is such that abrasion occurs while moving in both directions (back and forth). The speed of the oscillations is 60 cycles/min. A constant load of 40 N (4 kg·f) was applied to the abrading specimens. The entire abrasion process consisted of 15,000 cycles. This machine also has a counter attached to it to determine the number of cycles elapsed.

Reduction in cusp height was evaluated using a profile projector (Fig 2). Surface roughness was evaluated using a profilometer (Perthometer M1; Mahr, Göttingen, Germany) and scanning electron microscope (Stereoscan 360; Cambridge Instruments, Cambridge, MA) (Figs 3 to 6), and release of Ni and Cr ions was evaluated using atomic absorption spectrometer analysis.

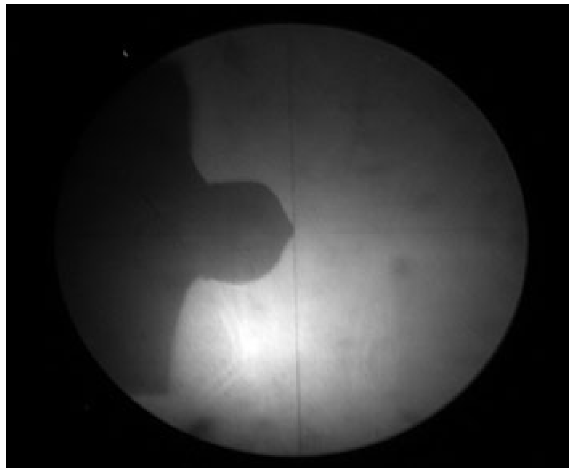

Figure 2 Superimposed image of a tooth specimen on the crosshairs of a profile projector to measure the reduction in cusp height.

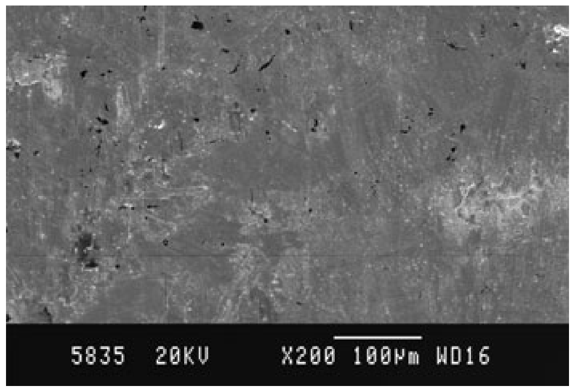

Figure 3 SEM projection of porcelain/saliva specimen along the wear track (200×).

Section 2

All instruments were calibrated according to ISI (Indian Standards Institute) norms, which are at par with ISO standards. The fabrication of Ni–Cr specimens was done according to standard laboratory procedures by a single laboratory technician at the rate of eight specimens per day with an interval between finishing of each specimen. Twenty-four of the 48 Ni–Cr specimens received porcelain firing finishing/glazing at the rate of 12 specimens per day by a single laboratory technician. Opaque porcelain (0.2 mm thick) was applied to each porcelain specimen. The thickness of dentin porcelain applied was 1 mm, and that of enamel porcelain was 0.5 mm. The thickness of each layer for each specimen was measured using a metal gauge. All readings were taken by a single examiner and were cross examined and verified by two independent examiners to eliminate bias. The data thus gathered was subjected to statistical analysis using one-way ANOVA test, Scheffé's fully significant difference procedure (sfsd), and Student's *t*-test.

Results

Scheffé's multiple comparison tests of mean reduction in cusp height of tooth specimens (Table 1) indicated a significantly higher mean cusp height reduction of tooth/porcelain specimens in beverage as compared to tooth/alloy specimens in saliva, tooth/alloy specimens in beverage, and tooth/porcelain specimens in saliva. The mean cusp height reduction of tooth/alloy specimens in beverage was significantly higher than that of tooth/alloy specimens in saliva. Also the mean cusp height reduction of tooth/porcelain specimens in saliva was found to be

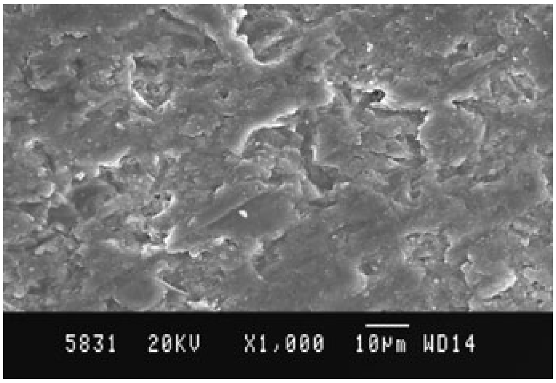

Figure 4 SEM projection of porcelain/beverage specimen along the wear track (1000×).

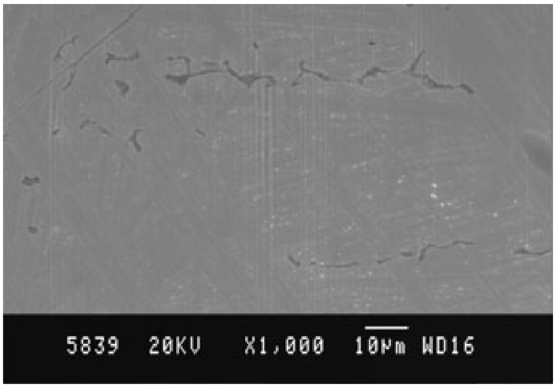

Figure 5 SEM projection of alloy/saliva specimen along the wear track (1000×).

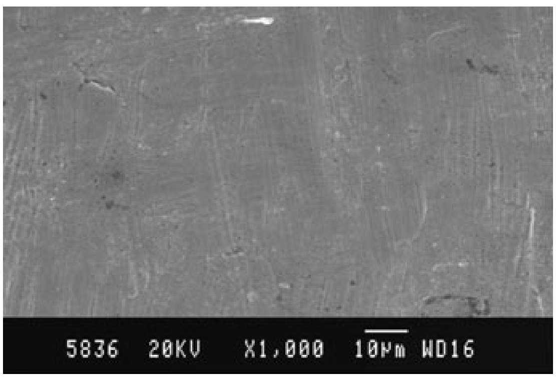

Figure 6 SEM projection of alloy/beverage specimen along the wear track (1000×).

Table 1 Comparison of mean reduction in cusp height (mm) of tooth specimens when abraded against alloy and porcelain specimens in artificial saliva and carbonated beverage media (standard deviation)

	Saliva	Beverage	*p*-Value
Tooth/alloy	0.4108 (0.1137)	0.6850 (0.0961)	0.001
Tooth/porcelain	0.7367 (0.1121)	1.2508 (0.1858)	0.001
p-Value	0.001	0.001	

Table 2 Comparison of mean surface roughness (μm) of alloy and porcelain specimens when abraded against tooth specimens in artificial saliva and carbonated beverage media (standard deviation)

	Saliva	Beverage	*p*-Value
Alloy	0.546 (0.1299)	0.4878 (0.1147)	0.8227
Porcelain	1.6411 (0.2160)	1.7267 (0.141)	0.5296
p-Value	0.001	0.001	

Table 3 Comparison of the release of Ni and Cr (μm/ml) when alloy specimens were abraded against tooth specimens in artificial saliva and carbonated beverage (standard deviation)

	Saliva	Beverage	*p*-Value
Ni	0.4826 (0.0751)	0.493 (0.0958)	0.7679
Cr	0.4962 (0.1491)	0.523 (0.0807)	0.5878

significantly higher than that of tooth/alloy specimens in saliva; however, the mean cusp height reduction of tooth/porcelain specimens in saliva was not significantly different from that of tooth/alloy specimens in beverage.

Scheffé's multiple comparison tests of mean quantitative surface roughness (Table 2) indicated a significantly higher mean quantitative surface roughness of porcelain/saliva specimens than alloy/saliva specimens and alloy/beverage specimens. The mean quantitative surface roughness of porcelain/beverage specimens was significantly higher than that of alloy/saliva and alloy/beverage specimens. The mean quantitative surface roughness of alloy/beverage specimens did not differ significantly from that of alloy/saliva specimens. Also the mean quantitative surface roughness of porcelain/beverage specimens did not differ significantly from that of porcelain/saliva specimens.

Statistical comparison (Student's *t*-test) between release of Ni and Cr ions when tooth specimens were abraded against alloy specimens in artificial saliva and carbonated beverage media (Table 3) revealed no statistically significant difference between the release of Ni ions between alloy/saliva and alloy/beverage specimens. Also, there was no statistically significant difference in the release of Cr ions between alloy/saliva and alloy/beverage specimens.

Discussion

Excessive consumption of drinks with low pH values could contribute to tooth wear. The acid in these drinks apparently demineralizes and softens the tooth surface, and the effect may be intensified by superimposed abrasion or attrition.[15] The pH of a dietary substance alone is not predictive of its potential to cause erosion, as other factors modify the erosive process. These factors are chemical (p*K*a values, adhesion and chelating properties, and calcium content), behavioral (eating and drinking habits, lifestyle, and excessive consumption of acids), and biological (saliva flow rate, buffering capacity, composition of saliva, pellicle formation, tooth composition, and dental and soft tissue anatomy).[21,22] Studies indicate that the presence of fluoride in enamel or acidic beverages, even in high concentrations, does little to prevent erosion of enamel by these acidic beverages.[23,24] Thus, the effect of carbonated beverage on the wear of enamel in a three-body wear pattern needed to be assessed.

It is hypothesized that acidic beverages cause significant erosion both in vitro and in vivo,[2,3,25] but this study demonstrated that a carbonated beverage caused significantly higher tooth wear when abraded against Ni–Cr and a porcelain restorative material, as compared to artificial saliva. In other words, this study suggests that carbonated beverages have detrimental effect in a three-body wear.

The abrasive effect of porcelain and Ni–Cr alloy against natural teeth has been well documented; however, the abrasive effect of these two materials against human enamel in a three-body wear pattern has not been compared in a single, unified study. In light of the increasing use of porcelain in posterior segments, it becomes critical to compare the abrasive effect of these two materials in a three-body wear pattern. This study attempted that. A wear-testing machine was used to simulate masticatory movements. The load applied was similar to that chosen in a study conducted by Jacobi et al.[26] The rate of cycling was based on a study that stated 60 to 80 cycles/min was a reasonable estimation for chewing cycle rate.[15] Meyer's artificial saliva was used as medium and was compared with a carbonated beverage, which formed the other medium.

The values for mean reduction of enamel when abraded against porcelain compare favorably with the values in the study conducted by Al Hiyasat et al.[15] In addition, this study found the abrasive effect of a porcelain to be significantly higher than that of Ni–Cr in the presence of both artificial saliva and a carbonated beverage medium.

This study compared the surface roughness of Ni–Cr and a porcelain material and also examined the effect of a carbonated beverage, if any, on the surface roughness of these restorative materials. In a ductile material such as metal, the material at the sharp end of the stress raiser deforms under stress, so the sharp notch becomes a rounded groove because of which the stress concentration is lowered (distributed). Hence, abrasion caused a smoothing of the surface of the metal. On the other hand, abrasion caused a significant roughening of the surface of the porcelain specimens due to the brittle nature of porcelain. Microfractures occurred along the wear track and increased the surface roughness in direct contrast to metals. The surface roughness values of porcelain/saliva and porcelain/beverage specimens (1.64 and 1.72 μm, respectively) compare well with the values provided by Derand and Veraby (1.1 to 6.5 μm)[12] and Al Hiyasat et al (0.54 to 0.60 μm).[15] The surface roughness of alloy/saliva and alloy/beverage specimens in this study were found to be 0.546 and 0.487 μm, respectively. This indicates no statistically significant effect of the carbonated beverage on the surface roughness of Ni–Cr. Also, according to this study, the carbonated beverage did not affect the surface roughness of the porcelain in three-body wear. This data leads us to the inference that the carbonated beverage tested does not have any role to play in the surface roughness of Ni–Cr and porcelain in a three-body wear. Hence, the fact that porcelain has significantly more surface roughness than Ni–Cr in a three-body wear should make us very critical about using porcelain for the occlusal surface of a restoration.

As a result of the increased popularity of Ni–Cr alloy, there has been an increase in concern about possible systemic and local effects of the metals when used in the oral cavity. Ni is considered moderately cytotoxic, whereas Cr is considered to have little cytotoxicity. Hence, the evaluation of these elements is critical.[25] In this study, the concentrations of these two elements were evaluated in the presence of two media (artificial saliva and carbonated beverage) under dynamic loading using an atomic absorption spectrophotometer.

In reference EPA 200a, the Environmental Protection Agency (EPA) sets the upper limit for Ni and Ni compounds in drinking water as 1.0 mg/l for 1 day. DWEL (a lifetime exposure concentration limit for protection of adverse, noncancerous health effects, assuming all exposure to a contaminant is from drinking water) for 10 days for a 10 kg child is set as 0.7 mg/l.[27] The EPA's lifetime limit (i.e., the concentration of a chemical in drinking water not expected to cause any adverse noncarcinogenic effects for lifetime exposure for a 70-kg adult consuming 2 l water per day) for Ni and Ni compounds is set at 0.7 mg/l. Similarly, the Food and Drug Administration (FDA) sets the upper limit concentration for Ni and Ni compounds in bottled drinking water at 0.1 mg/l (FDA 2003a 21 CFR 165.10).[27] As the statistics of this study revealed, carbonated beverages did not have any significant effect on the release of Ni when tooth specimens were abraded against Ni–Cr specimens. The mean release of Ni, irrespective of the medium, is 0.4879 mg/l. In a normal person, contact of opposing teeth occurs on an average of 13.20 min/day.[28,29] It can be computed that the mean release of Ni per specimen per day, considering the normal contact of opposing teeth/restoration to be 13.20 min/day, is 0.03 mg/l. This is only slightly less than the upper limit set by the EPA and FDA. It can safely be deduced that multiple Ni–Cr restorations can lead to a higher release of Ni. This factor certainly needs to be taken into consideration when providing multiple Ni–Cr restorations, especially in Ni-sensitive individuals or those who are exposed to higher environmental Ni exposure (e.g., chemical factory workers).

Several limitations must be noted. This was an in vitro investigation designed to mimic in vivo conditions, but may not have exactly replicated them. This study only evaluated one base metal alloy and one conventional porcelain. Other restorative materials should be investigated to compare the results of this investigation based on the parameters set in this research. Only one carbonated beverage (Pepsi) was evaluated. Its acidity and wear properties may not be similar to other acidic beverages, which are hypothesized to cause tooth wear. Also, there might be variation in the acidity, wear properties, and calcium content of Pepsi made from water at different sites. There is scope to study and compare the wear effects of other acidic beverages.

Based on these findings and within the limitations of this study, the following clinical implications can be drawn. As far as possible, conventional porcelain (porcelain with firing temperature greater than 850°C) should be avoided on occlusal surfaces opposing natural teeth. If esthetics dictate the use of a tooth-colored material for the posterior teeth, a porcelain facing should be provided, and the occlusal surface restored with metal/alloy. If all-porcelain restorations are unavoidable in the posterior region (patient demand, previous porcelain restorations), then cuspid-protected occlusion or anterior group function occlusion should be considered rather than group function.[17,30] Another alternative may be to consider use of ultra-low-fusing (firing temperature less than 850°C) porcelain on the occlusal surface.[17] In view of the increase in intake of acidic beverages, especially carbonated beverages among the younger population, the authors' view is to maintain a record of the amount of weekly intake of such beverages in susceptible populations, along with periodic recall visits every 6 months when the dentist also checks for the beginnings of tooth wear. Such longitudinal studies at multiple institutions and clinics will lead to an accurate estimation of the amount of the beverage, its pH, method of consumption, and any other associated factors that would lead to tooth wear. If an association is found between acidic beverage intake and tooth wear, the authors suggest reduction/stoppage of acidic beverage and acidic food intake and modification of acidic beverage intake (use of straw). Further studies are required to assess which acidic beverage is the least detrimental. When providing multiple Ni–Cr restorations, the health hazards due to release of Ni needs to be considered.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. Porcelain in a medium of carbonated beverage caused the highest wear of tooth specimens; Ni–Cr in artificial saliva caused the least wear.
2. Carbonated beverage caused significantly higher wear of tooth specimens as compared to artificial saliva, when abraded against either Ni–Cr or porcelain.
3. There was no significant difference in the reduction of cusp height of the tooth specimens abraded against Ni–Cr in carbonated beverage and that of tooth specimens abraded against porcelain in artificial saliva. All factors being equal, carbonated beverage caused almost as much wear as did porcelain.
4. Tooth specimens caused a significantly higher surface roughness of porcelain specimens than did Ni–Cr specimens, irrespective of the media used for abrasion.
5. Irrespective of the media used for abrasion, tooth specimens caused a similar amount of surface roughness for Ni–Cr specimens.
6. Irrespective of the media used for abrasion, tooth specimens caused a similar amount of surface roughness for porcelain specimens.
7. There was no influence of carbonated beverage on the release of Ni and Cr ions during the process of abrasion.

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