Effects of Various Beverages on Hardness, Roughness, and Solubility of Esthetic Restorative Materials

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ABSTRACT

Statement of the Problem: Restorative materials may either be exposed intermittently or continuously to chemical agents found in beverages, which may lead to biodegradation.

Purpose: This study was aimed to evaluate effects of various beverages on microhardness, surface roughness, and solubility of esthetic restorative materials.

Materials and Methods: Materials used were conventional glass ionomer, resin-modified glass ionomer, compomer, and composite resin. Microhardness of the restorative materials was measured using Vickers microhardness tester. Surface roughness was measured using surface profilometery. Solubility was measured using an electronic balance.

Results: In general, low pH beverages adversely affected the properties of the tested materials. Microhardness of tested materials was significantly decreased after immersion in the various beverages, whereas surface roughness and solubility were increased with the exception of natural milk. Natural milk and water did not affect the tested materials as Mirinda orange or mango juice did. Microhardness, roughness, and solubility of the tested materials in water were comparable with those of natural milk. After the immersion period, the conventional glass ionomer showed the roughest surface and exhibited the highest solubility, whereas composite resin was the smoothest surface and the lowest solubility. There was a negative correlation between surface roughness and microhardness, as well as between solubility and microhardness. There was a positive correlation between surface roughness and solubility.

Conclusions: Low pH beverages were the most aggressive media for glass ionomers and compomer, by contrast, composite resin was relatively less affected. Water and natural milk appeared relatively benign towards the tested materials.

CLINICAL SIGNIFICANCE

The clinical performance of dental restorations could be affected by pH changes in the oral cavity. Because of the increased consumption of low pH beverages, the materials' surfaces may become rough and dull at a clinically detectable level.

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INTRODUCTION

One factor, which has an appreciable influence on the satisfactory clinical performance of dental restorations, is their resistance to biodegradation. In the oral cavity, this process includes diverse phenomena, such as sliding, abrasion, chemical degradation, and fatigue. These mechanisms may operate either alone or in combination with others and, considering the intricacy of the oral environment; the breakdown of dental materials mediated by biological activity is very complicated.[1] On exposure to plaque acids,

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food-simulating constituents, and enzymes, resin-based restorative materials can undergo softening.[2]

The search for an ideal restorative material to replace natural tooth and demand for products with good mechanical and caries-protective properties, together with a simple clinical application procedure, have led to the development of a number of new restorative materials. Resin-modified glass-ionomer cements and compomers have been introduced for clinical use. In the oral cavity, many solutions (water, food substances) could potentially affect the behavior of materials.[3] Polyacid-modified composite resins (compomers) are surface-softened by an acidic environment. The acidic attack resulted in the loss of structural ions from the glass phase of polyacid-modified composites.[4] The chemical environment is one aspect of the oral environment, which could have an appreciable influence on the in vivo destruction of restorative materials. The resin matrix of the composite resin can be softened and filler constituents can be leached out when composites are exposed to certain chemicals/food-simulating liquids.[5] There are changes in surface composition when glass-ionomer cements are stored in saliva.[4,6] Light-cured glass ionomers are less resistant to softening by food simulating solutions than microfilled composites. Light-cured glass ionomers that use acid monomers in place of polyalkenoic acid are more resistant to softening than other categories of light-cured glass ionomers.[7]

Degradation of restorative materials cannot be attributed to wear alone, but involves chemical degradation as well. In vivo, these materials may either be exposed intermittently or continuously to chemical agents found in saliva, food, and beverages. Intermittent exposure occurs during eating or drinking beverages and juices until teeth are cleaned. Continuous exposure may, however, occur as chemical agents can be absorbed by different debris (such as calculus or food particles) at the margins of restorations or be produced by bacterial decomposition of debris.[8]

In the restorative procedures, one of the fundamental purposes is to obtain restorations with smooth surfaces, without porosity, resulting in better aesthetics and minimizing the accumulation of dental plaque. Therefore, roughness is an important property of the restoration surface, as it can affect friction, wear, optical properties, and mechanical attachment of foreign materials on the surface.[9]

One of the most important properties that determines the durability of restorative materials in the mouth is resistance to dissolution or disintegration.[10] It has been known for a long time that acidic food and drinks may soften dental hard tissues. The erosive activity of citric, malic, phosphoric, and other acids as ingredients of beverages and foodstuffs has been demonstrated in many in vitro, in situ, and in vivo studies.[6,7,11,12] There were statistically significant correlations between the prevalence of erosion and consumption of soft drinks, carbonated beverages, alcoholic drinks, fresh fruits, and others.[11]

Therefore, the hypothesis of the present investigation was low pH beverages could be adversely affect the properties of esthetic restorative materials. So, the purpose of this study was to evaluate the effects of acidic beverages (Mirinda orange and mango juice) and neutral media (deionized water and natural milk) on hardness, roughness, and solubility of conventional glass ionomer, resin-modified glass ionomer, compomer, and composite resin restorative materials.

MATERIALS AND METHODS

Materials and beverages used in this study are presented in Table 1. The pH of the test solutions was determined by using a calibrated pH meter (pH meter 3310, Jenway, Staffordshire, UK), which was calibrated with standard solutions. The accuracy of the pH detector was estimated by recording pH of the calibration solutions between each measurement. The pH electrode was immersed in 5 mL of the tested solution and the solution was stirred during testing using magnetic stirrer (Jenway 1100, Hotplate & Stirrer, Jenway). The measured pH of Mirinda orange was 2.85, natural mango juice was 3.49, natural milk was 6.34, and deionized water was 6.98. The pH of the water was used as a control solution throughout the tests.

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TABLE 1. The esthetic restorative materials and beverages used

Materials	Manufacturers
Medifil, conventional glass ionomer, shade A3.	Promedica, Neumünster, Germany
Vitremer, resin-modified, light-cured glass ionomer, shade A3.	3 M Dental Products, St. Paul, MN, USA
Composan glass, light-curing compomer, shade A3.	Promedica, Germany
Composan LCM, light-cured, microhybrid composite resin, shade A3.	Promedica, Germany
Deionized water (neutral medium), pH = 6.98.	Faculty of pharmacy, Mansoura University, Mansoura, Egypt
Natural milk (neutral medium), fresh cow milk without powder, U.H.T. cow milk, pH = 6.34.	Juhayna Food Industries, 6th October City, Egypt
Mirinda orange beverage (acidic medium), pH = 2.85.	Pepsi Cola, Cairo, Egypt
Mango juice (acidic medium), Mango NECTAR, 35% mango pulp, citric acid, water and sucrose, pH = 3.49.	Greenland Co., 10th of Ramadan City, Egypt

Hardness Testing

A total of 24 specimens were prepared from each material using Perspex mold (5-mm diameter and 2-mm thickness). Glass ionomers (Medifil and Vitremer) were supplied in powder/liquid forms, which were mixed according to the manufacturers' instructions and placed into the mold. Composan glass and composite resin (composan light-cured microhybrid [LCM]) materials, in turn, were injected by their own syringes and condensed within the mold. The materials' surface was covered by a Mylar strip, pressed flat with a microscopic glass slide to squeeze the excess material. The glass slide was held firmly during setting to avoid the presence of air bubbles and to obtain a smooth surface. Each specimen of Vitremer, composan glass, and composan LCM was irradiated for 40 seconds using a light-curing unit (SPRING Power LITE 75, High Point, NC, USA). The distance between the light source and specimens' surface was kept at zero distance. Conventional glass ionomer (Medifil) was set by auto polymerization at room temperature for at least 1 hour. After setting, the Mylar strip was removed and surface of the specimen was left undisturbed.

The specimens were divided into four groups, six specimens each. The first group was stored in deionized water for 1 week at a temperature of 37°C as a control. The other groups were immersed in 5 mL of one of the following test solutions: Mirinda orange, mango juice, and natural milk, for 3 hours per day at 37°C. Each specimen was immersed separately in a closed individual container containing the recommended immersion medium. After the immersion period, specimens were rinsed with deionized water then transferred to deionized water the rest of the day at 37°C. This immersion regimen was repeated in uninterrupted manner for 7 days. All solutions were changed each 24 hours before the new immersion period. The immersion media used in this study were from a newly opened can on each occasion that the solution was changed. After the storage time (7 days), specimens were taken out of the solutions, dried with a laboratory tissue.[4,10,13] Microhardness measurements were obtained by using a Vickers microhardness testing machine (Vickers microhardness tester, Vickers, Feasterville, PA, USA) at a 100-g force for 20 seconds. The microhardness number computed was based on the length of the indentation made on the specimens' surface. Three indentations were created for each specimen at the top surface only.

Surface Roughness Measurement

A total of 24 specimens were prepared from each material using transparent Perspex mold (5-mm diameter and 2-mm thickness). All specimens were prepared and classified as mentioned previously. The Mylar strip formed surface was used as a baseline for roughness testing. Specimens were examined for obvious voids. All specimens were thoroughly rinsed with water and allowed to dry for 24 hours, then the surface roughness (Ra) was measured using a profilometer (Talysurf E 10 A, Nikon, Tokyo, Japan).

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TABLE 2. Hardness (VHN) of the restorative materials in various immersion media

Medium	Materials			
	Medifil	**Vitremer**	**Composan glass**	**Composan LCM**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Deionized water pH = 6.98	39 ± 4[efg]	44 ± 6[cde]	46 ± 6[cd]	66 ± 6[a]
Mirinda orange pH = 2.85	27 ± 3[i]	35 ± 3[gh]	33 ± 2[h]	58 ± 6[b]
Mango juice pH = 3.49	35 ± 4[gh]	41 ± 6[def]	35 ± 4[fgh]	61 ± 6[ab]
Natural milk pH = 6.34	37 ± 5[fgh]	45 ± 4[cde]	47 ± 5[c]	66 ± 5[a]

Values with same superscripts are not significantly different.

	F-value	p value	Least significant difference
Materials	157.54	$p < 0.001$	2.812
Media	25.96	$p < 0.001$	2.81
Materials × media	10.03	$p < 0.05$	5.623

VHN = Vickers microhardness number.

Three measurements in different directions were recorded for each specimen and mean Ra value was determined in μm (baseline Ra). After the immersion period, the surface roughness of all specimens was reevaluated in a similar manner to that for the baseline condition.[1] The total mean surface roughness for each group was recorded.

Solubility Testing

A total of 24 specimens were prepared from each material in a stainless steel mold (10-mm diameter and 1-mm thickness). The specimens were prepared as mentioned previously. All specimens were kept dry in a vacuum-desiccating chamber at 37°C for 48 hours. This ensured completion of polymerization and specimen dehydration to allow determination of solubility from a stable baseline. Constant weight of specimens after desiccation must be obtained to ensure complete dehydration. Each specimen was weighed before immersion using an electronic balance (Sartorius MCI Research RC Z10 D, Sartorius AG, Gottingen, Germany). After the immersion period, specimens were re-desiccated and reweighed again. The difference between these two readings represented the loss of mass and was related to the surface area of the specimens to obtain a disintegration value (μg/cm^2).[4,13]

Statistical Analysis

Two-way ANOVA was used to determine the significant difference among the tested groups. Least significant difference test was used to determine the significant difference between these groups at $p \leq 0.05$.

RESULTS

Surface Microhardness

Table 2 shows the mean microhardness values of tested restorative materials after immersion in various media. Two-way ANOVA showed significant difference among the different restorative materials in various immersion media ($p < 0.001$). There were significant differences in the hardness of the restorative materials in different immersion media ($p < 0.001$). The interaction of the materials and immersion media was significantly different ($p < 0.05$). The average surface hardness of the materials in deionized water was significantly different from that measured for Mirinda orange, whereas it was not significantly different from that recorded for natural milk. The average surface hardness of the materials stored in Mirinda orange was significantly different from that measured for mango juice and natural milk

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TABLE 3. Surface roughness (Ra, μm) of the restorative materials in various immersion media

Medium	Materials			
	Medifil	**Vitremer**	**Composan glass**	**Composan LCM**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Deionized water pH = 6.98	0.2 ± 0.05^{fghi}	0.1 ± 0.003^{hi}	0.1 ± 0.01^{ghi}	0.03 ± 0.004^{i}
Mirinda orange pH = 2.85	4 ± 0.4^{a}	3 ± 0.3^{b}	3 ± 0.3^{c}	2 ± 0.3^{d}
Mango juice pH = 3.49	0.7 ± 0.1^{e}	0.3 ± 0.04^{fg}	0.4 ± 0.06^{f}	0.1 ± 0.01^{hi}
Natural milk pH = 6.34	0.6 ± 0.1^{e}	0.3 ± 0.04^{fgh}	0.3 ± 0.02^{fgh}	0.1 ± 0.01^{i}

Values with same superscripts are not significantly different.

	F-value	p value	Least significant difference
Materials	91.19	$p < 0.001$	2.812
Media	1585.66	$p < 0.001$	2.81
Materials × media	21.99	$p < 0.001$	5.623

with the exception of composan glass and composan LCM. There was a significant difference in the hardness of the different restorative materials after immersion in the tested media with the exception of Vitremer and composan glass in water, Mirinda orange, mango juice, and natural milk. There was no significant difference in hardness of the restorative materials in deionized water and natural milk, as well as in natural milk and mango juice except that measured for composan glass (compomer). There was no significant difference between the effect of Mirinda orange and mango juice on the hardness of composan glass and composan LCM. There was a significant difference between the effect of Mirinda orange and mango juice on the hardness of both types of glass ionomers.

Surface Roughness

Table 3 shows the mean values of surface roughness of the restorative materials after immersion in various beverages. Two-way ANOVA showed a significant difference in surface roughness among the different restorative materials after immersion in various immersion media for 1 week ($p < 0.001$). The interaction of materials and immersion media was highly significant ($p < 0.001$). The average surface roughness of the materials in deionized water was significantly different from that recorded for Mirinda orange and mango juice, whereas it was not significantly different from that measured for natural milk, with the exception of the conventional glass ionomer. The average surface roughness of the materials in Mirinda orange was significantly different from that found for mango juice and natural milk. Mirinda orange and mango juice had shown a significant increase in the surface roughness to a greater extent than that noted for deionized water and natural milk. The surface roughness of the materials immersed in natural milk was not significantly different from that immersed in deionized water, with the exception of conventional glass ionomer. There were significant differences between surface roughness of the restorative materials immersed in mango juice and those immersed in deionized water except that of composite resin.

Solubility

Table 4 shows the mean solubility values of the restorative materials after immersion in various media for 1 week. Two-way ANOVA showed a significant difference among the different restorative materials immersed in various media ($p < 0.001$). The interaction of materials and immersion media was significantly different ($p < 0.001$). All restorative materials showed solubility with various degrees in various beverages. The average solubility of the materials in deionized water was significantly different from those immersed in Mirinda orange and mango juice, whereas it was not

TABLE 4. Solubility (μg/cm^2) of the restorative materials in various immersion media

Medium	Materials			
	Medifil	**Vitremer**	**Composan glass**	**Composan LCM**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Deionized water pH = 6.98	0.7 ± 0.1^{h}	0.2 ± 0.02^{i}	0.3 ± 0.04^{i}	0.03 ± 0.01^{i}
Mirinda orange pH = 2.85	5 ± 0.6^{a}	4 ± 0.5^{bc}	4 ± 0.3^{c}	3 ± 0.5^{d}
Mango juice pH = 3.49	4 ± 0.5^{b}	3 ± 0.4^{e}	3 ± 0.2^{f}	1 ± 0.1^{g}
Natural milk pH = 6.34	0.7 ± 0.1^{h}	0.2 ± 0.03^{i}	0.2 ± 0.04^{i}	0.03 ± 0.003^{i}

Values with same superscripts are not significantly different.

	F-value	*p* value	Least significant difference
Materials	104.22	$p < 0.001$	0.1716
Media	927.62	$p < 0.001$	0.1716
Materials × media	14.48	$p < 0.001$	0.3431

significantly different from that found in natural milk. The average solubility of the materials in Mirinda orange was significantly different from that found in mango juice and natural milk. There was significant difference between solubility of the restorative materials in Mirinda orange, mango juice and that measured for deionized water and natural milk. Also, there was no significant difference in solubility of the restorative materials in deionized water and natural milk.

Correlation between the Different Properties

There was a negative correlation between surface roughness and hardness, as well as between hardness and solubility of the tested restorative materials, i.e., increased hardness followed by decreased surface roughness and solubility. There was a positive correlation between surface roughness and solubility, i.e., increased surface roughness followed by increased solubility of the restorative materials.

DISCUSSION

Mirinda orange was selected in this study because it has the lowest pH in all measured beverages. pH measured for Mirinda orange was 2.85; Pepsi cola was 2.90; Sprite was 3.13; and Fayrouz was 3.00. Mango juice was selected because it has a suitable intermediate acidic pH 3.49, whereas apple juice has pH 2.84. Natural milk was selected because it has neutral pH about 6.34 and is widely consumed.

There were statistically significant correlations between the prevalence of erosion and the consumption of soft drinks, carbonated beverages, alcoholic drinks, fresh fruits, and others. The erosive activity of citric, malic, phosphoric, and other acids as ingredients of beverages and foodstuffs has been demonstrated in in vitro and in vivo studies.[11,14] Citric acid is the main acid in many fruit drinks and juices, with typical concentrations of 15–45 mmol^{-1},[15] whereas non-alcoholic beverages contain phosphoric acid. Citric acid was found to be the most aggressive storage medium for glass ionomer cements, and also for the compomers. Pure composite resin, by contrast, was relatively unaffected by all of the acid solutions.[16] In the present study, Mirinda orange and mango juice have reduced the surface hardness and increased the surface roughness and solubility of glass ionomers and compomer restorative materials resembling the action of citric acid. The hardness of composite resin was significantly decreased by both beverages; on the other hand, their action on the surface roughness of composite resin was moderately affected. A previous study[4] showed changes in the microhardness and compressive strength of the compomers and glass ionomer cement when immersed in low pH soft drinks associated with a high rate of

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solubility. This finding suggests that these media weaken and cause deterioration of the materials' surfaces. Because of the increased consumption of low pH soft drinks, as a clinical consequence load resistance may be reduced and the materials' surfaces may become rough and dull at a clinically detectable level.

To minimize the oxygen inhibition layer, which may influence the results, the composites were cured against a Mylar strip. The results of this study indicated that all tested materials presented lower surface hardness as a result of storage in low pH beverages than the same materials stored in deionized water. The conventional glass ionomer was the most affected by acidic environment, whereas the composite resin was the least affected material. As a result of decreasing the pH of the beverages, the hardness was decreased, whereas the surface roughness and solubility were increased. The effect of the different immersion media was comparable on both resin-modified glass ionomer and compomer restorative materials. Natural milk did not affect the tested materials as the Mirinda orange or the mango juice did. The hardness of the tested materials in water was comparable with that of natural milk, because the pH of both media was nearly equal and in the neutral range.

In the present study, Mylar strip was used as the control surface for measurement of surface roughness because the Mylar strip formed the smoothest surface for restorations.[17] According to the results of this study, all restorative materials tested became rougher after they had been subjected to the lower pH-cycling regimen in Mirinda orange and natural mango juice. This can be attributed to the capability of acid media to soften the restorative materials.[18] The composite resin material showed lower surface roughness than the other restorative materials did. This may be due to the presence of silane coupling agent, which bond the filler chemically to the resin matrix, which may account for their hydrolytic stability.[19] The conventional glass ionomer was the most rough material in the acidic media followed by the resin modified glass ionomer and compomer restorative materials. The surface roughness of the tested materials in water was less than that in natural milk; this may be attributed to the higher pH of water than that of natural milk. The highest surface roughness of conventional glass ionomer may be due to the materials composition, where it presented larger mean particle sizes. Moreover, these materials are more sensitive to water and have longer setting time.[20]

The results of this study demonstrated that composite resin was the least soluble material in various media when compared with glass ionomer materials and compomer. Mirinda orange and mango juice caused a significant surface roughness and solubility to all tested materials because of the lowered pH. The solubility of different materials in water was comparable with that in natural milk because they had comparable and neutral pH. Within the limitations of this in vitro study, the tested null hypothesis that low pH beverages could adversely affect the properties of the esthetic restorative materials was accepted.

CONCLUSIONS

Within the limits of this study the following conclusions were drawn:

1 There was clear evidence that the low pH beverage was the most aggressive immersion medium for the tested glass ionomer and compomer restorative materials. The pure composite resin, by contrast, was relatively less affected by all beverages tested.
2 Unlike Mirinda orange and mango juice, water and natural milk appeared not aggressive towards all restorative materials.
3 The surface hardness reduction, and the increased surface roughness and solubility were different for each material, such that it was smaller for composite resin (composan LCM) and greater for conventional glass ionomer (Medifil) and resin-modified (Vitremer) glass ionomers, whereas compomer (composan glass) was in between.
4 There was a negative correlation between surface roughness and hardness, as well as solubility and hardness of the tested restorative materials, i.e., increased hardness followed by decreased surface roughness and solubility.

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5 There was a positive correlation between surface roughness and solubility, i.e., increased surface roughness followed by increased solubility of the restorative materials.

DISCLOSURE

The author does not have any financial interests in any of the products used in the article.

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