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Physical Properties of Nanohybrid and Microhybrid Resin Composites Subjected to an Acidic Environment: A Laboratory Study

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Clinical Relevance

Consumption of acidic beverages does not alter the color stability nor decrease the hardness of resin composites in comparison with nonacidic beverages. In general, the type of materials and polishing methods are important factors in the maintenance of resin composites.

SUMMARY

Background: This study investigated the hardness and color stability of five resin composites subjected to different polishing methods following immersion in distilled water or lactic acid for up to three months.

Methods and Materials: Three nanohybrid, Paradigm (3M ESPE), Estelite Sigma Quick (Tokuyama), Ice (SDI), and two microhybrid, Filtek P60 and Filtek Z250, composites were examined. Disc-shaped specimens (10×1.5 mm) were prepared and immersed in distilled water for 24 hours then polished using either silicon carbide paper, the Shofu polishing system or were left unpolished (control). The CIE values and microhardness were determined using a spectrophotometer and digital Vickers hardness tester, respectively (n=10) after one, 45, and 90 days of storage in distilled water or lactic acid. Data were analyzed using analysis of variance, Tukey test, and Pearson correlation coefficient.

Results: Ice exhibited the greatest color change, yet Paradigm and Filtek P60 demonstrated the least. Overall, discoloration of tested materials was multifactorial and the effect of storage media depended on the material, polishing method and time interval. The greatest hardness was obtained for Paradigm and the lowest for Estelite. Hardness was

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https://doi.org/10.2341/18-319-L

found to be significantly higher in lactic acid after 45 days (p=0.014) and even higher after 90 days (p<0.001) compared with distilled water.

Conclusions: An acidic environment did not adversely affect color stability or microhardness of the resin composites. There was a significantly mild reverse correlation between hardness and color change in both storage media.

INTRODUCTION

Resin composites are widely used as tooth-colored restorative materials due to excellent color match and ability to attain a highly polished surface. However, a change in color after exposure to the oral environment is a major reason for the replacement of composite restorations.[1] Discoloration of resin composites depends on the composition, surface texture, storage media, mode of cure and degree of conversion.[2-4] The factors related to the composition consist of resin matrix polymers, filler load, size and type, coupling agent, photoinitiator and accelerators.[4-6] The operator's liabilities such as inadequate light curing and improper surface finishing and polishing can also increase discoloration.[4] Furthermore, discoloration of resin composites can occur in the oral environment due to superficial degradation and plasticization as well as adsorption of staining agents from food, beverages, mouthwash, and plaque accumulation.[4,5]

Microhardness, defined as a material's resistance to indentation, is one of the physical properties associated with abrasion and wear resistance of resin composite and may affect a material's clinical performance and long-term durability.[7,8] Surface degradation is also an important factor that necessitates replacement of a restoration.[9] Other factors likely to affect surface hardness include the quality and technique of polishing,[4] material composition, filler loading,[10] and aging in various media.[11]

Previous studies have shown that the hardness and color stability of tooth-colored restorations change during water storage, as water acts as a carrier for staining agents during water sorption.[6,12,13] In addition, water sorption can lead to polymer degradation, which can cause porosity within the microstructure, resulting in further surface softening, filler loss and discoloration.[14,15] In the oral environment, surface biofilm can cause a drop in the local pH[16,17] that may accelerate surface degradation[7,18] and damage the surface integrity of the composite, consequently leading to increased staining susceptibility.[5,6,14]

Previous studies have investigated the effect of acidic beverages containing natural dyes, such as red wine, orange juice, cola, and so forth, on the surface hardness and discoloration of resin composites.[14,15] However, studies are lacking on the effect of organic acids produced by bacterial flora in the oral cavity (eg, lactic acid) on the hardness and color stability of resin composites.[15] Therefore, this study aimed to compare the effect of lactic acid or distilled water, on the color stability and hardness of five nanohybrid and microhybrid resin composites subjected to different finishing and polishing methods.

METHODS AND MATERIALS

Five resin composites (Table 1), two storage media and three finishing and polishing methods (Table 2) were used in this study.

Specimen Preparation

For each material, a total of 60 disc-shaped specimens (10-mm diameter × 1.5-mm thick) of shade A2 were prepared. Resin composite was placed into polyethylene molds, and the bottom and top surfaces were covered with clear Mylar strips (KerrHawe, Scafati, Italy) to prevent the formation of an oxygen-inhibited layer. Two glass slides were placed over the Mylar strips and pressed under finger pressure to extrude any excess material. The glass slides were removed, and the samples were polymerized from each side according to the manufacturers' instructions using an LED curing light (Radii plus LED; SDI, Bayswater, Victoria, Australia) with a wavelength of 440-480 nm and output of 1500 mW/cm^2. The specimen was separated from the mold, and the edges were ground using wet 1000-grit silicon carbide (SiC) paper.

The specimens were then immersed in distilled water at 37°C for 24 hours. The specimens of each material were randomly divided into three groups of 20. One side of two groups was polished, using either SiC papers up to 2000 grit (Zhenjiang Xinya Grinding Tools Co, Yangzhong City, China) or Shofu polishing discs (Shofu Inc, Kyoto, Japan), as displayed in Table 2. The third group was left unpolished after removal of the Mylar strip and acted as the control group. As described below, each specimen was washed and blotted dry with a paper towel, and the baseline color measurements and Vickers hardness test were carried out. Then, specimens of each group were subdivided into two

Table 1: *Description of All Resin Composites Used in the Study*

Resin Composite	Type	Manufacturer	Resin Matrix	Filler Content, Vol%; Type (Sizes)	Lot Number
Paradigm	Nanohybrid	3M ESPE, St Paul, MN, USA	Bis-GMA, UDMA, BISEMA, PEGDMA, TEGDMA	68; zirconia/silica (3 μm), Na Silica (20 nm)	N557215
Filtek P60 (F P60)	Microhybrid	3M ESPE, St Paul, MN, USA	Bis-GMA, UDMA, BISEMA,	61; zirconia/silica (0.01-3.5 μm)	N511095
Estelite Sigma Quick (ESQ)	Nanohybrid	Tokuyama, Dental Co., Tokyo, Japan	Bis-GMA, TEGDMA	63; SiO_2, ZrO_2, PFSC (200 nm and 0.2 μm)	158EY4
Filtek Z250 (F Z250)	Microhybrid	3M ESPE, St Paul, MN, USA	Bis-GMA, UDMA, BISEMA,	60; zirconia/silica (0.19-3.3 μm)	N450445
Ice	Nanohybrid	SDI, Victoria, Australia	UDMA, BISEMA, TEGDMA	61; SAS, AS (0.04-3 μm,)	131192T

Abbreviations: AS, amorphous silica; Bis-EMA, bisphenol A ethylmethacrylate; Bis-GMA, bisphenol A glycidyldimethacrylate; Na, nonagglomerated; PEGDMA, poly(ethylene glycol) dimethacrylate; PFSC, prepolymerized filler of silica composite; SAS, strontium aluminosilicate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

subgroups: half were randomly immersed in distilled water (pH=6.8), and the other half were placed into 0.01 mol/L lactic acid at pH 4 (n=10) and incubated at 37°C for a further 45 and 90 days. The solution was refreshed once per week and heated to 37°C before it was placed in the specimen container.

Color Measurement

Color measurements were obtained after each period in the liquids for each specimen using a spectrophotometer (Spectroshade; MHT Optic Research AG, Zurich, Switzerland). At the completion of each storage period (45 and 90 days), the specimens were washed for 10 seconds and blot dried and baseline measurements and CIE values (L_0, a_0, b_0) were recorded. Finally, the color change (ΔE_n) was calculated based on CIE values (L_n, a_n, b_n) using the following formula: $\Delta E_n = (\Delta L_n)^2 + (\Delta a_n)^2 + (\Delta b_n)^2]^{1/2}$

The differences were determined as ΔE_1 (1-45 days), ΔE_2 (45-90 days), and ΔE_3 (1-90 days).

Measurement of the Vickers Hardness

After 24 hour immersion in distilled water and following polishing, three randomly selected specimens of each group were subjected to Vickers hardness measurement using a digital microhardness tester (SCTMC, MHV-10002, Changhai, China) by applying a 300-g load with a dwell time of 15 seconds. Each specimen was subjected to indentation in three different locations, and the average microhardness was calculated. After 45 and 90 days of storage in distilled water or lactic acid, the same measurement procedures were repeated.

Statistical Analysis

The data were analyzed using SPSS software (version 18, SPSS Inc, Chicago, IL, USA). Three-way analysis of variance (ANOVA) was performed to determine if any interaction existed between the storage media, polishing methods and resin composites. Due to the significant interaction effects, subgroup analysis was applied using Student *t*-tests, one-way ANOVA and Tukey HSD tests. The correlation between ΔE and surface microhardness was assessed using the Pearson correlation coefficient. A *p* value of <0.05 was considered statistically significant.

RESULTS

Color Change

The effect of the three factors (polishing method, storage medium and composite) and their interaction

Table 2: *Polishing Systems and Instructions for Use*

Polishing System	Manufacturer	Instruction for Use
Super-Snap Rainbow Technique Kit (coarse, medium, fine, extra-fine)	Shofu Inc, Kyoto, Japan	Each sequence applied dry with 10 strokes using low speed with 12,000 rpm and light pressure for 30 seconds
Silicon carbide paper (sequence of 600, 1000, 1500, 2000 grit)	Zhenjiang Xinya Grinding Tools Co, China	Wet manual polishing in a single direction with light pressure as follows: coarse 15 strokes, medium 30 strokes, fine 45 strokes; specimen was washed for 10 seconds using an ultrasonic bath between paper grits
Mylar strip	Dentamerica Inc, San Jose, CA, USA	The surface of the resin composite was covered by a clear Mylar strip and glass slab before curing

Table 3: *Interactions Among the Three Factors Using Three-Way ANOVA*

Interaction	*p*-value*				
	Color Change			Hardness	
	ΔE_1	ΔE_2	ΔE_3	45d	90d
Material	<0.001	<0.001	0.010	<0.001	<0.001
Method	0.358	<0.001	0.025	<0.001	<0.001
Storage media	0.028	<0.001	<0.001	<0.001	<0.001
Material × Method	0.009	0.006	0.49	<0.001	<0.001
Storage media × Method	0.024	0.141	0.015	<0.001	<0.001
Material × Storage media	0.914	0.543	0.14	0.014	<0.001
Material × Storage media × Method	0.578	0.001	0.002	<0.001	<0.001

* *A* p*-value <0.05 was considered significant.*

was studied for each storage time (Table 3). The interaction between the combinations of factors is shown graphically in Figure 1A.

For all storage times, regardless of the polishing method and storage medium, there was a significant difference between resin composites ($p<0.001$). Ice demonstrated the greatest color change, followed by Estelite Sigma Quick (ESQ), Filtek Z250 (F Z250), with Paradigm and Filtek P60 (F P60) showing the least color change.

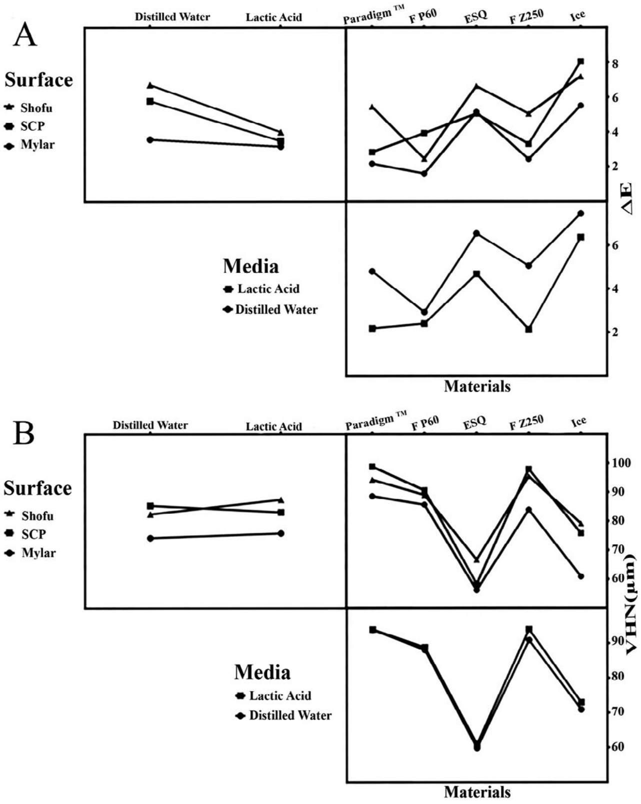


Figure 1. *Interaction plot; data means for color change ΔE (A) and Vickers hardness VHN (B).*

Regardless of the material and storage medium, the comparison between polishing methods showed a significant color change after 45 and 90 days of storage ($p<0.001$ and $p=0.025$, respectively). The specimens polished using the Shofu discs revealed the greatest color change followed by that of SiC paper and Mylar strip. In both distilled water and lactic acid, the effect of the polishing method used was dependent on the material and time of storage (Table 4).

Tables 5 and 6 show the overall means and standard deviations for ΔL_3, Δa_3, and Δb_3 of all polishing methods for each material in distilled water and lactic acid. After 90 days, distilled water immersion resulted in a visible color change ($\Delta E>3.3$) only in Ice ($\Delta E=5.09$) and Estelite ($\Delta E=6.97$) when cured under the Mylar strip. All materials showed a perceptible color change when polished using SiC paper or Shofu. L* differences had the greatest influence on the color change (ΔE) of the specimens. Overall, L* showed a large decrease, and a* and b* varied, showing a large increase for some materials and a slight increase for the remaining material. As an example, Estelite had an increase in b* and decrease in L*, with the specimens becoming darker "yellow." A similar trend of color change was observed for Estelite polished with SiC paper in distilled water. The significant color change of Ice polished with Shofu in distilled water was due to a decrease in L* and an increase in a*, with specimens becoming darker "red," whereas in lactic acid, this was due to only a significant decrease of L*. Significant discoloration of most specimens immersed in distilled water was due to a reduction of L* rather than an increase of a* or b*, resulting in a darker color. Figure 2 illustrates the main effect plot data means for color change after 90 days (ΔE_3).

Table 4: *Mean Color Change (ΔE) ± SD Between Two Different Storage Media for All Materials Using Three Different Finishing and Polishing Systems*[a]

Material	Mylar		Silicon Carbide Paper		Shofu	
	Distilled Water	Lactic Acid	Distilled Water	Lactic Acid	Distilled Water	Lactic Acid
ΔE_1						
Paradigm	1.74 ± 0.93 Aa	2.03 ± 0.58 Aa	0.66 ± 0.28 Ab	1.92 ± 0.93 Aa	3.79 ± 0.89 ABc	3.41 ± 1.61 Ac
F P60	1.04 ± 0.48 Aa	2.55 ± 0.67 Ab	1.31 ± 0.36 Aa	2.37 ± 0.78 Ab	2.94 ± 0.16 ACb	2.29 ± 0.69 Ab
ESQ	1.93 ± 0.53 Aa	3.38 ± 0.86 Ab	3.35 ± 0.44 Bb	4.78 ± 2.00 ABb	4.21 ± 0.93 ABb	2.95 ± 1.24 Ab
F Z250	1.76 ± 0.03 Aa	4.67 ± 0.66 Ab	2.48 ± 1.29 Ba	3.25 ± 1.18 ABb	1.41 ± 0.89 Ca	2.01 ± 0.24 Aa
Ice	4.50 ± 0.99 Ba	4.89 ± 1.00 Aa	5.08 ± 0.28 Ba	6.33 ± 1.76 Bb	5.04 ± 0.65 Ba	4.50 ± 1.20 Aa
ΔE_2						
Paradigm	2.81 ± 1.49 Aa	1.88 ± 0.29 Aa	4.27 ± 0.75 Ab	1.10 ± 0.53 Aa	4.41 ± 1.36 ABb	1.73 ± 1.17 ABa
F P60	1.81 ± 0.53 Aa	2.00 ± 0.97 Aa	4.85 ± 4.38 Ab	3.33 ± 3.60 Ab	2.30 ± 1.03 Aa	0.92 ± 0.18 Aa
ESQ	6.58 ± 0.82 Aa	1.85 ± 0.74 Ab	3.50 ± 0.90 Ac	1.83 ± 1.13 Ab	3.52 ± 2.00 ABc	3.94 ± 0.93 BCc
F Z250	1.58 ± 0.11 Aa	2.95 ± 0.68 Ab	1.70 ± 0.96 Aa	3.72 ± 1.07 Ab	7.61 ± 1.04 Bc	1.79 ± 0.81 ABa
Ice	1.96 ± 0.98 Aa	2.54 ± 0.44 Ab	7.43 ± 0.81 Ac	3.23 ± 0.48 Ab	7.47 ± 1.20 Bc	4.38 ± 0.94 Cb
ΔE_3						
Paradigm	1.85 ± 1.11 Aa	2.50 ± 1.40 ABa	4.44 ± 0.53 Ab	1.25 ± 0.04 Aa	8.11 ± 1.47 Ac	2.79 ± 0.38 Aa
F P60	1.65 ± 0.17 Aa	1.56 ± 0.08 Aa	4.54 ± 0.93 Ab	3.33 ± 1.00 Ab	2.59 ± 1.31 Ba	2.33 ± 0.63 Aa
ESQ	6.97 ± 0.98 Ba	3.30 ± 1.37 ABb	6.18 ± 2.21 Aa	3.93 ± 1.99 ABb	6.45 ± 1.66 ABa	6.81 ± 1.4 Ba
F Z250	2.29 ± 1.44 Aa	2.57 ± 1.42 ABa	4.32 ± 1.15 Ab	2.30 ± 1.30 Aa	8.55 ± 2.28 Ac	1.54 ± 0.07 Aa
Ice	5.09 ± 1.40 ABa	5.93 ± 1.43 Ba	9.40 ± 1.58 Ab	6.65 ± 0.84 Ba	7.85 ± 0.45 Ab	6.52 ± 1.32 Ba

[a] *In each column, mean values with different uppercase letters show a significant difference between the five materials ($p<0.05$). In each row, mean values with different lowercase letters show a significant difference between polishing methods in two storage media.*

Vickers Hardness

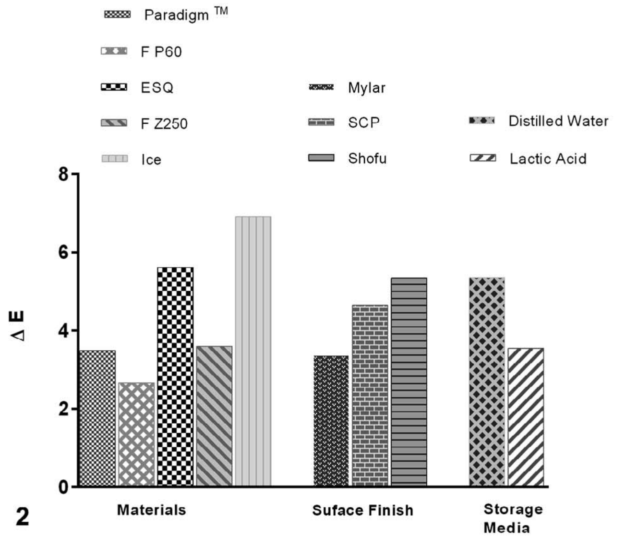
The effect of the three tested factors and the interaction between these factors were significant, as shown in Table 3. In general, hardness was found to be significantly higher in lactic acid ($p<0.001$) compared with distilled water. With an increase in storage time, the hardness value increased significantly ($p<0.001$), except for the specimens polished with SiC paper, which showed a transient decrease after 45 days followed by an increase in hardness after 90 days. Among the resin composites, the greatest hardness value was obtained for Paradigm and the lowest for ESQ followed by Ice (Table 7). The interaction between combinations of factors is shown in Figure 1B. Figure 3 illustrates the main effect plot data means for Vickers hardness values after 90 days.

Correlation Between Color Change and Vickers Hardness

There was a weak and reverse correlation between color change and hardness ($r=-0.264$, $p<0.001$). The same trend was noted for the storage media ($r=-0.282$, $p=0.007$, and $r=-0.232$, $p=0.028$, for distilled water and lactic acid, respectively) and the polishing method ($r=-0.288$, $p=0.026$; $r=-0.366$, $p=0.004$; and $r=-0.397$, $p=0.002$, for Mylar, SiC paper, and Shofu, respectively). There was no significant correlation between the hardness and color change for each material when analyzed separately.

Table 5: *Means and Standard Deviation of Δa, Δb, and ΔL for All Materials in Two Different Storage Media Using Three Different Finishing and Polishing Systems After Water Immersion*

	Polishing Method								
	Mylar			Silicon Carbide Paper			Shofu		
	Δa	Δb	ΔL	Δa	Δb	ΔL	Δa	Δb	ΔL
Paradigm	−0.07 ± 0.55	−1.30 ± 0.96	−0.60 ± 0.61	−1.70 ± 0.40	−3.30 ± 0.35	−2.37 ± 0.74	−2.23 ± 0.38	−6.37 ± 1.04	−4.50 ± 1.04
F P60	−1.33 ± 0.25	0.23 ± 0.75	−0.53 ± 0.58	−1.83 ± 0.87	−2.07 ± 3.51	−2.50 ± 3.54	−0.97 ± 0.31	0.27 ± 0.32	−2.30 ± 1.47
ESQ	−0.70 ± 0.26	−4.80 ± 2.80	−4.87 ± 1.80	−0.10 ± 0.61	−3.77 ± 1.65	−4.87 ± 1.56	−1.70 ± 0.95	−3.57 ± 3.17	−4.77 ± 1.05
F Z250	−0.53 ± 0.45	−0.73 ± 1.24	−1.80 ± 1.47	−0.13 ± 0.42	−2.10 ± 1.77	−3.53 ± 0.83	−1.33 ± 0.29	−4.87 ± 1.70	−6.90 ± 1.59
Ice	−0.87 ± 0.80	0.93 ± 0.55	−4.87 ± 1.40	−2.13 ± 0.68	−3.53 ± 1.45	−8.43 ± 1.10	−3.07 ± 0.15	−0.63 ± 0.85	−7.17 ± 0.49



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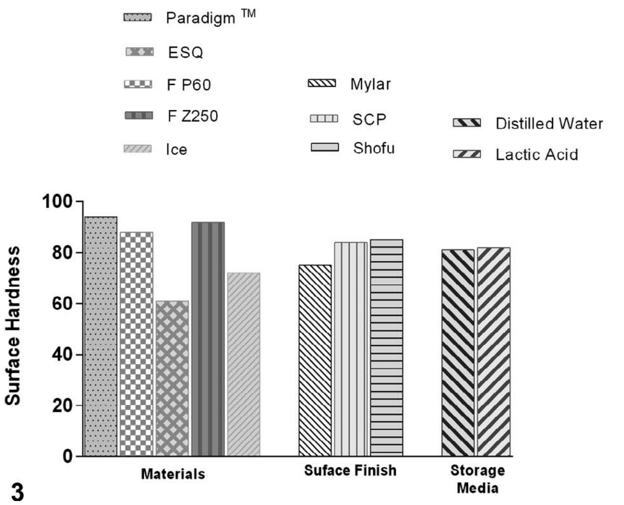

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Figure 2. *Main effect plot; data means for color change (ΔE).*

Figure 3. *Main effect plot; data means for Vickers hardness value (VHN).*

DISCUSSION

In the oral environment, restorative materials face an acidic challenge produced by bacterial metabolism or the consumption of acidic foods and beverages. The results of the present study indicated that after 45 days of storage in lactic acid, the color change of the resin composites tested were significantly greater than when stored in distilled water. This may be explained by the direct relationship between water sorption and discoloration of the resin composites.[6,14] In a previous study, it was shown that resin composite immersed in lactic acid had greater sorption/solubility and diffusion coefficient.[19] Conversely, our results revealed that within 90 days of storage, the total color change in distilled water was more pronounced. It has been confirmed that a color difference of $\Delta E \geq 3.3$ is the critical value for visual perception of esthetic restorations.[20,21] Our findings showed that the color stability of only one of the tested composites showed a color change of less than 3.3 when stored in distilled water; however, in lactic acid, three resin composites presented acceptable color stability ($\Delta E < 3.3$).

The effect of storage media on hardness has been investigated in previous studies, showing a greater degree of micromorphological damage when materials were immersed in an acidic medium compared with distilled water. Organic acids can impose a detrimental effect on wear and surface degradation of polymeric resins and resin composites,[19] which may accelerate the degradation process and thus reduce the life span of a restoration.[19] In particular, lactic acid has been shown to decrease the surface hardness of resin composites.[17,22] Chadwick and others[23] determined that after one year storage of three resin composites (Occlusin, ICI Dental; P-30, 3M; and Fulfil, Caulk Dentsply) in distilled water and lactate, the surface microhardness of all composites was reduced.[23] Buchalla and others[24] noticed only minor negative effects on resin-based luting cements when stored in acidic solutions.[24] In contrast, Asmussen and others[25] found no significant change in the hardness of bisphenol A diglycidyl methacryalate (Bis-GMA)–based polymers immersed in lactic acid. Similarly, Munchow and

Table 6: *Means and Standard Deviations of Δa, Δb, and ΔL for All Materials in Two Different Storage Media Using Three Different Finishing and Polishing Systems After Lactic Acid Immersion*

	Polishing Method								
	Mylar			Silicon Carbide Paper			Shofu		
	Δa	Δb	ΔL	Δa	Δb	ΔL	Δa	Δb	ΔL
Paradigm	−0.53 ± 0.21	−0.40 ± 0.20	−2.30 ± 1.65	−0.60 ± 0.44	−0.33 ± 0.98	0.27 ± 0.64	−0.27 ± 0.40	−2.57 ± 0.55	−0.93 ± 0.38
F P60	−0.50 ± 0.10	0.73 ± 0.86	0.43 ± 1.62	−1.27 ± 0.83	−0.73 ± 2.32	−1.10 ± 2.55	−0.97 ± 0.31	−1.43 ± 0.55	−1.47 ± 0.67
ESQ	0.07 ± 0.84	−1.70 ± 1.25	−2.50 ± 1.51	0.00 ± 1.31	−2.53 ± 2.38	−2.30 ± 1.49	−1.70 ± 0.17	−5.07 ± 0.97	−4.20 ± 1.15
F Z250	−1.50 ± 0.36	−1.47 ± 0.90	−1.37 ± 1.29	−1.33 ± 0.06	−0.57 ± 1.59	−0.37 ± 1.93	0.03 ± 0.25	0.63 ± 0.78	−1.10 ± 0.70
Ice	−1.93 ± 0.15	−1.73 ± 1.25	−5.27 ± 1.27	−2.20 ± 0.50	−0.37 ± 0.21	−6.23 ± 1.02	−1.77 ± 0.12	−1.00 ± 1.95	−6.00 ± 1.31

Table 7: *Comparison of Vickers Hardness Value Between Two Different Storage Media for All Materials Using Three Different Finishing and Polishing Systems Analyzed by Independent t-Tests*[a]

Material	Mylar		Silicon Carbide Paper		Shofu	
	Distilled Water	Lactic Acid	Distilled Water	Lactic Acid	Distilled Water	Lactic Acid
Baseline						
Paradigm	84.37 ± 0.13 Aa		92.26 ± 0.32 Aa		89.18 ± 0.21 Aa	
F P60	84.79 ± 2.82 Aa		88.1 ± 0.21 Ba		84.22 ± 0.59 Ba	
ESQ	43.35 ± 0.08 Ba		52.47 ± 0.94 Cb		54.98 ± 0.92 Cb	
F Z250	78.74 ± 1.17 Ca		88.88 ± 1.72 Bb		86.22 ± 0.30 Db	
Ice	52.82 ± 0.41 Da		70.84 ± 1.01 Db		65.15 ± 0.48 Eb	
45 days						
Paradigm	80.69 ± 0.81 Aa	87.45 ± 0.64 Ab	87.75 ± 0.83 Ab	91.44 ± 0.73 Ab	92.63 ± 0.42 Ab	92.17 ± 0.31 Ab
F P60	85.91 ± 0.34 Ba	85.38 ± 0.59 Ba	86.31 ± 0.23 Ba	87.37 ± 2.25 Ba	88.16 ± 0.42 Ba	87.67 ± 0.33 Ba
ESQ	41.39 ± 1.03 Ca	49.51 ± 1.92 Cb	46.28 ± 0.76 Ca	51.03 ± 0.29 Cb	51.50 ± 0.86 Cb	48.47 ± 0.79 Cb
F Z250	82.36 ± 2.73 Aa	82.95 ± 2.31 Da	83.02 ± 3.36 Da	89.54 ± 2.70 Da	83.05 ± 0.75 Aa	85.54 ± 3.31 Da
Ice	57.34 ± 0.60 Da	55.35 ± 0.59 Ea	55.77 ± 3.29 Ea	62.58 ± 1.92 Eb	63.08 ± 0.04 Db	64.49 ± 0.60 Eb
90 days						
Paradigm	84.16 ± 0.25 Aa	93.08 ± 0.17 Ab	105.29 ± 2.26Ac	92.11 ± 0.21 Ab	91.82 ± 0.35 Ab	96.63 ± 0.53 Ab
F P60	85.66 ± 0.34 Ba	85.59 ± 0.32 Aa	92.35 ± 1.15 Aa	88.92 ± 0.45 Aa	86.12 ± 0.57 Ba	91.88 ± 0.70 Ba
ESQ	51.82 ± 0.52 Ca	60.52 ± 0.35 Bb	58.39 ± 0.16 Bb	58.26 ± 0.42 Bb	69.29 ± 0.59 Cc	64.12 ± 0.38 Cb
F Z250	83.74 ± 0.53 ABa	84.06 ± 0.42 Ca	97.96 ± 0.09 Ab	97.86 ± 0.54 Ab	90.89 ± 0.40 Da	100.03 ± 1.35 Bb
Ice	65.76 ± 0.40 D	56.03 ± 0.19 D	73.15 ± 0.49 C	78.36 ± 0.33 C	73.82 ± 0.33 E	84.53 ± 0.16 D

[a] *In each column, mean values with different uppercase letters show a significant difference level in the ANOVA test between five materials ($p<0.05$). Data are represented as mean ± SD*

others[26] reported a slight increase in the surface hardness of Filtek Z250 when immersed in 0.02 N lactic acid compared with distilled water. The results of our study showed no significant difference between distilled water and lactic acid. However, as Table 7 presents, immersion in lactic acid caused a slight increase in hardness dependant on the material and polishing method.

Among the materials tested, regardless of the time interval, polishing method, or the storage medium, Ice had the greatest color change followed by ESQ and F Z250, with the lowest values being observed for F P60 and Paradigm, respectively. Ertas and others[4] reported a similar finding showing less discoloration for F P60 and F Z250 compared with a microhybrid resin composite (Quadrant LC, Cavex) and two nanohybrids (Filtek Supreme, 3M-ESPE; Grandio, Voco). Since the type and compositions of the resin matrix strongly affect the hydrophilicity, it can play an important role in the long-term color stability of restorations.[14] As shown in Table 1, F P60 and F Z250 contain no TEGDMA in their matrix composition. It was acknowledged that the addition of small amounts of TEGDMA into a Bis-GMA–based resin composite significantly increased the water sorption of Bis-GMA–based resins.[27]

Other parameters such as the filler load, size, distribution, and type can influence the surface roughness, polishability, hardness, and water sorption of the resin composite.[14] Although a higher filler-resin ratio has contributed to low water sorption and staining susceptibility of resin composites,[2] the role of filler size, particularly when comparing microhybrid and nanohybrid composites, is still an ongoing controversy.[28,29] It has been indicated that during polishing procedures, voids may be produced by the shaving off of filler particles; hence, in nanohybrids, smaller particles are plucked out; therefore, smaller voids are created on the surface compared with microhybrids.[30] Consequently, it is expected that discoloration would be lower in the composites with smaller particles.[4] Topcu and others[29] in their study on the color change of resin composites after 24 hour immersion in eight staining solutions reported that nanocomposite exhibited the least discoloration. In contrast, others[4,5,28] showed a significantly greater discoloration for a nanohybrid (Grandio Nano, Voco) than a microhybrid (Arabesk top, Voco). In our study, two nanohybrids (Ice and ESQ) showed greater color change compared with two microhybrids (F P60 and F Z250) and a nanohybrid (Paradigm). Paradigm also showed the highest microhardness followed by F P60 and F Z250. The lowest color change and the highest hardness values for Paradigm can be attributed to its higher filler volume loading (68 vol%) compared with the other resin composites (60-63 vol%) used in this study. The great influence of filler loading on the Vickers hardness of resin composites has been acknowledged previously.[9,31,32] Nevertheless, discoloration of resin composites is multifactorial and seems to be material dependent.

CONCLUSION

Within the limitations of this study, in comparison with distilled water, the color stability and microhardness of the resin composites were superior in lactic acid. The hardness and color stability of two nanohybrids (Ice and ESQ) were found to be lower than those of microhybrids (F Z250 and F P60). Furthermore, Paradigm, a nanohybrid with the highest filler loading in this study, exhibited the greatest hardness and was the second best in terms of color stability. Using Mylar strips caused the lowest hardness and discoloration, and the highest discoloration was reported with the specimens using the Shofu polishing system. The results of the present study are valid for the laboratory conditions used. Laboratory data may provide a perception into clinical performance; however, a direct relationship between laboratory and clinical performance cannot always be assumed.

Acknowledgments

A special thanks to SDI and 3M ESPE Victoria, Australia, for generously providing the materials. The funding granted (14704) to conduct this research was provided by Shiraz University of Medical Sciences.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article

(Accepted 31 August 2019)

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