Original Article

Evaluation of staining and color changes of a resin infiltration system

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ABSTRACT

Objective: To analyze the staining and color changes of a resin infiltrant system used for management of white spot lesions (WSLs).

Materials and Methods: WSLs were artificially created on left buccal halves of 48 extracted human teeth. These sites were then treated with resin infiltration (RI) while the right halves of the teeth remained as nonresin (NRI) areas. Six groups were formed (n = 8 teeth/group) and were exposed to the following: red wine, coffee, orange juice, combined staining agents, accelerated aging, and distilled water for 1 week. The teeth were then polished with a prophy cup and polishing paste. Color properties were assessed using a spectrophotometer at baseline (T0), after each exposure (T1), and after polishing (T2). Color difference (ΔE^*) was calculated between each time point for both halves of the teeth (RI and NRI). Data were analyzed with a two-way analysis of variance with presence of resin infiltration and staining agents as the main effects for each time point pair. Multiple comparisons were made with a Bonferroni post hoc test. The level of significance was set at $P < .05$.

Results: The red wine and combined staining agent groups caused the greatest color change between all intervals ($P < .05$). Significant interactions were recorded between resin infiltration application and staining agents at all time periods ($P < .05$). The presence of resin infiltration as a main effect did not affect color change between T0 and T2 ($P > .05$).

Conclusions: RI areas showed higher staining susceptibility than did NRI areas. However, prophylaxis had a strong effect on reversing the discoloration of both RI and NRI areas. (*Angle Orthod.* 2016;86:900–904)

KEY WORDS: Resin infiltrant; Staining agents; Color changes; White spot lesions

INTRODUCTION

A common issue following orthodontic treatment with fixed appliances is the presence of smooth-surface enamel demineralization, or white spot lesions (WSLs).[1] WSLs form when a patient's oral hygiene practices are inadequate, thus plaque remains on their teeth for an extended period.[2] It has been reported that roughly half of patients completing orthodontic treatment have some form of WSLs, substantiating the urgent need for effective preventive or corrective measures.[3–6]

The use of fluoride to minimize or prevent demineralization has been previously shown to be effective.[7–10] Fluoride ions delivered through mouth rinses, varnishes, gels, and sealants have been reported to reduce the severity and incidence of WSLs in orthodontic patients.[7–10] However, due to lack of patient compliance, enamel demineralization remains a challenge in orthodontics, and in some cases the presence of white spots may cause significant esthetic problems. The esthetics of postorthodontic WSLs can be improved using microabrasion[11–14] and resin infiltration tech-

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Table 1. Specifics of ISO4892-2: 2006—Standard Used for Accelerated Aging

Artificial aging standard: ISO4892-2: 2006	
Irradiation light	Daylight
Radiance CT	340 nm
Dosage (kJ/m^2)	300/450
Light exposure—dry (min)	102
Sprinkle time—wet (min)	18
Chamber air temperature (°C)	38 ± 3
Black standard temperature	68°C (Max, 99°C)

niques,[15–19] wherein success is attributed to the removal or masking of the superficial lesions.

Resin infiltration therapy utilizes a low-viscosity resin that readily flows into an etched enamel substructure. Once it has infiltrated, the material is light-cured. The refractive index of the resin is very close to that of enamel, which virtually eliminates the appearance of the WSLs. Studies have been conducted investigating the ability of resin infiltrants to mask WSLs, and they have shown to do this effectively.[15–19] The question remaining is whether resin-treated enamel stains and ages the same as untreated enamel. Over time, teeth undergo color changes due to normal use including exposure to food and drink. This occurs because many common foods and drinks contain particles that are attracted to the inorganic component of enamel, hydroxyapatite.[20] When consumed, these particles may infiltrate the porous enamel structure and become intertwined in the matrix, altering its color properties. Although this is generally not a rapid process, particles may accumulate in the matrix over time, resulting in a significant color change.[20]

In today's society, significant importance is placed on dental esthetics. In an individual without restorations, all teeth change color at approximately the same rate. In an individual with both unrestored and restored teeth, however, qualities and rates of color change may not be consistent. It is important to make this comparison to elucidate the long-term esthetic effects of using resin infiltrants.

The purpose of this study was to assess the effects of staining on the color properties of tooth areas treated with a resin infiltrant compared with nontreated areas.

MATERIALS AND METHODS

Procedure

A total of 48 extracted human teeth were included. Eleven premolars and 37 molars were used since there are no significant differences in the enamel quality of different types of teeth.[21] Exclusion criteria were the presence of stain, demineralization, decay, fluorosis, enamel defects, or restorations. Before the study, the right half of the buccal surface of each tooth was protected with two coats of clear nail polish (Revlon, New York, NY). On the left half, WSLs were artificially created using an acidic solution as described by Subramaniam et al.[22] and then treated with Icon resin infiltrant (Icon Infiltrant, DMG, Hamburg, Germany), per manufacturer's instructions. The right half of each tooth will be referred to as nonresin infiltrated (NRI) and the left half as resin infiltrated (RI). Next, both sides were polished with polishing discs (fine and superfine, Shofu Dental, San Marcos, Calif), running at 11,000 rpm with each disc for 5 seconds, removing the nail polish from the right side.

Six groups were evaluated: red wine immersion (RW, n = 8, PopCrush Red Blend, PopCrush Wines, Acampo, Calif), coffee immersion (CF, n = 8, Peet's Ground Coffee, French Roast, brewed per manufacturer's instructions: 2 tablespoons of coffee/6 ounces of water), orange juice immersion (OJ, n = 8, Safeway Farms 100% Pure Orange Juice, Phoenix, Ariz [from concentrate—no pulp]), a combination group that underwent immersion in red wine, coffee, and orange juice (CM, n = 8), a group exposed to accelerated aging (AA, n = 8, Atlas Suntest XXL, per standard: ISO4892-2: 2006, Table 1), and a control group exposed to distilled water throughout the experiment (CT, n = 8). The RW, CF, and OJ groups were exposed to their respective solutions 24 h/d for 7 days. Solutions were replaced every 24 hours. The CM group was immersed in red wine, coffee, and orange juice each for 24 hours, then this cycle was repeated, and then 8 hours in each solution on the final day. The AA group was exposed to light/dark and wet/dry cycles per ISO Standard ISO4892-2: 2006 to a total of 450 kJ/m^2. Next, the buccal surfaces of all teeth (both RI and NRI) were polished at 5000 rpm with a prophy cup, using polishing paste (Enamel Pro, medium grit, mint flavor; Plymouth Meeting, Pa) for 30 seconds.

Color Assessment

Spectrophotometric color measurements were performed using the SpectroShade Micro spectrophotometer (MHT Optic Research AG, Niederhasli, Switzerland). Spectrophotometric assessments were performed at baseline (T0), after 7 days of immersion in staining solution or exposure to 450 kJ/m^2 for the AA group (T1), and after polishing (T2), to record the color coordinates of the RI and NRI areas of each tooth.

Instrumental color measurements were performed using the Commission International de L'Eclairage L*a*b* color notation system (CIELAB).[23] The SpectroShade was calibrated according to the manufacturer's instructions. A custom positioning table was fabricated to position the SpectroShade relative to the buccal surface of each tooth in a fixed, standardized, and repeatable position for each measurement. The

Table 2. Color Changes (ΔE*) and SD Between Time Points[a]

	T0–T1, Mean (SD)			T1–T2, Mean (SD)			T0–T2, Mean (SD)		
Staining Agent	Resin	Nonresin	Difference	Resin	Nonresin	Difference	Resin	Nonresin	Difference
Red wine (RW)	42.4 (7.1)	29.2 (5.5)	13.2	29.9 (8.0)	13.7 (6.3)	16.2	13.9 (2.1)	17.4 (3.0)	−3.5
Coffee (CF)	8.0 (2.6)	4.1 (2.2)	3.9	5.5 (2.7)	1.6 (0.8)	3.9	4.9 (1.0)	3.5 (1.7)	1.4
Orange juice (OJ)	6.6 (4.4)	6.7 (3.4)	−0.1	5.3 (3.0)	3.9 (3.4)	1.4	3.6 (1.3)	4.9 (3.2)	−1.3
Combination (CM)	28.0 (4.2)	22.2 (10.5)	5.7	17.5 (4.1)	12.6 (8.8)	4.9	11.2 (1.6)	10.2 (2.7)	1.0
Accelerated aging (AA)	6.1 (2.9)	4.8 (2.7)	1.3	2.1 (1.7)	2.6 (1.7)	−0.5	4.8 (1.8)	3.4 (1.7)	1.4
Control (CT)	0.9 (0.3)	0.9 (0.5)	0.0	1.4 (0.9)	1.5 (0.9)	−0.1	1.3 (0.8)	1.4 (0.7)	−0.1

[a] T0–T1 indicates baseline vs after staining/aging; T1–T2, after staining/aging vs after polishing; T0–T2, baseline vs after polishing.

base of the positioning table allowed the spectrophotometer to be oriented in the same position each time it was placed on the table. The upper member of the table contained a fixed, asymmetrically indexed holding cup, into which customized tooth positioning jigs were inserted and removed with identical orientation between time points. Customized silicone tooth positioning jigs (ClearBite, DenMat, Lompoc, Calif) were fabricated so that the buccal surface of each tooth was centered within the focal target box of the SpectroShade at an angle such that a tangent from the center of the buccal surface ran parallel to the lens of the focal box, ensuring that positioning was both optimized and repeatable for each measurement. A standardized millimetric grid was affixed to the viewing screen of the SpectroShade. The grid was used to identify and record coordinates of two points: one located halfway between the midline of the buccal surface and the left proximal surface of each tooth and the other located halfway between the midline and the right proximal surface, which served as the precise locations where measurements were made at all time points. Three measurements were taken at each location at each time point, and the average values for L* (lightness, achromatic color coordinate), a* (green/red coordinate), and b* (blue/yellow coordinate) were calculated. From these average values, the resultant color difference (ΔE*) between each two time points (T0–T1, T1–T2, T0–T2) was calculated as follows[24]:

$$\Delta E^* = \left[(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2 \right]^{1/2}$$

Statistical Analysis

Data from each time interval were analyzed using a two-way analysis of variance with the presence of resin infiltration and staining agent serving as the main effects. Multiple comparisons were made with the Bonferonni post hoc test. Statistical tests were performed using IBM SPSS Statistics 23.0 for Mac (SPSS Inc, Chicago, Ill). Level of significance was set at $P < .05$.

RESULTS

Table 2 presents the mean and standard deviations of color differences for each time interval. The RW and CM groups showed the greatest color differences (ΔE*) for both RI and NRI surfaces between T0–T1, T1–T2, and T0–T2. All other groups had much smaller color changes for RI and NRI, as well as smaller differences between the two sides. As expected, the CT group showed virtually no difference between the color changes of the two sides.

Presence of resin infiltration significantly affected the ΔE* between T0–T1 and T1–T2 (Table 3, $P < .05$). This means that, if the type of staining agent was disregarded, there were significant differences between RI and NRI areas for the T0–T1 and T1–T2 intervals. However, the T0–T2 evaluation showed that both the RI and NRI surfaces were affected similarly by the entire experiment (Table 3, $P > .05$). The staining agent as a main effect caused significant differences at all evaluation periods (Table 3, $P < .05$). Multiple comparisons showed that the RW and CM groups

Table 3. ANOVA for ΔE* Between Time Points[a]

	T0–T1					T1–T2					T0–T2				
Effects	Type III Sum of Sq.	df	Mean Square	F	*P* Value	Type III Sum of Sq.	df	Mean Square	F	*P* Value	Type III Sum of Sq.	df	Mean Square	F	*P* Value
Presence of resin infiltration	384.3	1	384.3	15.9	.000	441.1	1	441.1	19.7	.000	.8	1	.8	.1	.657
Staining agent	15,310.1	5	3062.02	127.3	.000	5549.4	5	1109.8	49.7	.000	2297.6	5	459.5	103.0	.000
Presence of resin infiltration *staining agent	513.4	5	102.6	4.2	.002	771.6	5	154.3	6.9	.000	76.2	5	15.2	3.4	.007

[a] T0–T1 indicates baseline vs after staining/aging; T1–T2, after staining/aging vs after polishing; T0–T2, baseline vs after polishing.

showed significant differences when individually compared with other groups at each time interval ($P < .05$).

Significant interactions were recorded between the presence of resin infiltration application and staining agent at each time interval (Table 3, $P < .05$). This finding means that the intensity of color differences did not follow a similar trend when surface type was exposed to different agents at any of the evaluation periods.

DISCUSSION

The CIELAB 50:50 perceptibility threshold and 50:50 acceptability threshold in dentistry were found to be $\Delta E^* = 1.2$ and 2.7, respectively.[25] This means that 50% of observers will note a perceptual difference between two colors when the ΔE^* is 1.2. Similarly, 50% of observers will determine a color difference to be acceptable at a ΔE^* of 2.7, while the other 50% will consider this color difference unacceptable. Based on our findings, resin infiltration surfaces showed higher staining susceptibility compared with regular enamel surfaces upon exposure to staining agents and accelerated aging. Nevertheless, between T0 and T1, all staining agents and accelerated aging groups had ΔE^* value differences outside the limit of clinical acceptability compared with the control group (Table 2) for both RI and NRI areas.

Rey et al.[26] showed that 1-mm thick, disk-shaped specimens of resin infiltrant (Icon) showed a higher discoloration range than did several marketed bonding systems after exposure to coffee, tea, or red wine. This could be a clinical concern for resin infiltration applications over time. However, data from our study showed that polishing reduced the effects of discoloration. As a result, ΔE^*s of both RI and NRI surfaces were very close to the T0–T2 interval. This could be explained by the similarity between the refractive indexes of the normal enamel surface and the resin infiltration system (Icon) used in this study.[19] Between T1 and T2, the color difference values for all groups showed consistent changes, indicating that polishing had a strong effect on decreasing staining on both RI and NRI surfaces. RW, as an example, had a ΔE^* for RI of 42.4 and 29.2 for NRI before polishing (Table 2). Polishing produced a reversal effect in color coordinate values, with RI having a ΔE^* of 29.9 and an NRI of 13.7 (Table 2). This indicates that 71% of the initial staining on the RI side of the teeth in the RW group was eliminated by polishing and 47% on the NRI side. Similarly in the CF group, staining was reduced 69% on the RI side and 39% on the NRI side. Our findings are in agreement with those of Borges et al.,[27] who found that wine and coffee resulted in significant color alteration in their resin-treated bovine enamel/dentin cylindrical samples. Similarly, their study showed that polishing the specimens minimized the extent of extrinsic staining.

In a study without taking the polishing factor into consideration, Rey et al.[26] recommended advising patients to avoid consuming stain-forming food and beverages. However, results of the current study suggest that, for patients who do not consume red wine, the amount of color change of teeth treated with resin infiltration would remain almost identical with normal enamel surfaces. The evaluation that was most clinically applicable in our study was between T0 and T2. This span most accurately reflected the daily range of exposures of a patient's teeth. The staining and accelerated aging simulated eating and drinking, and the polishing represented cleaning of teeth. As a result, the average difference between the ΔE^*s of RI and NRI areas (Table 2) all fell below the acceptable range except for the RW. This is mostly because RW stained more than the other solutions (ΔE^* of 42.4 for RI and 29.2 for NRI from T0–T1; Table 2). As a general rule, it should be the clinician's responsibility to warn his or her patients about the long-term effects of consuming colored beverages and foods, especially red wine, in order to increase the longevity of the resin infiltration in esthetically important areas.[26,28]

Our results showed that, if the type of staining agent is disregarded, the presence or absence of resin infiltration would not affect the color difference significantly for the T0–T2 interval since prophylaxis had a strong effect on reversing discoloration of both RI and NRI areas. This finding is promising for utilization of resin infiltration techniques in the management of WSLs. It has already been reported that resin infiltrant can penetrate subsurface demineralized enamel up to 400 μm,[29] which makes polishing following heavy staining feasible, as explained in our methods. However, regular day-to-day tooth brushing, especially using battery-powered toothbrushes, has also been shown to be efficient for removal of extrinsic staining for both enamel[30] and resin surfaces.[31,32] Since susceptibility to extrinsic staining by a resinous material may also be related to the type of resin matrix used,[33] the clinical outcome will likely depend on the individual case. It would be interesting, however, to evaluate the effects of mechanical or battery operated toothbrushes on the optical properties of resin infiltration therapy. Additionally, the long-term effects of tooth bleaching in resin-treated areas should be explored further.

CONCLUSIONS

- Enamel treated with resin infiltrant was more susceptible to discoloration than was regular enamel when exposed to various staining agents.

- Red wine stained resin- and non-resin-treated surfaces more than did coffee, orange juice, or accelerated aging.
- Prophylaxis of teeth after staining and accelerated aging caused a highly evident reversal of staining effects.
- The intensity of color changes depended on the individual staining agent. The presence of resin had no effect on the color difference between T0 and T2 when the staining agent type was disregarded.

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