TRIBOCHEMICAL TOOTH WEAR IN COLA BEVERAGES

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Abstract. *Tooth wear has multiple causes, and it is difficult to establish the contribution of each affecting factor. Literature points to corrosion and abrasion as the predominant agents. In order to improve the understanding of the phenomenon, the influence of chemical degradation in the tooth surface tribological parameters will be studied. The chemical agent consisted in inserting the samples in an acid medium, cola beverage, during a predetermined period of time. The samples where examined before and after the chemical exposure. Visual inspection, profilometry and hardness tests were used to analyse the surfaces. The obtained results for the degraded areas were compared to the results for the control group. It was observed loss of dental structure mainly in the nucleous zone of roughness. Hardness results indicate a softening of the affected surfaces. The results were compared with abrasion controlled wear so as to further understand the tribochemical tooth wear.*

Keywords: *tribochemical tooth wear, corrosion, cola beverage, profilometry*

1. Introduction

Teeth wear is a natural process involving different mechanisms. Excessive teeth wear is one of the most important pathologic and tribological problems of the human body, related to adhesion, abrasion, chemical and fatigue processes (Mair et al.,1996). Currently, researchers in dentistry employ the term erosion to describe the loss of dental substance due to chemical processes not involving the action of known bacteria, whereas in engineering erosion is defined as the abrasive destruction of materials by the movement of liquids or gases (Grippo and Simring, 1995). When materials are physically degraded by chemical or electrochemical reactions, the term employed in engineering is corrosion. In this work, dental erosion will be referred to as a corrosion process.

Teeth corrosion can be caused by intrinsic and extrinsic factors. Intrinsic factors are regurgitation of gastric material associated to diseases such as nervous bulimia and anorexia, recurring vomits due to gastric diseases and gastroesophagic reflux. Examples of extrinsic factors are the ingestion of acidified beverages and deserts made of citric fruits, topic use of cocaine in the oral cavity, prolonged exposure to acid environments such as swimming pools with incorrect water treatment and decrease of salivar flux due to diabetes. Lesions of intrinsic origin are more frequently found in the palatine or lingual regions of anterior teeth and in the occlusal region of posterior teeth (Silva and Damante, 1995), whereas those of extrinsic origin are localized preferentially in the cervical third of the vestibular region in anterior teeth (Netto, 2000). According to Zero (1996), the main extrinsic etiologic factor causing teeth corrosion derives from acids coming with the diet. The same author states that a precise relationship between diet acids and teeth corrosion has not yet been established because the acid effects can be altered by biological factors, such as the chemical composition and flux of saliva, as well as by behavior characteristics associated with oral hygiene habits and diet.

The corrosive lesions left in the dental surface are characterized initially by the loss of enamel brightness, and the surface becomes smooth, wide, shallow and without sharp angles. When they reach the dentin, they provoke sensibility to cold and to heat and osmotic pressure. When they occur in restored teeth, the restorations become prominent, being projected above the dental surface (Maia and Modesto,1996).

Various in vitro studies have shown that acid corrosion produces a zone of softened enamel which is a few micrometers deep and extremely susceptible to physical wear (Eisenburger and Addy, 2002). It was already demonstrated that beverages whith pH below 5.5 are capable to begin the process of dissolution of the dental enamel, especially when consumed in an excessively way and for prolonged periods of time (Maia and Modesto,1996). Cola soft drinks present acid pH, around 2.36, include phosphoric acid in its constitution, which turns them potentially corrosive. For that reason and for the fact of being very popular and globally consumed, this kind of drink will be used as corrosion etiological agent in this study.

The aim of this study is to evaluate the topographical changes and the hardness variation of the dental enamel due to the chemical action of cola beverage and to try to elucidate the mechanism of corrosion front to the global dental wear.

2. Materials and methods

2.1 Overview

The first evaluation of the effect of the cola beverage on the enamel surface consisted of visual inspection of three teeth after they have been submerged into the drink for one week. For the other evaluation techniques, three groups of samples of healthy and extracted teeth were constituted, submitted to different types of preparations and appraised in two different moments in the research, before and after have been submerged into the drink for 90 minutes. We will denominate the surfaces as initial or modified in agreement with the moment of the evaluation. There was no attempt in this study to determine the origin of the extracted teeth. The constitution of the groups and the techniques which were used are presented next:

1. Group 1 was composed of 5 inferior incisor teeth, which were healthy and extracted for evaluation by three-dimensional contact profilometry. These teeth were previously cleaned with Hobinson brush, dried and mounted in blocks of acrylic resin to facilitate the adaptation in the profilometer.

2. Group 2 was composed of 3 plane samples obtained by sectioning a healthy and extracted molar also for evaluation by profilometry.

3. Group 3 was composed of 9 plane samples obtained through the sectioning of three healthy and extracted molars teeth to be submitted to Vickers micro-hardness test.

Two fluid portions of a cola soft drink can were separated for chemical analysis. The first portion was considered as the sample control while a tooth was deposited into the other during 90 min. The aim of the analysis was to observe possible ionic changes between the tooth and the drink evidencing possible chemical reaction.

For obtaining the samples of the groups 2 and 3, the teeth were embedded in acrylic resin, taken to the cutting machine (Isomet) and split up by diamond disk in 3mm thick sections, normal to the longitudinal axis. There was no specific preparation to the sections, such as grinding or polishing. The number of samples obtained from each tooth depended on its size and morphology.

The initial objective was to study the influence of the chemical attack in the external surface of the dental enamel, attempting to obtain closer results to the observed clinically. Therefore the teeth of group 1 were appraised without previous preparation and directly in the enamel surface. The choice of lower incisive teeth in this group was made due to its plainer anatomy, which facilitates the application of the profilometry technique. However, through the analysis of the results, it was not observed a regular behavior of the samples. Several of the factors that can influence the characteristic of the initial surface, composition and structure of the enamel, such as nutrition, age and sex, could not be controlled. We assumed that the non-regularity of the samples behavior is related to these factors. Starting from that hypothesis, we decided to use samples of the same tooth and thus the group 2 was generated. However, to preserve the structure of the dental surface, the samples were subjected to the minimum of manipulations.

Besides observing the superficial texture of the enamel, it was also an objective of the work to measure the hardness of the superficial layer of the tooth. However, as the morphology of the tooth was very irregular, it was very difficult to adapt it to the micro-hardness equipment. A reasonably good focus of the optical devise was not achieved to observe the indentation diameter. So we also chose to use plane sections of a same tooth (group 3) with a minimum of interventions.

2.2 Profilometry

The three samples in group 2 were taken to the profilometer (Hommel Tester T8000,Hommelwerke Gmbh) in the two steps of the research (before and after immersion) where all the section of the tooth (enamel, dentine and pulpar region) were examined (Fig. 1). Through the analysis software, MoutainsMap, it was possible to focus only on the area of the enamel and to separate it for analysis (Fig. 2). During this procedure, the maximum of care was taken so that the initial and modified surfaces were really coincident (Fig. 3 and 4). Then we made the filtering for obtaining the roughness profile, the adjustment of the material curve and the extraction of the parameters of superficial texture.

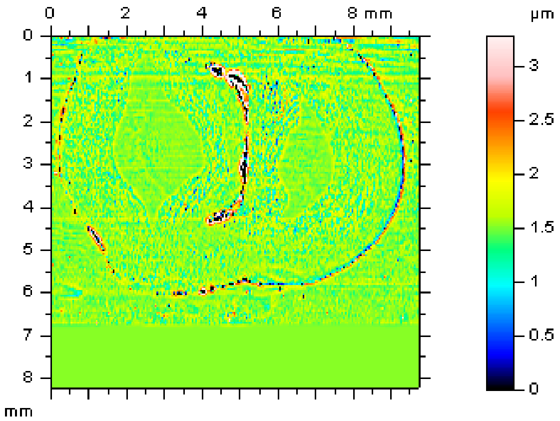


Figure 1. Total image obtained by profilometry

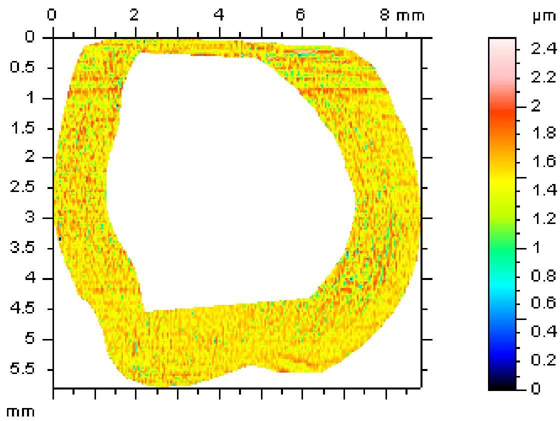


Figure 2. Selection of the enamel layer for analysis

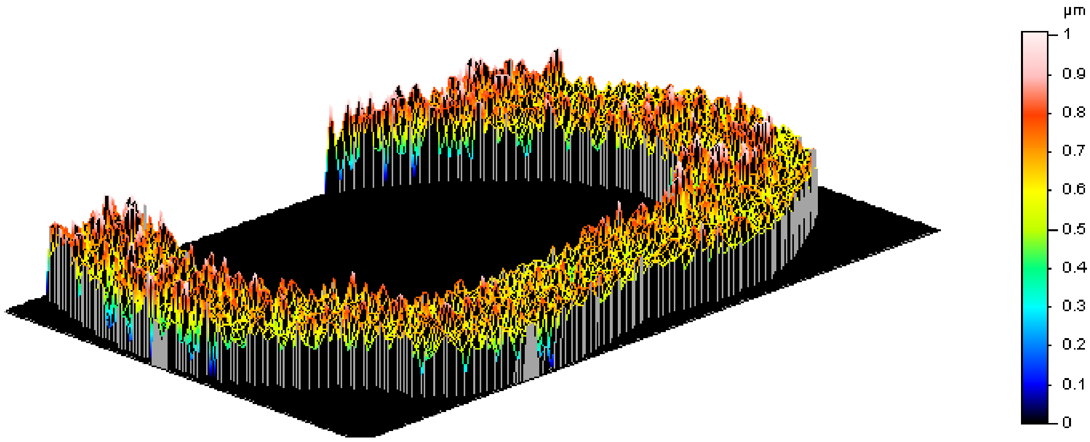


Figure 3. Initial surface of the sample 1 of the group 2

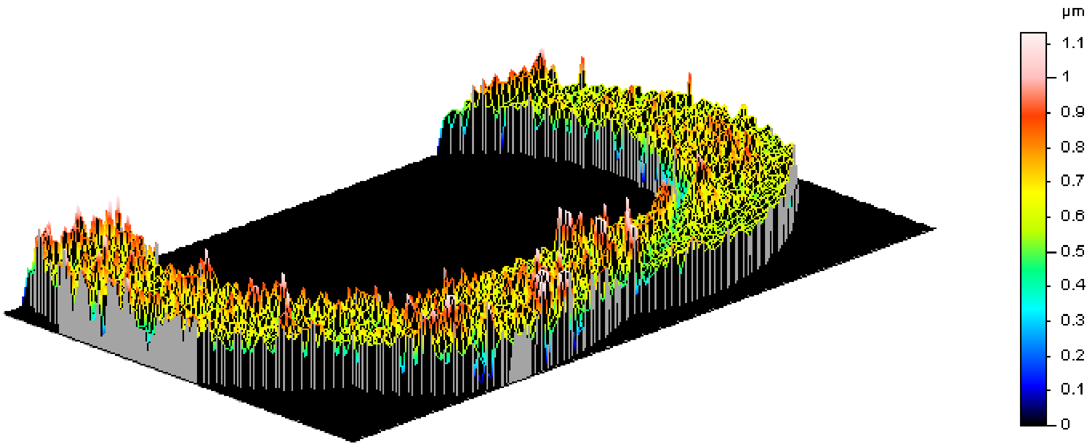


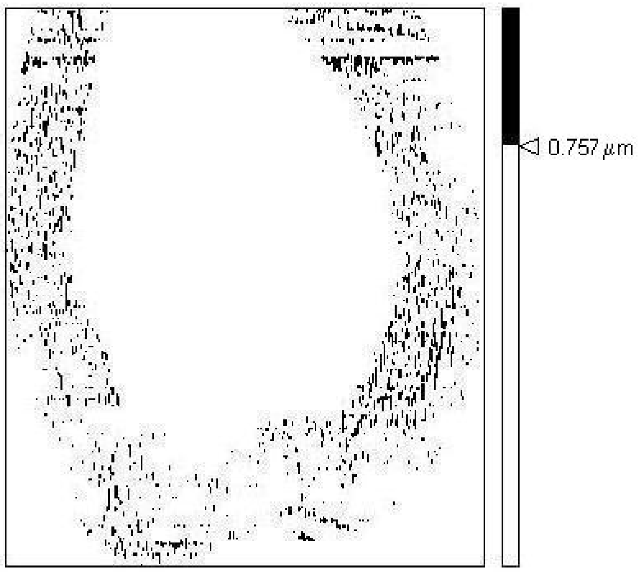
Figure 4. Modified surface of the sample 1 of the group 2

As in every profilometric analysis, it was necessary to select parameters which are sensitive to the studied phenomenon. In most studies of the literature the material loss is determined through the reduction of the vertical dimensions of the enamel, mainly evaluating the quadratic medium roughness,Sq texture parameter (West et al., 1998; Shabanian and Richards,2002; Eisenburger and Addy, 2002). We chose to determine additionally the volumetric material loss, taking the maximum advantage to the statistical tools of the available analysis software.

The software allows us to select a surface layer delimited by two different depths for which the volumes of material and voids are calculated. These volumes are expressed in percentages of the total volume of the layer. For example, in

Fig.5, the composition of a surface in two layers can be noted, the superior in dark color and the inferior in clear color. Observe the superior layer is composed by 96.5% of voids and 3.48% of material.

The material percentage of each layer in relation to the total surface material volume can be expressed graphically as a continuous curve in function of depth. This curve is called the material curve and is exemplified in Fig.6.



	□	■
Area (%)	88.7	11.3
Volume of void (%)	25.3	96.5
Volume of material (%)	74.7	3.48

Figure 5. Surface composition in two layers

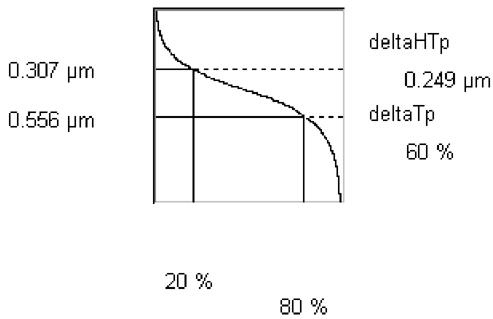


Figure 6. Material curve obtained for the initial surface of the first sample of the group 2

One of the difficulties in establishing the comparison between the initial and modified surfaces was the lack of fixed points of reference. However, we observed that, up to a certain depth from the highest point of each surface, the rate between the amount of material and existing voids in this established layer stayed practically unaffected. In other words, the corrosion phenomenon affected little the area of the picks. Thus we concluded that a good conduct for analysis would be to maintain this area as our reference. The above mentioned depth was considered that corresponding to 20% of the amount of material contained in the total roughness of the initial surface. Then we decided to establish two other areas of interest below the area of picks. These areas were limited by the depth corresponding to 80% of the amount of material and denominated nucleus and valleys zone. Figure 6 illustrates the process for obtaining the two reference depths in relation to the highest pick through the material curve.

The material and voids percentages of each layer as well as the Sq parameter were determined for the initial and modified surfaces and the same ones could be compared. For the data obtained by the profilometry, formal statistical studies were not performed.

2.3 Micro-hardness test

The samples of the group 3 were submitted to Vickers micro-hardness test (Microhardness tester FM, future-tech) in the two moments of the research (before and after immersion). The time of indentation was 15 seconds and the load 200gf. In each section 15 indentations were made and the micro-hardness measure was determined through the average of the 15 found values. Statistical tests of averages equality were accomplished to verify if there was the softening of the surface due to the chemical action of the beverage.

3. Results

3.1 Visual inspection

The visual inspection done on three teeth after they have been submerged in the drink for one week revealed that there was loss of the brightness of the enamel, the surface was rough and with brown stains, specially in the cervical area.

3.2 Profilometry

The results of the profilometric analysis of the group 1 did not show a regular behavior of the surfaces in response to the chemical action of the beverage and therefore they will not be presented.

For group 2, the depths corresponding to 20% and 80% of material in relation to the total roughness of the initial surfaces are $0.307\mu m$ and $0.556\mu m$ for the sample 1, $0.369\mu m$ and $0.649\mu m$ for the sample 2 and $0.303\mu m$ and $0.487\mu m$ for the sample 3.

Table 1 presents the percentages of voids and material found in the three areas of interest, picks, nucleus and valleys zones, for the initial and modified surfaces of each sample of the group 2. As previously mentioned, there was not a significant variation of these percentages in the zone of picks due to the chemical action of the beverage, in none of the samples (variations <4%). For the nucleus zone we observed that there was appreciable change of the rate void/material due to the corrosion, resulting in the loss of dental structure in the three samples. In relation to the valleys zone, it was verified that the influence of the beverage, resulting in loss of dental structure, increased from sample 1 to sample 3, as the sections moved away from the outer surface to the inner of the tooth.

Table 2 shows the values for the quadratic medium roughness, Sq, found for the initial and modified surfaces of the samples of group 2 and their respective variations. It can be observed that there was practically no variation of this parameter for sample 1 and that there was an increasing variation for the samples 2 and 3, being larger for the last sample.

Table 1. Percentages of voids and material found in each zone of interest
for the initial and modified surfaces and respective variations

	Picks Zone		Nucleus Zone		Valleys Zone	
	voids	material	voids	material	voids	material
Initial Surface 1	94,5%	5,6%	48,3%	51,7%	5,5%	94,5%
Modified Surface 1	98,5%	1,5%	79,9%	20,1%	10,2%	89,8%
Variation 1	4,0%	-4,0%	31,6%	-31,6%	4,7%	-4,7%
Initial Surface 2	94,4%	5,6%	48,7%	51,3%	5,4%	94,6%
Modified Surface 2	97,4%	2,6%	83,2%	16,8%	17,8%	82,2%
Variation 2	3,0%	-3,0%	34,5%	-34,5%	12,4%	-12,4%
Initial Surface 3	95,3%	4,7%	48,4%	51,6%	5,1%	94,9%
Modified Surface 3	99,3%	0,7%	98,7%	1,3%	46,2%	53,8%
Variation 3	4,0%	-4,0%	50,3%	-50,3%	41,1%	-41,1%

Table 2. Sq values found for the initial and modified surfaces and respective variations

	Sample 1			Sample 2			Sample 3		
	Initial surf.	Modified surf.	Variation (%)	Initial surf.	Modified surf.	Variation (%)	Initial surf.	Modified surf.	Variation (%)
Sq(μm)	0.166	0.157	-5.4	0.188	0.277	47.3	0.135	0.262	94.1

3.3 Micro-hardness test

Table 3 presents the equality test of averages between the Vickers micro-hardness values found for the initial and modified surfaces of each sample of the group 3. t can be noticed that there was a statiscally significant variation of the hardness in all but one of the nine samples due to the chemical action of the beverage. In the eight others there was a reduction of the surface micro-hardness, evidencing the effect of the corrosion.

3.4 Chemical analysis

In the chemical analysis the concentration of phosphorous, sodium and calcium was evaluated in the two beverage samples. The phosphorous concentration was not significant in none of the two samples and also there was not a significant difference of sodium concentration between them. For the control sample, the calcium concentration found was 6.5 mg/L while for the sample that received the deposition of the tooth during 90 min the concentration was of 9.83mg/L. This difference of concentrations shows that there was ionic change between the tooth and the liquid, once they formed a closed atmosphere. Thus the loss of calcium of the tooth for the liquid can be considered as an effect of the chemical action of the drink on the tooth.

Table 3. Equality test of the averages between the values of Vickers micro-hardness found for the initial and modified surfaces of each sample of the group 3

Samples	m1	m2	S1	S2	SP	n1	n2	t_o	n	$t_{\alpha/2,n}$	Results
1 initial x modified	366.00	160.42	94.49	14.21	67.57	15	15	8.333	28	2.048	The averages are different
2 initial x modificada	353.61	119.40	29.63	9.58	22.02	15	15	29.129	28	2.048	The averages are different
3 initial x modified	244.10	193.29	49.95	32.49	42.14	15	15	3.302	28	2.048	The averages are different
4 initial x modified	363.24	274.12	39.56	54.52	47.63	15	15	5.124	28	2.048	The averages are different
5 initial x modified	342.27	300.86	19.37	39.89	31.35	15	15	3.617	28	2.048	The averages are different
6 initial x modified	349.32	280.74	47.46	42.81	45.19	15	15	4.156	28	2.048	The averages are different
7 initial x modified	395.51	160.06	53.84	16.78	39.87	15	15	16.171	28	2.048	The averages are different
8 initial x modified	348.07	258.36	32.25	47.94	40.86	15	15	6.013	28	2.048	The averages are different
9 initial x modified	375.32	344.94	54.88	35.36	46.16	15	15	1.802	28	2.048	The averages are not different

$H_0 : m1 = m2$ $H_1 : m1 \neq m2$ Rejection Criterion for H_0: $t_o > t_{\alpha/2,n}$ 95% reliability

4. Discussion

The work reveals that from a simple visual inspection is possible to observe the effects caused by the drink on the surface of a tooth.

The corrosion phenomenon is strongly influenced by the initial condition of the surface. It is clear from the results of the profilometry for the incisive teeth of the group 1, which did not show a regular behavior in response to the chemical action of the beverage, that dental enamel is a complex structure, heterogeneous not only for different types of teeth but also in relation to other factors, such as age, sex and nutrition, which could not be controlled in this research. It is necessary to outline these difficulties for the development of an efficient methodology for evaluation of the phenomenon. An attempt was made in this sense when plane samples were obtained from the same tooth, forming group 2. In this case it was already possible to observe some regular patterns. The phenomenon practically did not affect the picks zone whereas it resulted in sensitive loss of dental structure in the nucleus zone for the three samples. For the valleys zone it was observed that the influence of the beverage increased from sample 1 to sample 3 as the sections moved away from the outer to inner surface of the tooth. This can be related to the fact that the enamel hardness decreases in the same direction. Thus, for the sample 3, probably softer, the corrosion effect was larger. The same could be verified in relation to the variation of the quadratic medium roughness, Sq. As the sections moved away from the outer surface, there was an increase of surface irregularity, evidencing again that corrosion affects more the less hard surface.

In previous works (Bastos et al.,2004a; Bastos et al.,2004b) the abrasive wear due to contact and sliding of two dental surfaces was approached. It was observed that this process occurs mainly by fragile fracture due to the formation of successive lateral cracks that begin in the sub-surface and reach the outer surface, leading to material removal. Thus, it was noticed that abrasion can modify the surface topography as a whole, from the valley to pick zones, differently from that observed for the corrosion. When the two actions, mechanic and chemical, happen simultaneously, it is named tribochemical wear (Holmberg and Mathews, 1994; Hutchings, 1992). We believe that the effects of the two actions are not just added as they interact mutually. For instance, through corrosion, the material loss in the nucleus of the roughness reduces the load support capacity of the surface and thus the effects of abrasion will still be more severe. Additionally, the reduction of surface hardness can lead to plastic deformation and modify the wear mechanisms. Abrasive wear can also accelerate the corrosion, once it removes the layer of chemical reaction, leaving a new layer susceptible.

Although there were previous works to prove the corrosive potential of acid beverages, we were interested in accomplishing a new study due to the possibility of using a more sophisticated equipment, which allows us to evaluate the surface in a three-dimensionally manner, whereas more commonly two-dimensional profiles and observation of images generated by Scanning Electronic Microscopic are used. So it was possible to verify the volumetric material variation in a layer of fixed width instead of verifying only the reductions of vertical dimensions.

The immersion time of the samples into the beverage used in the proposed methodology can be considered excessive when compared with the ingestion practice, but it was indispensable that in this pilot project the modifications of the superficial topography were severe to the point of being detected by profilometry so as to explain the active mechanism. To validate the observed results, we propose the study to be repeated in larger scale using a statistically significant number of samples.

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