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# Effect of mouthwash on color change and solubility of composite resins

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## ABSTRACT

**Aims**: This study aimed to evaluate the effects of currently available mouthwashes on color changes and solubilities of composite resins by comparing them.

**Methods**: Three different types of composite resins, namely nanofill, nanohybrid, and microhybrid resins (Filtek Ultimate, Estelite Sigma Quick, and Filtek Z250, respectively), were used in thisstudy. A total of 120 samples, with 40 foreach composite material, were prepared. The composite resins were placed in plastic molds of 10 mm × 2 mm with round disc shapes and polymerized with an LED light device. After finishing and polishing them with a polishing disc, the prepared samples were stored in distilled water. Initial color measurements were performed using the VITA Easyshade V device (VITA, Germany) for color stability evaluations. For solubility measurements, the dry weights of the samples were measured and their diameters and thicknesses were recorded with a caliper. Samples from each group were then immersed in three different mouthwashes (Kloroben, Listerine Advanced White, and Colgate Plax) twice a day for 2 minutes for 14 days. After 14 days, color and weight measurements were repeated for all samples. Kruskal-Wallis and Mann-Whitney U tests were used in the statistical analysis of the data.

**Results**: Significant color changes were detected in all samples as a result of color measurements ($p<0.05$). Significant differences were observed for all solution groups in terms of color change, but the lowest amount of color change was observed with the Colgate Plax solution. Comparisons of composite groups revealed that Filtek Ultimate was the composite with the lowest amount ofcolor change. Positive solubility values were recorded for all samples as a result of solubility measurements. Although no significant difference was observed among composite groups in terms of solubility, higher solubility levels were detected withthe Kloroben, Listerine Advanced White, and Colgate Plax solutionscompared to the control group.

**Conclusion**: In thisstudy, in all evaluated composite groups, acceptable levels of color change and solubility were detected, with values varying depending on the composite material after immersion in the mouthwashes.

**Keywords**: Composite resin, mouthwash, color change, solubility

## INTRODUCTION

Composite resins are now among the most commonly used dental restoration materials due to their advanced aesthetic, mechanical, and physical properties. They have become widely used, especially with the advancements in adhesive technology. Despite the progress in composite resins, however, color stability remains an important issue. Color change is one of the most common reasons for the replacement of restorations (1).

After composite resin restorations are applied to teeth, they are in constant interaction with the oral environment (2). They are exposed to the chemical components of saliva, water, food, and oral hygiene products in the mouth. Polymer-based composite resins are negatively affected by the fluid environment in the mouth. They can absorb water and solvents and release certaincomponents, including filler particles. This phenomenon, known as water sorption and solubility, can have negative effects on the resin matrix structure (3).

Mouthwashes can be used with or without a dentist's recommendation for different purposes including the treatment of periodontal infections such as gingivitis and periodontitis, prevention of dental caries orbad breath, plaque control, daily oral hygiene routines, and whitening effects (4). These mouthwashes, containing water, antimicrobial compounds, salts, organic acids, preservatives, coloring agents, and sometimes alcohol, can have harmful effects on oral soft tissues, teeth, and restorative materials (5,1).

The aim of this study is to examine the effects of mouthwashes with different contents that are widely used today on the color change and solubility of three different types of composite materials.

## METHODS

Ethics committee decision is not required as it does not contain human and animal material. All procedures were carried out in accordance with the ethical rules and the principles.

In this study, three different types of A2 shade composite materials were used, includingnanofill (3M ESPE Filtek Ultimate Universal Restorative, 3M, St. Paul, MN, USA), microhybrid (3M ESPE Filtek Z250 Universal Restorative, 3M, St. Paul, MN, USA), and nanohybrid (Tokuyama EsteliteSigma Quick, Tokuyama Dental Corp., Tokyo, Japan) composites. Forty samples were prepared from each of these composites, resulting in a total of 120 samples. Plastic molds with a diameter of8mm and thickness of 2 mm containing circular voids were used to prepare the samples. Cement-glass was placed under the molds, followed by transparent tape. The composite materials were condensed into the molds using a dental spatula to eliminate any air voids and transparent tape was placed over them, followed by cement-glass. Excess materialswereremoved by gently pressing the compositesdown and obtaining a smooth surface. Polymerization was then carried out using an LED light device according to the manufacturer's recommendations for each composite type. Glass of1mm in thickness was used for standardization of the distance between the composite and the light device during polymerization and the head of the light device was held perpendicular to the glass. The prepared samples were polished using Sof-Lex discs and then stored in distilled water at 37°C in an incubator for 24 hours.

A chlorhexidine and benzydamine hydrochloride-based antiseptic mouthwash (Kloroben, Drogsan, Ankara, Turkey), whitening mouthwash (Listerine Advanced White, Johnson & Johnson, Istanbul, Turkey), and alcohol-free mouth care solution (Colgate Plax, Colgate-Palmolive, Istanbul, Turkey) were used as experimental solutions, while distilled water was used for the control group.

Each sample disc was numbered and four subgroups were created for each composite resin group to be immersed in the chosen solutions (n=10). The designated solutions were added to closed bottles with volumes of 20 mL. The samples were immersedin these bottles according to mouthwash groups twice a day for 2 minutes at 12-hour intervals for 14 days. After each immersion, the samples were rinsed and held in distilled water until the next immersion. The samples in the control group were kept in distilled water throughout the experimental period.

Initial color measurements of the samples were carried out in the Dicle University Faculty of Dentistry's Prosthetic Dentistry Laboratory using a spectrophotometer (VITAEasyshade V, VITAZahnfabrik, Bad Sackingen, Germany). This procedure was performedagainsta white background in a dark room. Color measurementswere repeated three times for each composite sample. L*, a*, and b* values in the CIELAB color system were recorded for all samples individually.

The initial weights of the samples were recorded as M1 in micrograms. The diameters and thicknesses of the samples were measured with a caliper (Jensen JP-1, Germany) and average values were calculated. The average diameter of each sample was calculated in mm²and the average thickness in mm³ using the equation$V=\pi r^2 h$.For initial solubility measurements, the samples were kept in a desiccator (EN025, NUVE, Ankara, Turkey) containing silica gel at 37°C for 22 hours. Subsequently, they were kept in aMikrotest MST-55 oven (Mikrotest, Ankara, Turkey) at 24°C for 2 hours. After measuring the dry weights of the samples on a balance with sensitivity of 0.0001 mg (Precisa XB 220A, Switzerland), it was determined whether there was a weight change of more than 0.2 mg, and the same procedures were repeated after 24 hours. The initial weight of each of the samples, theweight loss of which was found to be less than 0.1 mg (with fixed weight), was thus recorded as M1 in micrograms.

After 14 days, the samples were washed and dried and the color was measured again under the sameconditions. These second values were recorded and the color change value was calculated for each sample using the following formula:

$$\Delta E=[(L1^*-L2^*)2+(a1^*-a2)2+(b1^*-b2^*)2]½$$

For the repetition of solubility measurements, samples were kept in a desiccator for 24 hours, as atthe beginning of the experiment, in order to regain their constant weight. When the constant weight was obtained, the new values were recorded as M³. In this process, the following formula was applied:

$$W_{SL}\ (\mu g/mm^3) = M_1\ (\mu g) - M_3\ (\mu g) / V\ (mm^3)$$

$W_{SL}$: Water solubility V: Sample volume

## Statistical analysis

The analysis of the data obtained in this study was carried out with Licensed IBM SPSS Statistics Version 21 package program. The unit numbers of the variables were taken into account, and whether they were normally distributed or not was tested with the Shapiro Wilk's test. When analyzing the differences between the groups, the Kruskal Wallis H Test was used when there was no normal distribution. In case of significant difference in the comparison of more than two groups, Post-Hoc tests (Mann Whitney U test with Bonferroni correction) were used to determine which groups had a significant difference. While evaluating the data, 0.05 was used as the significance value. It has been reported that there is a significant difference if $p<0.05$ is found, and there is no significant difference if $p>0.05$ is found.

**Table 1. Composite materials used in the study**

| Composite materials | Resin matrix | Inorganic Particle | Filler Particle Ratio | Manufacturer Company and Lot No. |
|---|---|---|---|---|
| Filtek™ Ultimate | Bis-GMA,UDMA TEGDMA,PEGDMA, Bis-EMA | Silica, Zirconium | 63% by volume, 78.5% by mass | 3M ESPE,ABD 3920A2B |
| Filtek™ Z250 | Bis-GMA,UDMA TEGDMA,Bis-EMA | Silica, Zirconium | 60% by volume, 82% by mass | 3MESPE,ABD 6020A2 |
| Estelite Sigma Quick | Bis-GMA, TEGDMA | Silica, Zirconium | 71% by volume, 82% by mass | Tokuyama Dental Corp. Japan E7802 |

**Table 2. Mouthwash solutions used in the study**

| Name Of Mouthwash | Mouthwash Content | Manufacturer |
|---|---|---|
| Distilled water (Control Group) | Deionized water | Deionized Water,BrtrChemical |
| Chlorobene | 0.12% chlorhexidine gluconate 0.15% benzydamine hydrochloride | Drogsan Pharmaceuticals IndustryTrade Inc. |
| Listerin Advanced White | Aqua, tetrapotassium, pyrophosphate, pentasodium, triphosphate, alcohol, sorbitol, thymol, menthol, sodium saccharin, sodium fluoride | Johnson and Johnson Sanitary Materials Industry. Trade Ltd. |
| Colgate Plax | Aqua, glycerin, propylene glycol, cetylpyridinium chloride, sorbitol, sodium, saccharin, sodium fluoride, menthol, aroma | Colgate-Palmolive Cleaning Product. Industry Trade Inc. |

## RESULTS

### Findings of ΔE values

In terms of average ΔE values after mouthwashes and soaking in distilled water, the ΔE value of the Filtek Ultimate group was lower compared to the Filtek Z250 and Estelite Sigma Quick groups (**Table 3**).

**Table 3. Comparison of ΔE values between composite groups**

| | Composite groups | | | | | | Kruskal Wallis H Test | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | Median | Min | Max | Sd | Mean Rank | H | p |
| ΔE value | | | | | | | | 25.458 | 0.001 |
| FU | 40 | 4.45 | 4.32 | 2.49 | 8.49 | 1.24 | 39.66 | | |
| FZ250 | 40 | 6.21 | 6.34 | 3.19 | 8.35 | 1.36 | 78.63 | | |
| ESQ | 40 | 5.6 | 5.22 | 2.54 | 9.97 | 1.84 | 63.21 | | |
| Total | 120 | 5.42 | 5.25 | 2.49 | 9.97 | 1.66 | | | |

When mouthwashes and distilled water were evaluated, the ΔE value of Colgate Plax solution was significantly lower than Chloroben and Listerine Advanced White solutions. There was no significant difference between the other solutions (**Table 4**).

In the 3M Filtek Ultimate composite group, the ΔE value of the Distilled Water solution was significantly lower than that of Chloroben and Listerin Advanced White solutions. In the 3M Filtek Z250 composite group, the ΔE value of the Colgate Plax solution was significantly lower than that of the Chlorobene solution.In the Tokuyama Estelite Sigma Quick composite group, the ΔE value of Colgate Plax solution was significantly lower than that of Listerin Advanced White and Distilled Water solutions.

There was no significant difference in values between the composite groups in Colgate Plax and Listerine Advanced White solutions ($p>0.05$) (**Table 6**).

In the chlorobene solution, the value of the Filtek Z250 composite group was higher. Although there was no significant difference between Estelite Sigma Quick and Filtek Ultimate composite groups, the value of the Filtek Ultimate group was lower.

In distilled water solution, the ΔE value of 3M Filtek Ultimate composite group was lower than that of 3M Filtek Z250 and Tokuyama Estelite Sigma Quick composite groups (**Table 6**)

### Resolution Findings

There was no statistically significant difference between the composite groups in terms of solubility values ($p>0.05$).

There was a significant difference between the solutions in terms of solubility values ($p<0.05$). The solubility values of Chloroben, Colgate Plax and Listerine Advanced White solutions were higher than the distilled water solution. There was no statistically significant difference between the other solutions (**Table 8**).

In the 3M Filtek Ultimate composite group, solubility values differed significantly between solutions ($p<0.05$). In the 3M Filtek Ultimate composite group, the solubility value of the Distilled Water solution was lower than that of Colgate Plax and Listerin Advanced White solutions (**Table 9**).

In the 3M Filtek Z250 composite group, solubility values differed significantly between solutions ($p<0.05$). In the 3M Filtek Z250 composite group, the solubility value of the Distilled Water solution was lower than the Chloroben, Colgate Plax, and Listerine Advanced White solutions (**Table 9**).

In the Tokuyama Estelite Sigma Quick composite group, solubility values differed significantly between solutions ($p<0.05$). In the Tokuyama Estelite Sigma Quick composite group, the solubility value of the Distilled Water solution was lower than that of Chlorobene, Colgate Plax, and Listerine Advanced White solutions (**Table 9**).

**Table 4. Analysis results regarding the differences in solutions in terms of ΔE values**

| | Solutions | | | | | | Kruskal Wallis H Test | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | Median | Min | Max | Sd | Mean Rank | H | p |
| ΔE value | | | | | | | | 15.643 | 0.001 |
| K | 30 | 5.7 | 5.31 | 3.45 | 8.35 | 1.45 | 67.35 | | |
| LAW | 30 | 6.06 | 6.1 | 3.06 | 8.49 | 1.57 | 74.28 | | |
| CPlax | 30 | 4.48 | 4.14 | 2.54 | 7.65 | 1.29 | 40.67 | | |
| Distilled water | 30 | 5.45 | 4.89 | 2.49 | 9.97 | 1.92 | 59.7 | | |
| Total | 120 | 5.42 | 5.25 | 2.49 | 9.97 | 1.66 | | | |

**Table 5. Analysis of the difference in solutions in terms of ΔE values in composite groups**

| | ΔE values | | | | | | Kruskal Wallis H Test | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | Median | Min | Max | Sd | Mean Rank | H | p |
| FU | | | | | | | | 12.373 | 0.006 |
| K | 10 | 4.68 | 4.53 | 3.56 | 5.87 | 0.78 | 24.7 | | |
| LAW | 10 | 5.26 | 4.95 | 3.06 | 8.49 | 1.83 | 25.8 | | |
| C Plax | 10 | 4.39 | 4.52 | 3.08 | 5.47 | 0.79 | 22 | | |
| Distilled Water | 10 | 3.46 | 3.67 | 2.49 | 3.81 | 0.46 | 9.5 | | |
| Total | 40 | 4.45 | 4.32 | 2.49 | 8.49 | 1.24 | | | |
| FZ250 | | | | | | | | 10.884 | 0.012 |
| K | 10 | 7.23 | 7.52 | 5.28 | 8.35 | 1.08 | 29.05 | | |
| LAW | 10 | 6.51 | 6.34 | 5.79 | 8.03 | 0.67 | 22.5 | | |
| C Plax | 10 | 5.12 | 5.28 | 3.19 | 7.65 | 1.56 | 12.4 | | |
| Distilled Water | 10 | 5.99 | 6.08 | 4.63 | 7.57 | 1.16 | 18.05 | | |
| Total | 40 | 6.21 | 6.34 | 3.19 | 8.35 | 1.36 | | | |
| ESQ | | | | | | | | 16.883 | 0.001 |
| K | 10 | 5.18 | 5.13 | 3.45 | 6.9 | 0.98 | 18.6 | | |
| LAW | 10 | 6.4 | 6.49 | 3.55 | 8.42 | 1.75 | 25.95 | | |
| C Plax | 10 | 3.94 | 3.85 | 2.54 | 7.05 | 1.22 | 8.95 | | |
| Distilled Water | 10 | 6.9 | 7.14 | 4.2 | 9.97 | 1.81 | 28.5 | | |
| Total | 40 | 5.6 | 5.22 | 2.54 | 9.97 | 1.84 | | | |

**Table 6. Analysis results regarding the difference in composite groups in terms of ΔE values in solutions**

| | ΔE value | | | | | | Kruskal Wallis H Test | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | Median | Min | Max | Sd | Mean Rank | H | p |
| K | | | | | | | | 16.034 | 0.001 |
| FU | 10 | 4.68 | 4.53 | 3.56 | 5.87 | 0.78 | 9.4 | | |
| FZ250 | 10 | 7.23 | 7.52 | 5.28 | 8.35 | 1.08 | 24.4 | | |
| ESQ | 10 | 5.18 | 5.13 | 3.45 | 6.9 | 0.98 | 12.7 | | |
| Total | 30 | 5.7 | 5.31 | 3.45 | 8.35 | 1.45 | | | |
| LAW | | | | | | | | 4.16 | 0.125 |
| FU | 10 | 5.26 | 4.95 | 3.06 | 8.49 | 1.83 | 10.9 | | |
| FZ250 | 10 | 6.51 | 6.34 | 5.79 | 8.03 | 0.67 | 18.3 | | |
| ESQ | 10 | 6.4 | 6.49 | 3.55 | 8.42 | 1.75 | 17.3 | | |
| Total | 30 | 6.06 | 6.1 | 3.06 | 8.49 | 1.57 | | | |
| C Plax | | | | | | | | 4.964 | 0.084 |
| FU | 10 | 4.39 | 4.52 | 3.08 | 5.47 | 0.79 | 15.85 | | |
| FZ250 | 10 | 5.12 | 5.28 | 3.19 | 7.65 | 1.56 | 19.7 | | |
| ESQ | 10 | 3.94 | 3.85 | 2.54 | 7.05 | 1.22 | 10.95 | | |
| Total | 30 | 4.48 | 4.14 | 2.54 | 7.65 | 1.29 | | | |
| Distilled Water | | | | | | | | 19.865 | 0.001 |
| FU | 10 | 3.46 | 3.67 | 2.49 | 3.81 | 0.46 | 5.5 | | |
| FZ250 | 10 | 5.99 | 6.08 | 4.63 | 7.57 | 1.16 | 19.1 | | |
| ESQ | 10 | 6.9 | 7.14 | 4.2 | 9.97 | 1.81 | 21.9 | | |
| Total | 30 | 5.45 | 4.89 | 2.49 | 9.97 | 1.92 | | | |

**Table 7. Analysis results regarding the differences in composite groups in terms of solubility values**

| | Composite groups | | | | | | Kruskal Wallis H Test | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | Median | Min | Max | Sd | Mean Rank | H | p |
| Solubility values | | | | | | | | 5,312 | 0,07 |
| FU | 40 | 3.55 | 2.98 | 0 | 9.96 | 2.62 | 53.94 | | |
| F Z250 | 40 | 4.85 | 4.98 | 0 | 9.96 | 2.83 | 70.65 | | |
| ESQ | 40 | 3.56 | 3.98 | 0 | 7.96 | 2.31 | 56.91 | | |
| Total | 120 | 3.99 | 3.98 | 0 | 9.96 | 2.65 | | | |

**Table 8. Analysis results regarding the differences in solutions in terms of solubility values**

| | Solutions | | | | | | Kruskal Wallis H Test | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | Median | Min | Max | Sd | Mean Rank | H | p |
| Solubility values | | | | | | | | | |
| K | 30 | 4.21 | 4.48 | 0 | 9.96 | 2.23 | 64.75 | 51.424 | 0.001 |
| LAW | 30 | 5.71 | 5.97 | 0 | 9.96 | 2.69 | 82.12 | | |
| C Plax | 30 | 4.78 | 4.98 | 0.96 | 8.96 | 2.12 | 72.38 | | |
| Distilled water | 30 | 1.25 | 0.99 | 0 | 2.98 | 0.74 | 22.75 | | |
| Total | 120 | 3.99 | 3.98 | 0 | 9.96 | 2.65 | | | |

**Table 9. Analysis results regarding the difference in solutions in terms of solubility values in composite groups**

| | Solubility values | | | | | | Kruskal Wallis H Test | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | Median | Min | Max | Sd | Mean Rank | H | p |
| FU | | | | | | | | | |
| K | 10 | 3.28 | 2.98 | 0 | 7.96 | 2.49 | 19.6 | 14.694 | 0.002 |
| LAW | 10 | 4.78 | 4.98 | 0 | 9.96 | 2.92 | 25.7 | | |
| C Plax | 10 | 4.97 | 4.98 | 0.96 | 7.96 | 2.11 | 27.3 | | |
| Distilled Water | 10 | 1.17 | 0.96 | 0 | 1.99 | 0.64 | 9.4 | | |
| Total | 40 | 3.55 | 2.98 | 0 | 9.96 | 2.62 | | | |
| FZ250 | | | | | | | | | |
| K | 10 | 4.98 | 4.48 | 2.98 | 9.96 | 2.2 | 21.4 | 23.798 | 0.001 |
| LAW | 10 | 7.47 | 7.96 | 3.98 | 9.96 | 1.95 | 31.1 | | |
| C Plax | 10 | 5.37 | 5.48 | 0.99 | 8.96 | 2.36 | 23.2 | | |
| Distilled Water | 10 | 1.58 | 1.99 | 0 | 2.98 | 0.85 | 6.3 | | |
| Total | 40 | 4.85 | 4.98 | 0 | 9.96 | 2.83 | | | |
| ESQ | | | | | | | | | |
| K | 10 | 4.38 | 4.98 | 0.99 | 5.97 | 1.83 | 24.65 | 17.133 | 0.001 |
| LAV | 10 | 4.88 | 5.97 | 0 | 7.96 | 2.41 | 27.05 | | |
| C Plax | 10 | 3.98 | 3.98 | 0.99 | 6.97 | 1.82 | 22.6 | | |
| Distilled Water | 10 | 0.99 | 0.99 | 0 | 1.99 | 0.66 | 7.7 | | |
| Total | 40 | 3.56 | 3.98 | 0 | 7.96 | 2.31 | | | |

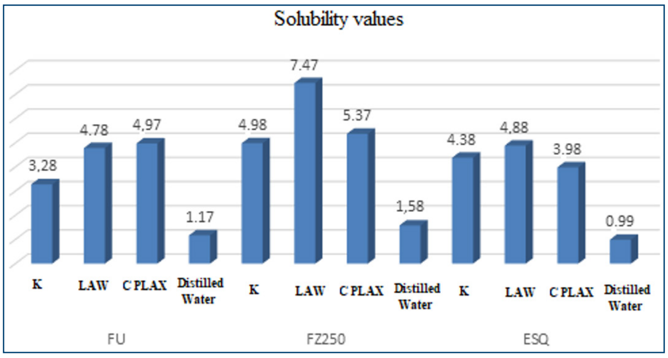


**Figure 1.** Differences in solubility values in composite groups and solutions

The solubility values in the Listerine Advanced White solution differed significantly between the composite groups ($p<0.05$). In the Listerin Advanced White solution, the solubility value of the 3M Filtek Ultimate and Tokuyama Estelite Sigma Quick composite groups was lower than the 3M Filtek Z250 composite group.

## DISCUSSION

Color stability and solubility of composite materials upon exposure tovarious chemicals are important factors affecting the clinical life of aesthetic restorations (6,7). Recent studies have reported that visible color changes in restorations are among the most important reasons for the replacement of composite restorations in the anterior region (7). Water absorption and water solubility of composite restorations cause changes in their biological structures, aesthetic losses, and deterioration of marginal and surface properties. As a result, the clinical success of the restorations may decrease. For these reasons, the effects on color change and solubility of three different mouthwashes for three different composite types with different contents were evaluated in our study.

Nanofill, nanohybrid, and microhybrid composite resins are commonly used in different clinical settings due to their differences in chemical structure and filler content. Kloroben, Listerine Advanced White, and Colgate Plax mouthwashes were used as test solutions in the present study, chosen from among themouthwashes currently widely used in Turkey considering differences in their chemical contents, whether they contain alcohol, and differences in pH values. Distilled water was selected for the control group to mimic a moist environment such as that created by saliva, oral fluids, and water that composite restorations are exposed to in the oral cavity.

In the literature, the result of the studies examining the effect of mouthwashes on the color change or surface properties of different restorative materials differ in term of the immersion times of samples in solutions. These times vary among studies from not being immersed for 1 minute a day for 60 days to keeping samples in solutions continuously for 28 days. However, in daily life,mouthwashes are generally used twice a day for 1-2 minutes. In addition, teeth and restorations are constantly in contact with saliva. Due to its cleansing properties, saliva reduces the discoloration that may occur on teeth and restorations. Therefore, in our study, samples were kept in mouthwash solutions twice a day for 2 minutes each for 14 days to mimic daily use. As pH changes can affect diffusion and consequently solubility and color change, fresh solutions were used every 12 hours to prevent variations in pH levels in our study (8).

In our study, to prevent the results from being affected by polymerization times, all samples were polymerized according to the manufacturer's instructions. At the same time, to standardize the light distance during polymerization, a glass slidewas placed between the light device and the samples. The samples were prepared with diameters of 10 mm to ensure that the light device's tip diameter of11 mm was not exceeded. The thickness of the samples was determined as 2 mm due to the maximum polymerization depth of the composite resins being 2 mm.

In a study conducted by Barbosa et al., the effects of different finishing and polishing systems on the surface roughness of composite resin materials with different structures were compared and it was emphasized that the most ideal surfaces could be obtained using the Sof-Lex disc system (9). In our study, after polymerization, the samples were polished with aluminum oxide-containing discs (Sof-Lex XT, 3M, St. Paul, MN, USA).

In our study, we used the VITAEasyshade V spectrophotometer (VITAZahnfabrik, Bad Sackingen, Germany), which can measure colors at wavelengths between 400 and 700 nm, allows for standard repetitions and gives reliable results, and can show the equivalent of the color on the VITA scale as well as L*a*b* values. Considering previous studies on materials used in dentistry, although the most widely used CIELAB system is generally considered sufficient to detect color changes, it has also been reported that the CIEDE 2000 system is much more sensitive in detecting color differences (8,186). For this reason, values with $\Delta E$ greater than 3.1 were considered to be significant in terms of color change, based on the CIEDE 2000 system,for color change calculations in our study.

Significant color changeswere observed in all composite groups kept in distilled water and the mouthwashes that we used in our study. It was determined that Colgate Plax, an alcohol-free mouthwash, caused significantly less color change for theFiltek Z250 and Estelite Sigma Quick composite materials than the Klorobenor Listerine Advanced White mouthwashes.The fact that Colgate Plax producedlower amounts ofcolor change in the Estelite Sigma Quick group compared to distilled water is an important finding of our study. It was previously reported that cetylpyridiniumchloride, an ingredient of Colgate Plax, creates roughening and coloring effects on the surfaces of restorative materials (10). In previous studies, Listerine Advanced White was shown to have bleaching effects on colored composite resins (11), and in our study, it exerted coloring effects in all composite groups. It is thought that such effects may be caused by the organic acids and alcohol that it contains. The color change caused by the chlorhexidine in Kloroben mouthwash is one of its well-known side effects.

In various studies, it was reported that the color effects of mouthwashes increase with decreasing pH values and increasing alcohol contents. The fact that Colgate Plax (pH5.9) has a higher pH value than Kloroben (pH5.5) and created smaller amounts of color change supports those previous findings. Colgate Plax has a lower pH value compared to Listerine Advanced White (pH6.15), but it is thought to cause lower amounts of color change due to the fact that it does not contain alcohol.

As another finding of our study, significantly lower amounts of color change wereobserved for the Filtek Ultimate samples immersed in Kloroben mouthwash compared to the Filtek Z250 samples, and forFiltek Ultimate samples immersed in distilled water compared to both the Filtek Z250 and Estelite Sigma Quick groups. Although there was no statistically significant difference in color change between the composites in Listerine Advanced White and Colgate Plax mouthwashes, Filtek Ultimate was determined as the composite material with the leastcolor change. This finding is most likely due to the fact that the samples made ofFiltek Ultimate, as ananofill composite,hadsmaller particle sizes compared to the Filtek Z250 composite,amicrohybrid type. On the other hand, in contrast toEstelite Sigma Quick, which has a nanohybrid structure, Filtek Ultimate contains both UDMA and Bis-EMA, which have lower average particle sizes and higher resistance to color change than Bis-GMA and TEGDMA (12). It was previously reported in the literature that the color stability of resin composites increases with decreasing inorganic particle sizes (13,14). As a result of the study conducted by Ertaş et al., microhybrid composite resins were found to be more colored than nanohybrid composite resins due to the size of the filler particles (15).

The solubility of resin composites is explained by the release of unreacted monomers, inorganic particles, oligomers, and ions that move away from the structure. Composite solubility is also related to the water absorption of the composite because the solvent must penetrate the polymer so that leachable components can be released from the material (16). The ratio of filler particles and the contactof filler particles with the resin also have important effectson solubility. Composite resins with low filler content create more spaces and passageways for water molecules moving into the polymer matrix, increasing the free volume and the water absorption required for proper fluid absorption. Depending on the water absorption mechanism, solubility may increase when residual monomers or small polymer rings break off from the resin (17).

Monomers such as TEGDMA, Bis-GMA, and UDMA in the composite resins we used in this study contain polar hydrophilic unitswith areas that support water absorption (TEGDMA: ethylene dioxide;Bis-GMA: hydroxyls; UDMA: urethane) (18). Bis-GMA and TEGDMA are more hydrophilic than UDMA, and UDMA has lower solubility due to the presence of urethane groups. Khokhar et al. observed that composite resins containing UDMA had lower rates of water absorption (19). In our study, Estelite Sigma Quick, which does not contain UDMA, unlike the other composites,had lower resolution than Filtek Z250. However, its resolution was similar to that ofFiltek Ultimate.

It is known that the combination of nanoparticles to form nanoclusters in nanofill composites reduces the gaps between filler particles, which causes more filler loading in the resin and reduces water absorption and solubility compared to microhybrid composites (20). In our study, the detection of significantly higher solubility in the microhybrid 3M Filtek Z250 composites kept in Listerine Advanced White solution compared to other composite groups containing nanofillersis in line with that information.

When the solutions we used in our study were examined, significantly higher solubility was found in all mouthwash groups compared to the control group. This is thought to be related to the various substances contained in mouthwashes. Excluding the control group, the pH of all solutions was less than 7, and Listerine Advanced White also contains alcohol. Solutions with low pH valuesproduce methacrylic acid, causing enzymatic degradation over time (21). In addition, the acid can reduce the pH in the organic matrix, hydrolyze ester groups from dimethacrylate monomers to form carboxylic acid and alcohol molecules, and trigger monomer separation. The results of a study by Abu-Bakr et al. showed that the acidic nature of their solutions played a role in the degradation of composite resins (22). Alcohol is an effective dimethacrylate solvent. It can affect solubility by softening the polymer matrix of composite resins and increasing the amount of unreacted monomers and oligomers(23). Although there wereno statisticallysignificant differences between our solution groups in terms of solubility, Listerine Advanced White was determined to bethe solution causing the highest solubility. This is thought to be due to the alcohol content of Listerine Advanced White.Sarett et al. reported that the alcohol contents of mouthwashes adversely affected the water absorption and solubility of composite resins (24). Pereira et al. similarlyfound that mouthwashes containing alcohol caused more solubility forcomposite resins than those without alcohol (25).

Our study showed that the effects of mouthwashes on the color change and solubility of composite resins varied depending on the material. Color stability and solubility varied depending on the structure of the organic matrix of the composite, the size and amount of filler particles, and the chemical structure and contents of the mouthwashes.

## CONCLUSION

Different levels of clinically unacceptable color change were observed in all composite groups evaluated in this study after immersion in mouthwashes. The color stability of the composite resins was found to be directly related to the structure of the resin matrix and the filler particle size. Filtek Ultimate, with a nanofill particle structure, was determined as the composite material with the lowest amount of color change. It was also observed that color stability changed according to the chemical contents and pH valuesof the mouthwashes. The Colgate Plax mouthwash was determined to cause the lowest amountof color change. When evaluated in terms of solubility, levels of dissolution were found to be related to the filler particle size of the composite resin. While solubility changes were determined for all composite samples in all mouthwash groups, the microhybridFiltek Z250 composite was found to be the composite material experiencing the highest solubility. In terms of the solutions, the highest amount of solubility was observed with the Listerine Advanced White mouthwash. Within the limitations of this study, considering that significant color changes may occur in the composite materialsof existing restorations as a result of regular exposure to mouthwashes and that dissolution may affect the clinical life of restorations, it can be suggested that the contents of mouthwashes should be taken into account when dentists recommend mouthwashes to their patients.

## ETHICAL DECLARATIONS

**Ethics Committee Approval:** Ethics committee decision is not required as it does not contain human and animal material.

**Informed Consent:** Due to the nature of the study, informed consent is not required.

**Referee Evaluation Process:** Externally peer-reviewed.

**Conflict of Interest Statement:** The authors have no conflicts of interest to declare.

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**Author Contributions:** All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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