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Original article

Colour stability of resin infiltrated white spot lesion after exposure to stain-causing drinks

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ABSTRACT

Background: The resin-based materials are used extensively in esthetic restorations but are. prone to color changes over time.
Aims: To assess the discoloration effect of red tea, Arabic coffee, and black coffee on the resin infiltrated white spot lesions (WSL). Moreover, to investigate the impact of time (1d, 3d, and 7d) on the discoloration of the resin infiltrated WSLs.
Materials and methods: Thirty-three extracted human premolar teeth were used to create WSLs, and ICON resin infiltration treatment was performed to obliterate the enamel pores. Teeth with resin infiltrated WSLs were sectioned into two halves by cutting mesio-distally and cross-sectionally at 1 mm below the CEJ. The resin infiltrated specimens was exposed to control (artificial saliva) and staining subgroups. Colour stability was assessed using the CIE L*a*b* system.
Results: Analysis of variance ($p < 0.05$) and Tukey's multiple comparison tests revealed an insignificant color change in the control group. The immersion of resin infiltrated specimens at time intervals of 1 d ($p < 0.001$), 3 d ($p < 0.001$), and 7 d ($p < 0.001$) showed significant differences in color change.
Conclusion: Resin infiltrated WSLs showed marked color changes after exposure to red tea, black coffee, and Arabic coffee over time. Severe discoloration of the infiltrant was evident with the use of red tea compared to black coffee and Arabic coffee. This suggests that ICON resin-based composite material might not be a suitable material for WSL infiltration.

1. Introduction

Dental caries is a common multifactorial disease that depends on host vulnerability, micro-organisms, sugar-rich diet, and time to progress (Devang Divakar et al., 2017). Caries lesion is the outcome of a complex cycle involving many disturbances of the mineral equilibrium between the tooth and the dental plaque, culminating in mineral degradation. This imbalance may be manifested clinically in various forms from the first occurrence as an enamel opacity (i.e., white spot) to large cavities that can reach the dental pulp (Fejerskov et al., 2015).

A white spot lesion (WSL) is defined as subsurface enamel porosity from carious demineralization on the smooth surfaces of the tooth. It appears as a milky white opaque region (Summitt et al., 2001). Lesions show an intact surface layer, followed below the body with the most porous lesion. The active WSL has a chalky, opaque appearance, as light is dispersed mainly within the body of the lesion (Kidd and Fejerskov, 2004).

Several options are available for the treatment of WSLs. Enhancing remineralization using fluoride or phosphopeptide amorphous calcium phosphate has been shown to have a positive effect on caries arrest. Nonetheless, clinical trials have not demonstrated a cosmetic change or a substantial decrease in carious lesions (Bailey et al., 2009). Though micro-abrasion is effective for shallow WSLs yet is technically demanding and may involve the removal of enamel's minerals. Composite or ceramic restorative methods have

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been commonly used with excellent cosmetic results but are typically associated with a major loss of hard dental tissue (Meireles et al., 2009). However, these treatment methods require high patient compliance, also the restoration option would weaken the tooth structure and require frequent replacement (Dorri et al., 2015).

Recently, resin infiltration has been presented as a minimally invasive approach that could effectively prevent the advancement of caries. Such a concept necessitates the resin to infiltrate and obliterate the WSL pore. The main goal is to fill the pores in the lesion body with a low-viscosity light-curing resin by capillary action. Thereby preventing further spread of bacteria and, consequently, the progression of the caries lesion. Placement of resin infiltrate on WSL establishes a barrier within the caries lesion that can reinforce the enamel structure, avoid/delay cavitation and surface disruption (Meyer-Lueckel and Paris, 2010). Moreover, resin infiltration does not require anaesthesia, removal of anatomical tooth structure, and not to mention, patient's compliance (Kugel et al., 1995). Besides, the refractive index of the infiltrating resin (1.51) is similar to hydroxyapatite and hence it has been shown to mask WSLs (Paris et al., 2013; Torres et al., 2011). However, resin-based materials are prone to discolouration due to the adsorption of dyes after exposure to exogenous sources.

Based on the sorption and solubility parameters of the resin matrix, prolonged exposure to dyes and acidic solutions may degrade resin monomers by swelling, plasticization, softening, oxidation, hydrolysis, and affecting color stability (Silva et al., 2017). Hence, there is a need to evaluate the esthetic aspects of WSLs treated with resin infiltration after immersion in various colored drinks. Therefore, this laboratory study was aimed to assess the discoloration effect of red tea, Arabic coffee, and black coffee on the resin infiltrated WSLs at different time points. We hypothesized that there would be no colour change in resin infiltrated WSLs of the teeth using different colored drinks.

2. Materials and methods

Thirty-three extracted human premolar teeth were used to create WSLs. ICON resin infiltration treatment was performed to obliterate the enamel pores. Afterwards, teeth with resin infiltrated WSLs were exposed to different drinks (red tea, arabic coffee, and black coffee). The color changes after 1d, 3d, and 7d intervals were recorded by using a spectrophotometer (V-730, Jasco, Japan) and compared between the groups. An IRB approval (RC/IRB/2019/218) was obtained from the research centre of Riyadh Elm University for conducting the study.

Any teeth with the presence of caries, restorations, or enamel defects were excluded from the study. All chosen teeth were stored in widely used 0.1% thymol solution at room temperature until they were utilized in the study. On the day of the study, the teeth samples were removed from the solution, washed, and dried for use.

2.1. Development of artificial WSLs

To create a WSL on the enamel of labial and lingual surfaces, each tooth was immersed for 4 days in a demineralizing solution (10 mL). This solution was composed of calcium chloride (2.2 mM), monopotassium phosphate (2.2 mM), acetic acid (0.05 mM) having pH adjusted to 4.4, and potassium hydroxide (1 M) (Prasada et al., 2018).

2.2. ICON infiltration treatment

A 15% hydrochloric acid gel (Icon-Etch) was applied on the demineralized enamel surface for 2 min and then water rinsed and air-dried for 30 s, followed by the application of ethanol (Icon-Dry) for 30 s and additional air drying was performed. The low-viscosity resin infiltrant (Icon-Infiltrant) was applied on the surface two times, the first time for 3 min and the second time for 1 min. Both applications were light-cured for 40 s. Resin infiltrated teeth were polished with rubber cup for removal of the excess resin.

2.3. Baseline color measurement

After polishing, the baseline line color shade of all the teeth (T_0) was recorded by spectrophotometer devise based on the CIE L* a* b* system using the Spectramagic software system. All the data were recorded in a special form.

2.4. Preparation of the artificial saliva and coloring solutions

Artificial saliva was prepared according to the formulation of Gohring *et al.* (Prasada et al., 2018). The pH was maintained between 7.4 and 7.8. A soluble Arabic coffee (Nescafe, Saudi Arabia; pH = 4.8), and instant black coffee (Nestle, Brazil; pH = 5.0) solutions were prepared using 25 g of powder to 250 mL of water, and red tea (Twinnings™, Chile; pH = 3.4).

2.5. Teeth sectioning

Thirty-three Poly Vinyl Chloride (PVS) tubes having a diameter of 28 mm and thickness of 10 mm were used as a mould to fill the self-cure orthodontic resin material (Technosin) in which infiltrated teeth were embedded before the setting of the resin. Each embedded tooth was sectioned longitudinally mesiodistally from occluso-central till the root to get 66 specimens by using a cutting machine (Isomet 4000 micro saw, Buehler, USA). Next, the specimens were divided into three main groups with two subgroups having 11 specim ens (11 Buccal and 11 lingual). All the specimens were then embedded in the acrylic tubes, color coded and exposed to various coloring agents.

2.6. Colorimetric analysis

The test specimen's color measurements were performed after 1 d (T_1), 3 d (T_2), and 7 d (T_3) by using CIE L* a* b* system. While the color measurements of the control specimens were performed at baseline and after 3 d. For each measurement, the values of L*, a*, and b* were recorded and the values of the changes of L* (ΔL), a* (Δa), and b* (Δb) at different time intervals and the overall color change (ΔE) was calculated. All the color values were measured by using Labscan XE Spectrophotometer.

2.7. Statistical analysis

Sample power calculation was performed prior to research and the normality was checked using Shapiro–Wilk test ($p > 0.05$). Descriptive statistics of mean and standard deviation values were calculated for the color coordinates L*, a*, and b* at different intervals. Color differences at time points were obtained by using $\Delta E^* = [(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2]^{1/2}$. Color differences were compared among different groups by using a one-way ANOVA test followed by Tukey's multiple comparison tests. The interaction effect between time and subgroups on color change value was analyzed using two-way ANOVA. A pairwise comparison was performed using a paired *t*-test. A value of $p < 0.05$ was con-

sidered significant for all statistical purposes. All the analysis was performed by using IBM-SPSS 25 (Armonk, NY; USA) (Poornima et al., 2019).

3. Results

The differences in color coordinates (Δ L, Δa and Δ b) values after 72 h of specimen immersion in artificial saliva and overall change in color ΔE are displayed in Table 1. The mean change of color coordinates (Δ L, Δa and Δ b) for the control subgroups of black coffee (9.21 ± 4.05, 0.87 ± 0.52 and 2.42 ± 3.15), Arabic coffee (8.24 ± 4.01, 0.51 ± 0.94 and 1.87 ± 3.09) and red tea (7.56 ± 4.62, 0.53 ± 0.93 and 0.50 ± 3.90). An overall change in color values ΔE was observed in specimens immersed in control subgroups of black Coffee (9.95 ± 4.29) followed by Arabic coffee (9.01 ± 3.99) and red tea (8.83 ± 3.89).

The mean difference in color coordinates and overall color change values (Δ L1, Δ a1, Δ b1 and ΔE1) between baseline-24 h (T_0-T_1) for all the specimens immersed in various coloring agents are displayed in Table 2. Specimens exposed to the red tea showed higher Δ L1(18.51 ± 4.90) and overall color change value ΔE1 (20.49 ± 5.35) compared to the others. While Arabic coffee showed a higher mean change in Δ a1 (0.56 ± 0.59) and Δ b1(-0.75 ± 2.57) compared to others.

The mean difference in color coordinates and overall color change values (Δ L2, Δ a2, Δ b2 and ΔE2) between baseline-72 h (T_0-T_2) for all the specimens immersed in various coloring agents are displayed in Table 3. Specimens exposed to the red tea showed higher Δ L2(23.33 ± 6.14) and overall color change value ΔE2 (24.87 ± 6.44) compared to the others. While specimens in Arabic coffee showed higher mean change in Δ a2 (0.08 ± 0.60) and Δ b2(-1.37 ± 2.80) compared to others.

The mean difference in color coordinates and overall color change values (Δ L3, Δ a3, Δ b3 and ΔE3) between baseline-1 week (T0-T3) for all the specimens immersed in various coloring agents are displayed in Table 4. Specimens exposed to the Red Tea showed higher Δ L3(21.15 ± 5.43) and overall color change value ΔE3 (23.12 ± 5.48) compared to the others. While specimens in Arabic coffee showed higher mean change in Δ a3 (-0.31 ± 0.67) and Δ b3(-2.81 ± 3.32) compared to others.

The mean difference in color coordinates and overall color change values (Δ L4, Δ a4, Δ b4 and ΔE4) between 24 h −72 h (T_0-T_3) for all the specimens immersed in various coloring agents are displayed in Table 5. Specimens exposed to the red Tea showed higher Δ L4(4.82 ± 1.42), Δ b4(0.66 ± 1.32) and overall color change ΔE4 (5.23 ± 1.37). While specimens exposed to the Arabic coffee demonstrated higher Δ a4 (−0.48 ± 0.18) compared to the others.

The mean difference in color coordinates and overall color change values (Δ L5, Δ a5, Δ b5 and ΔE5) between 24 Hours −1week (T_1-T_3) for all the specimens immersed in various coloring agents are displayed in Table 6. Specimens exposed to the red tea showed higher Δ L5(2.64 ± 1.55) and Δ b5(0.18 ± 2.07). While Arabic coffee showed a higher Δ a5 (-0.87 ± 0.35) compared to others. However, a higher overall color change value ΔE5 (4.92 ± 2.43) was observed with the specimens immersed in black coffee between 24 Hours −1week.

The mean difference in color coordinates and overall color change values (Δ L6, Δ a6, Δ b6 and ΔE6) between 72 Hours −1 Week (T_2-T_3) for all the specimens immersed in various coloring agents are displayed in Table 7. Specimens exposed to the red tea showed a higher Δ L6(-2.18 ± 1.69) and Δ b6(-0.48 ± 1.45) value. While specimens in Arabic coffee showed a higher mean change in Δ a6 (0.39 ± 0.26) and a higher value of overall color change ΔE6 (5.77 ± 1.75).

The color change value of the specimen was not significant between 24 h and 72 h, and 24 h and 1 week. However, between 72 h and 1 week specimens demonstrated significant differences in color change values among different groups (p = 0.009). Pairwise comparsions indicated that the specimens immersed in Arabic coffee showed significantly higher color change (5.77 ± 1.75) value compared to the red tea (3.05 ± 0.95). However, there was no significant difference in color change observed among the specimens immersed in black coffee (4.83 ± 2.73) and Arabic coffee (5.77 ± 1.75), and red tea and black coffee (4.83 ± 2.73). The details are in Table 8.

Color change value (ΔE) of specimens immersed in control and treatment subgroups are displayed in Fig. 1. Specimens exposed to the control subgroups did not show any significant color change (p = 0.788). While specimens exposed to different treatment subgroups showed significant color change (ΔE) (p < 0.001). Pairwise comparison of mean (ΔE) values indicated that the specimens exposed to red tea (24.87) demonstrated significantly higher (ΔE) value compared to the specimens in Arabic coffee (15.83). Similarly, specimens exposed to black coffee (22.03) had significantly higher (ΔE) values compared to Arabic coffee (15.83). However, there was no significant difference of color change (ΔE) between red tea (24.87) and black coffee (22.03).

4. Discussion

In the present study, color coordinates for the specimen were recorded at several time intervals after exposure to the coloring agents. Since the purpose of the study was to assess the color changes through ΔL*, Δa*, and Δb* calculation after ICON application. The coordinates L*, a*, and b* values of the specimen were collected at baseline, 24 h, 72 h and 1-week storage in distilled water, red tea, black coffee and Arabic coffee for the assessment of overall color change (ΔE).

Color coordinates L*, a*, and b* were not significant at baseline, however, after exposure to the red tea, Arabic coffee, and black coffee a significant variation in the color coordinates were observed suggesting possible color changes. The present study effectively created the WSLs and resin infiltration and found significant differences in color changes after exposure to staining agents. This can be verified by the absence of significant differences ΔE among the specimens immersed in the control subgroup (Artificial saliva) compared to the treatment subgroups in which statistically significant differences were found. This study found variations in ΔE val-

Table 1
Mean and SD values of Δ L, Δa, Δ b, and ΔE after 72 Hours in control subgroup.

Control (Artificial saliva)	After immersion in artificial saliva							
	Δ L		Δ a		Δ b		ΔE	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control-Black Coffee	9.21	4.05	0.87	0.52	2.42	3.15	9.95	4.29
Control-Arabic coffee	8.24	4.01	0.51	0.94	1.87	3.09	9.01	3.99
Control-Red Tea	7.56	4.62	0.53	0.93	0.50	3.90	8.83	3.89

Table 2
Values of Δ L1, Δa1, Δ b1, & ΔE1 between Baseline and 24 Hours (T_0-T_1).

Group	Δ L1		Δ a1		Δ b1		ΔE1	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Black coffee	16.77	4.74	−0.70	0.60	−5.91	3.88	18.39	3.78
Arabic coffee	11.92	3.27	0.56	0.59	−0.75	2.57	12.23	3.24
Red Tea	18.51	4.90	−3.26	2.06	−7.02	4.45	20.49	5.35

Table 3
Values of Δ L2, Δa2, Δ b2, and ΔE2 between Baseline and 72 Hours (T_0-T_2).

Group	Δ L2		Δ a2		Δ b2		ΔE2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Black coffee	20.67	3.97	−1.71	0.73	−6.25	3.64	22.03	3.50
Arabic coffee	15.53	3.36	0.08	0.60	−1.37	2.80	15.83	3.37
Red Tea	23.33	6.14	−4.57	2.32	−6.36	3.54	24.87	6.44

Table 4
Values of Δ L3, Δa3, Δ b3, and ΔE3 between Baseline and 1 week (T_0-T_3).

Group	Δ L3		Δ a3		Δ b3		ΔE3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Black coffee	17.20	4.08	−2.90	0.96	−9.15	3.98	20.17	3.55
Arabic coffee	10.05	2.82	−0.31	0.67	−2.81	3.32	10.89	2.95
Red Tea	21.15	5.43	−5.07	2.44	−6.84	3.29	23.12	5.48

Table 5
Values of Δ L4, Δa4, Δ b4, and ΔE4 between 24 and 72 Hours (T_1-T_2).

Group	Δ L4		Δ a4		Δ b4		ΔE4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Black coffee	3.90	1.77	−1.01	0.44	-0.34	1.14	4.18	1.82
Arabic coffee	3.61	0.69	-0.48	0.18	-0.62	0.96	3.81	0.67
Red Tea	4.82	1.42	−1.31	0.49	0.66	1.32	5.23	1.37

Table 6
Values of Δ L5, Δa5, Δ b5 and ΔE5 between 24 Hrs.-1wk (T_1-T_3).

Group	Δ L5		Δ a5		Δ b5		ΔE5	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Black coffee	0.43	2.62	−2.21	0.68	−3.24	2.86	4.92	2.43
Arabic coffee	−1.88	1.21	-0.87	0.35	−2.06	1.78	3.08	1.91
Red Tea	2.64	1.55	−1.81	0.91	0.18	2.07	3.86	1.55

Table 7
Values of Δ L6, Δa6, Δ b6, and ΔE6 between 72 Hrs. −1wk (T_2-T_3).

Group	Δ L6		Δ a6		Δ b6		ΔE6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Black coffee	−3.47	1.91	−1.20	0.69	−2.90	2.23	4.83	2.73
Arabic coffee	−5.49	1.41	**-0.39**	0.26	−1.44	1.45	5.77	1.75
Red Tea	−2.18	1.69	-0.50	0.64	**-0.48**	1.45	3.05	0.95

Table 8
Overall color Changes (ΔE) of specimen in different groups at varios time interval.

Group	(T_0-T_1)		(T_0-T_2)		(T_0-T_3)		(T_1-T_2)		(T_1 −T_3)		(T_2-T_3)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Black coffee	18.39	3.78[a]	22.03	3.50 [a]	20.17	3.55[a]	4.18	1.82	4.92	2.43	4.83	2.73[ab]
Arabic coffee	12.23	3.24[b]	15.83	3.37[b]	10.89	2.95[b]	3.81	0.67	3.08	1.91	5.77	1.75[a]
Red Tea	20.49	5.35 [a]	24.87	6.44[a]	23.12	5.48[a]	5.23	1.37	3.86	1.55	3.05	0.95[b]
F	11.400		10.829		26.179		3.159		2.348		5.526	
p	**<0.001**		**<0.001**		**<0.001**		0.057		0.113		**0.009**	

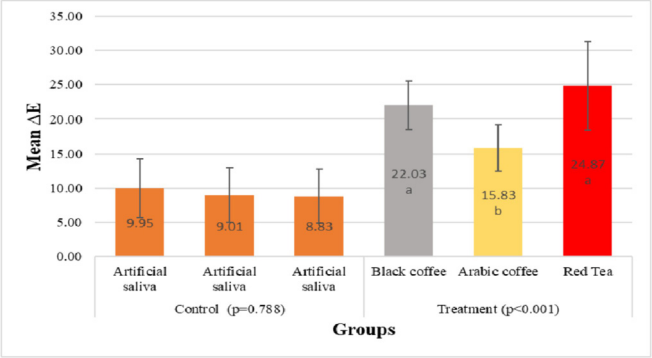

Fig. 1. Color change values (ΔE) among control and Treatment subgroups.

ues in different treatment subgroups over a period of time. Hence, the null hypothesis is rejected.

The color change observed in the resin infiltrated specimen could be explained based on the fact that despite satisfactory polymerization and polishing, resin-based materials are vulnerable to pigmentation caused by common foods and drinks, leading to significant discoloration (Ceci et al., 2017; Borges et al., 2014; Furuse et al., 2020). Both resin infiltrated control (range 8.83 – 9.95) and treatment (15.83 – 27.87) subgroups showed ΔE value higher than 3.3 units, in line with the other reported studies,(Ceci et al., 2017; Borges et al., 2014; Furuse et al., 2020;19:e201674-e.) which explains the clinically unacceptable color change after exposure to treatment subgroup. Although exposure to artificial saliva caused a color change in resin infiltrated lesions, but it did not differ significantly among control subgroups. While exposure to red tea, Arabic coffee and black coffee induced clinically significant and noticeable alterations in color of the specimens Silva et al., 2017; Ceci et al., 2017; Borges et al., 2014; Furuse et al., 2020).

Treatment subgroup of black coffee, Arabic coffee and red tea resulted in clinically perceivable color changes after 1 day, 3 days and 1 week. All the tested specimens showed color change value of (ΔE > 3.3). The highest color change value of specimens ΔE = 20.91 was recorded after 3 days of immersion in the staining solution, but, it reduced after 1 week. Red tea showed the highest mean ΔE value (24.87), followed by black coffee (22.03) and Arabic coffee (15.83). While Rey et al. (2014) reported a mean ΔE for coffee (33.64) and tea (17.76), which are contradictory to the current study. It has been reported that both tea and coffee contain yellow colorants. The discoloration of materials by tea was mainly due to surface adsorption of the colorants. Discoloration by coffee was due to both adsorption and absorption of colorants. The absorption and penetration of colorants into the organic phase of materials were probably due to the compatibility of the polymer phase with the yellow colorants of coffee (Um and Ruyter, 1991).

Changes observed in the color resin infiltrated specimens can be attributed to the presence of the TEGDMA (Triethylene glycol dimethacrylate) within the composition of the ICON. TEGDMA is the key component of the resin icon infiltration as it can penetrate deep into the lesion (Sideridou et al., 2003). It has been found that resin consisting mainly of TEGDMA is the favoured alternative because a higher lesion penetration coefficient (Paris et al., 2010). Nevertheless, TEGDMA has the highest water sorption rate, causing discoloration of resin (Khan et al., 2020a, 2020b). Thus, after storage in staining solutions, Icon became more discolored with the incorporation of the additional colorant. Moreover, discoloration may be related to the rate of water sorption, with water being the carrier for pigments to penetrate deep into the resin matrix. Thus, staining sensitivity tended to correspond to water sorption rate. To overcome this effect few studies have proposed the polishing of the specimens to reduce the coloring effect (Paris et al., 2013; Borges et al., 2014). However, the polishing may result in needless enamel wear caused by abrasion (Araújo et al., 2015).

In this study, WSLs were artificially created, which may not simulate naturally induced WSLs. Moreover, the mineral content of the tooth might be different from one individual to another as their oral environment and oral hygiene practices vary affecting WSLs. Additionally, this study did not evaluate the infiltrator penetration depth. Future studies should explore the role of saliva, food dyes, water, dental structure or ions from the oral cavity, and infiltrator penetration depth on the resin infiltration's color stability.

5. Conclusion

Within the limitations, the following points can be concluded:

- Resin infiltrated WSLs showed marked color changes after exposure to red tea, black coffee, and Arabic coffee over time.
- Severe discoloration of the infiltrant was evident with the use of red tea compared to black coffee and Arabic coffee.
- Color change values varied across different intervals, and the highest color change was observed after 3 days of exposure to the staining solution.
- Clinicians should be aware that resin infiltrated WSLs may become discolored when exposed to red tea, black coffee, and Arabic coffee over time.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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