RESEARCH ARTICLE

Color Changes of Restorative Materials with Different Surface Finishing Processes Applied and Kept in Different Solutions

Alper Ozdogan[1], Ozcan Akkal[2], Zeynep Sen Yilmaz[3]

Abstract

Aim: Investigation of color changes of restorative materials with different surface finishing processes applied and kept in different solutions.

Materials and methods: Totally 240 rectangular prism specimens were used in this study. Specimens were produced by four different restorative materials (two composites, lithium disilicate ceramic and zirconia) and each group was randomly divided into three groups. The three different surface finishing processes were applied to the specimens, and again, each group was randomly divided into four groups ($n = 5$). The initial color measurements were performed by spectrophotometer and recorded, after that the specimens were kept in four different solutions for a total of 28 days. The first 7- and 28-day color measurements of the specimens were made by spectrophotometer and recorded. Data were analyzed with Kruskal–Wallis and Tamhane's T2 test.

Results: There was a statistically significant difference between the discolorations of the restorative materials ($p < 0.001$) and was no statistical difference between the different polishing processes ($p > 0.05$) during all periods. Although there was a statistically significant difference between the discolorations during 0–7 days and 7–28 days ($p < 0.001$), there was no statistically significant difference between the discolorations during 0–28 days ($p > 0.05$).

Conclusion: During 0–28 days of investigations, different solutions cause a color change in restorative materials, and surface polishing processes are of no importance in this case.

Keywords: Color, Composite, Lithium disilicate, Surface polishing, Zirconia.

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Introduction

Nowadays, people's greatest expectation regarding oral and dental health is esthetics. Therefore, restorative materials play a very significant role in dentistry clinical practices. Along with the development of technology, the esthetic properties of esthetic restorative materials have also improved. Composites, glass-ceramics, and zirconia restorations take up quite a large space in the esthetic procedure steps of prosthetic dental treatment.[1] Composite resins first began to be used in dentistry in the 1960s, and nowadays, they have become commonly used in the anterior and posterior regions.[2] Composites are esthetic filling materials consisting of organic, inorganic, and binding components that are bonded to tooth tissue by adhesion.[3] Zirconia ceramics with superior mechanical properties began to be used in dentistry in the 1990s.[4] Zirconia, which is a polymorphic material, is used as an alternative to metal framework systems due to its sufficient esthetic properties as well as its good mechanical properties.[5] Nowadays, they are covered with a veneer restoration and are used as frameworks,[6] and also they are preferred in the production of esthetic restorations monolithically.[7] All-ceramic restorations are a group of materials with ever-increasing popularity due to their superior esthetic properties, biocompatibility, and corrosion-resistant structures.[8] Glass-ceramics with lithium disilicate content are systems that show good adhesion to the tooth structure, have high flexural strength, and also allow for the production of monolithic restorations.[9–11]

Color is one of the most important parameters that affect the clinical durability of restoration as well as its esthetic character. The restorations applied are expected to be similar to natural teeth and to display a natural appearance. It is also expected that the restoration will maintain its color for a long time and will not lose its color by being affected by intraoral changes. Discolorations can be external or internal. External discolorations can occur due to poor oral hygiene, the effect of restorations, plaque build-up, dietary habits, and the presence of chromogenic microorganisms.[12] Drinks, such as, tea, coffee, juice, coke, and wine, which are frequently consumed in daily life, can cause discoloration in teeth and restorations. Apart from these drinks, mouthwashes used as an antimicrobial agent can also cause dental discoloration.[13]

Objective and reliable measurement devices, such as, spectrophotometer and colorimeter, are used to evaluate the discoloration.[14] In dentistry, the color properties of natural teeth and restorative materials can be measured using the Commission Internationale de l'Eclairage (CIE) color system.[15] ΔE values in

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these measurements are evaluated as follows: $\Delta E < 3$ is clinically undetectable, $\Delta E = 3–5$ is clinically acceptable, and $\Delta E > 5$ is clinically unacceptable.[16]

Additional adaptation procedures may be required before a restoration is placed in the mouth. In this case, there may be deterioration in the surface polish of the restoration. The polished surfaces of restorations must be reconstructed before they are cemented to the mouth. In such cases, the polishing process can be applied with polishing rubbers or kits at the chairside to regain the lost surface polish in restorations.[17] For this purpose, different polishing kits have been offered for use by the manufacturers. Different systems including tungsten carbide finishing burs, diamond rotary instruments, silicone rubber disks, and silicon carbide or aluminum oxide-coated abrasive disks form the content of polishing kits.[18]

This study aims to investigate the discolorations of restorative materials that have been treated with different surface finishing processes and kept in different solutions. The hypotheses of the study are as follows: (i) the most discoloration will occur in composite specimens, (ii) differences in surface finishing processes will affect the discolorations of restorations, and (iii) different solutions and holding time in solutions will increase the discolorations of materials.

Materials and Methods

Within the scope of the study, four restorative materials, three different polishing systems, and four different solutions were used. Information about the materials used in the study is presented in Table 1. A total of 240 rectangular prism specimens with the dimensions of $10 \times 4 \times 2$ were prepared, consisting of 60 specimens of each restorative material. As a result of the power analysis conducted to determine the number of specimens, the G*Power software program (v.3.0.10) was used to obtain the highest power level with the smallest specimen size. The analysis showed that at least five specimens were required for the highest power level (power = 80, $\alpha = 0.05$).

Table 1: The materials and solutions are used in the study

Material type	*Brand name*	*Manufacturer*
Nano hybrid composite	Grandio	Voco
Nano-filled composite	Clear Majesty Esthetic	Kuraray Noritake
Lithium disilicate glass ceramic	IPS e.max Press	Ivoclar Vivadent
Zirconium	Prettau Zirconia	Zirkonzahn
Glaze for lithium disilicate	IPS e.max Press Ceram Glaze Paste	Ivoclar Vivadent
Glaze for zirconia	Glaze Plus	Zirkonzahn
Ceramic polishing kit	Luster Intraoral Twist Kit	Hager & Meisinger
Ceramic polishing kit	OptraFine Assortment	Ivoclar Vivadent
Tea	Lipton Earl Grey	Unilever
Coffee	Nescafe Gold	Nestle
Coke	Coca Cola	Coca Cola Comp.
Mouthwash	Tantum Verde	Angelini

The color of the restorative materials was determined to be A1 according to the Vita scale, and the specimens were prepared according to the manufacturer's instructions in line with their own production techniques. In the preparation of composite specimens, molds from silicone-based impression material (elite HD + putty soft; Zhermack, Badia Polesine, Italy) were prepared by the initial dimensions. Composite resins (Grandio, Clearfil Majesty Esthetic) were placed in silicone molds by the incremental technique and polymerized by an LED curing device Valo Grand (Valo; Ultradent, South Jordan, Utah, USA) for 20 seconds. After the obtained specimens were removed from the molds, marginal corrections and final finishing processes were performed using Soflex discs (Sof-Lex™; 3M ESPE, Maplewood, New Jersey, USA). The wax patterns (Elastiwac; Keram & Keramik) prepared for lithium disilicate specimens were taken into investment (IPS e.max Special Investment Material; Ivoclar Vivadent) and pre-heated at 850°C for 1 hour after the investment hardened. Following this heat treatment, IPS e.max Press ingots (Ivoclar Vivadent) were pressed at 920°C with a temperature increase rate of 60°C/minute in the EP 600 oven with the initial temperature of 700°C, after 25 minutes of holding time. Zirconia specimens were produced from Prettau blocks (Zirkonzahn GmbH, Gais, Italy) by engraving with the help of a CAD/CAM unit (Yenadent D40 CAM unit; Yenadent, ZenoTec, İstanbul, Turkey) with a thickness of $10 \times 4 \times 2$ mm. The sintering process of the specimens in the sintering furnace (Zirkonofen, Gais, Italy) was performed as per the manufacturer's instructions with the initial temperature of 300°C and the holding time of 30 minutes, the final temperature of 1540°C reached in 60 minutes, and the holding time of 90 minutes at 1540°C.

After measuring the dimensions of all the specimens obtained with the help of a digital micrometer and making sure that they were correct, the specimens in each group were randomly divided into three groups for polishing processes. The polishing processes applied to the specimen surfaces are as follows:

Conventional Polishing

The denture sealant agent (Palaseal; Kulzer&CoGmbH, Wefirheim/Ts, Germany) was applied to the composite specimen surfaces and polymerized in the polymerization unit (HiLite Power; Heraeus Kulzer; Hanau, Germany) for 6 minutes. For the conventional polishing of lithium disilicate and zirconia specimens, the glaze materials specific to each material were fired by applying them in a thin layer.

Meisinger Polishing Kit

Polishing rubbers included in the kit were applied to the specimen surfaces according to the order (green–blue–red–yellow) in the manufacturer's instructions. The rotating speed of the handpiece was applied by the same researcher in the form of circular movements for each polishing rubber for 60 seconds, with a maximum of 10,000 rpm and an average pressure of 2 N and without water cooling, according to the manufacturer's instructions.

OptraFine Polishing Kit

Polishing rubbers included in the kit were applied to the specimen surfaces according to the order (light blue–dark blue) in the manufacturer's instructions. The rotating speed of the handpiece was applied by the same researcher in the form of circular movements for each polishing rubber for 60 seconds, with a maximum of 10,000 rpm, water cooling, and an average pressure of 2 N, according to the manufacturer's instructions. Then, the

polishing paste (OptraFine HP PolishingPaste; Ivoclar Vivadent AG) in the kit was applied to the specimen surfaces with the same handpiece speed and pressure, this time without water cooling, for 60 seconds and in the form of circular movements.

The specimens, of which surface polishing was completed, were numbered, and the initial color measurements were performed by a single researcher with the help of a spectrophotometer (VITA EasyShade V; VITA Zahnfabrik, Bad Sackingen, Germany), with the background in a gray tone.[19] All measurements of the specimens placed in the background were performed in the "single tooth" mode of the spectrophotometer. Three measurements were made on the gray background from the right, left, and middle regions of each specimen and averaged. Before each measurement, the spectrophotometer was calibrated according to the manufacturer's recommendations. The color values of all specimens were recorded according to the CIE L*a*b* system. With the formula $\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, the mean value of each specimen was obtained[20] and recorded as $\Delta E(0)$. The specimens, of which color measurements were completed, were randomly divided into four groups ($n = 5$) and kept in four different solutions in a dark, closed environment and at room temperature for 7 and 28 days. The solutions were replaced every day to ensure standardization. After 7 days, the specimens were removed from the solutions, washed, and dried. The color measurements of the specimens were performed by the first measurement protocol, and the color value of each specimen was recorded as $\Delta E(7)$. The specimens, of which measurements were completed, were placed in the solutions again, and at the end of the 28th day, color measurements were performed according to the initial protocol by removing them from the solutions, and the ΔE value of each specimen was recorded as $\Delta E(28)$.

Statistical analysis of the data was conducted with the Kolmogorov–Smirnov homogeneity test and Kruskal–Wallis test using the IBM v.20 packaged software (SPSS v.20.0; SPSS Inc., Chicago, Illinois, USA). Tamhane's T2 multiple comparison tests was used for intergroup comparisons.

Results

According to the data obtained from the results of the Kruskal–Wallis test (Table 2):

It was observed that there was a statistically significant difference between the discolorations of the restorative materials during 0 to 7, 7 to 28, and 0 to 28 days ($p < 0.001$), and there was no statistical difference between the discolorations related to different polishing processes during 0 to 7, 7 to 28, and 0 to 28 days ($p > 0.05$). In the comparison of the solutions in which they were kept, although there was a statistically significant difference between the discolorations during 0 to 7 and 7 to 28 days ($p < 0.001$), there was no statistically significant difference between the discolorations during 0 to 28 days ($p > 0.05$). The mean, standard deviation values, and Tamhane's T2 multiple comparison test results of the groups are shown in Tables 3 to 5. The 0 to 7, 7 to 28, and 0 to 28 days color

Table 2: Kruskal–Wallis test results of the groups

Groups		*0–7 days*	*0–28 days*	*7–28 days*
Restorative materials	Chi-square	81.408	136.590	60.010
	df	3	3	3
	Asymp. Sig.	0.000	0.000	0.000
Polishing procedures	Chi-square	0.221	0.457	0.308
	df	2	2	2
	Asymp. Sig.	0.896	0.796	0.857
Solutions	Chi-square	11.890	5.683	29.126
	df	3	3	3
	Asymp. Sig.	0.008	0.128	0.000

Table 3: 0 to 7 days mean ΔE values and Tamhane's T2 multiple comparison test results for groups

	0–7 days		
Material	*Mean*	*Std. Dev.*	*N*
Grandio	3.99[a]	2.02	60
Clearfil Majesty Esthetic	3.95[a]	2.10	60
IPS e.max Press	0.96[b]	0.56	60
Prettau Zirconia	0.11[c]	0.02	60
Conventional	3.06	2.13	80
Meisinger	1.25	0.96	80
OptraFine	1.54	1.29	80
Tea	0.32[A]	0.72	60
Coffee	1.19[A,B]	1.52	60
Coca Cola	1.89[B]	1.05	60
Mouthwash	2.39[B]	3.20	60

[a–c]Mean significantly different for restorative materials; [A,B]Mean significantly different for solutions ($p < 0.05$)

Table 4: 7 to 28 days mean ΔE values and Tamhane's T2 multiple comparison test results for groups

	7–28 days		
Material	*Mean*	*Std. Dev.*	*N*
Grandio	5.98[a]	1.78	60
Clearfil Majesty Esthetic	5.02[a]	2.44	60
IPS e.max Press	1.54[b]	1.34	60
Prettau Zirconia	0.56[c]	0.54	60
Conventional	0.23	0.55	80
Meisinger	1.38	1.14	80
OptraFine	1.57	1.33	80
Tea	2.58[A]	1.69	60
Coffee	2.01[A]	1.51	60
Coca Cola	1.25[B]	0.65	60
Mouthwash	2.76[A]	1.44	60

[a–c]Mean significantly different for restorative materials; [A,B]Mean significantly different for solutions ($p < 0.05$)

Table 5: 0 to 28 days mean ΔE values and Tamhane's T2 multiple comparison test results for groups

	0–28 days		
Material	*Mean*	*Std. Dev.*	*N*
Grandio	6.04[a]	4.01	60
Clearfil Majesty Esthetic	7.15[a]	4.82	60
IPS e.max Press	1.53[b]	0.80	60
Prettau Zirconia	0.56[b]	0.43	60
Conventional	2.82	1.83	80
Meisinger	2.72	2.12	80
OptraFine	3.44	2.88	80
Tea	3.41	3.16	60
Coffee	3.28	2.47	60
Coca Cola	1.61	1.13	60
Mouthwash	2.69	2.92	60

[a,b]Mean significantly different for restorative materials ($p < 0.05$)

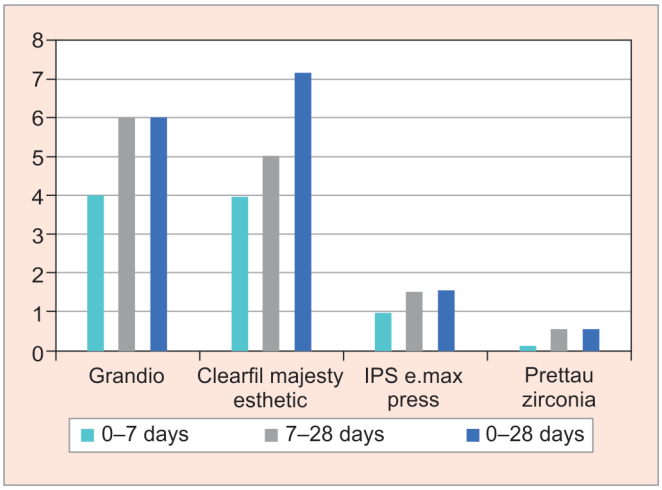

Fig. 1: Graph showing the color changes of the restorative materials at 0 to 7, 7 to 28, and 0 to 28 days

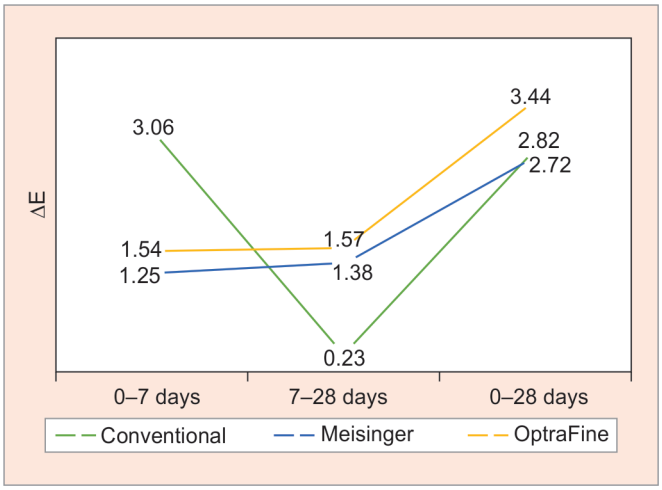

Fig. 2: Graph showing the color changes of the polishing methods at 0 to 7, 7 to 28, and 0 to 28 days

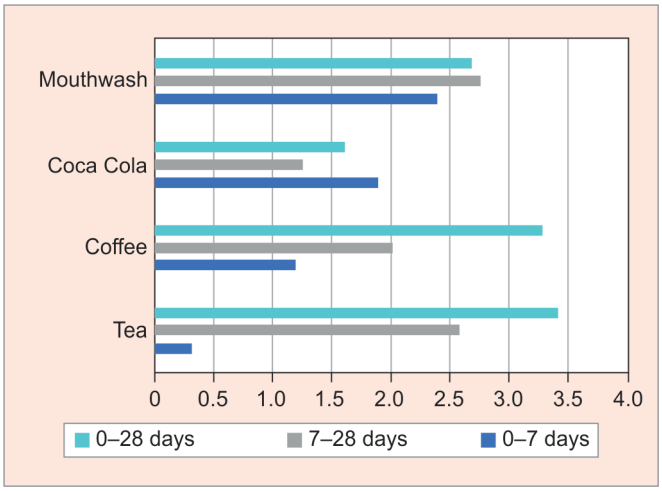

Fig. 3: Graph showing the color changes of the solutions at 0 to 7, 7 to 28, and 0 to 28 days

changes of the materials polishing methods and solutions used in the study are shown in Figures 1 to 3.

When the discolorations between 0 and 7 days belonging to the groups were examined according to Tamhane's T2 multiple comparison test results:

It was observed that the most discoloration occurred in Grandio composite and then in Clearfil composite and the difference between them was not statistically significant ($p > 0.05$), the least discoloration occurred in Prettau zirconia, IPS e.max Press had more discoloration than Prettau zirconia, and there was a difference between them and composites ($p < 0.001$). When the solutions in which they were kept were evaluated, it was observed that the least discoloration occurred in the specimens kept in tea and they showed a statistically significant difference with other solutions except for coffee ($p < 0.05$), the most discoloration occurred in the specimens kept in the mouthwash, they were followed by the specimens kept in coke and coffee, respectively, and the difference between them was not statistically significant ($p > 0.05$).

When the discolorations between 7 and 28 days belonging to the groups were examined according to Tamhane's T2 multiple comparison test results:

It was observed that the most discoloration occurred in Grandio composite as in the discolorations between 0 and 7 days and then in Clearfil composite and the difference between them was not statistically significant ($p > 0.05$), the least discoloration occurred in Prettau zirconia, IPS e.max Press had more discoloration than Prettau zirconia, and there was a difference between them and composites ($p < 0.001$). When the solutions in which they were kept were evaluated, it was observed that the most discoloration occurred in the specimens kept in the mouthwash, they were followed by the specimens kept in tea and coffee, respectively, the difference between them was not statistically significant ($p > 0.05$), and the least discoloration occurred in the specimens kept in coke, and they showed a statistically significant difference with all other solutions ($p < 0.05$).

When the discolorations between 0 and 28 days belonging to the groups were examined according to Tamhane's T2 multiple comparison test results:

It was observed that the most discoloration occurred this time in Clearfil composite and then in Grandio composite, and the difference between them was not statistically significant ($p > 0.05$). It was observed that the least discoloration occurred in Prettau Zirconia specimens, and they were followed by IPS e.max Press specimens. Although the difference between them was not statistically significant ($p > 0.05$), they showed a significant difference with composite specimens ($p < 0.001$). It was found that there was no statistically significant difference in the discolorations during 0 to 28 days between polishing processes and solutions in which the specimens were kept ($p > 0.05$).

According to the Wilcoxon test results conducted to examine the relationship between the discolorations according to the days, it was concluded that:

- Discolorations between 0 and 7 days and discolorations between 0 and 28 days showed a statistically significant difference ($p < 0.001$).
- Discolorations between 0 and 7 days and discolorations between 7 and 28 days did not show a statistically significant difference ($p > 0.05$).
- Discolorations between 7 and 28 days and discolorations between 0 and 28 days showed a statistically significant difference ($p < 0.001$).

Discussion

This study aimed to investigate the discolorations of restorative materials that have been treated with different surface finishing processes and kept in different solutions for different periods. As a result of the study, our first hypothesis was accepted since most discoloration occurred in composite specimens. However, other hypotheses were rejected because different surface finishing processes did not affect the discoloration statistically, and although there were differences between the discolorations of the groups during 0 to 7 and 7 to 28 days, there was no statistically difference between the discolorations during 0 to 28 days and all solutions in which they were kept.

Numerous factors, such as, dehydration, water absorption, surface roughness, and colored peroxide compounds formed as a result of the oxidation of carbon–carbon double bonds are effective in the discoloration of esthetic restorative materials.[21] The discoloration of restorative materials may vary depending on the patient's eating habits, the drinks consumed and the frequency of consumption, oral hygiene care, and the structure of the materials. The discoloration occurs as a result of the color pigments in food taken with diet discoloring the surface, or the pigments diffusing together with the liquid into the framework material and between the molecules.[22] The limit value of the color difference noticeable by the human eye or the acceptable color difference was determined as different values as a result of different studies. The acceptable values were specified as between $\Delta E = 1$, $\Delta E = 2$, $\Delta E = 3$, $\Delta E > 3.3$ or $\Delta E = 3.3$ and $\Delta E > 3.7$ or $\Delta E = 3.7$.[23] On the one hand, Seghi et al.[24] reported that the mean acceptable color difference value should be $\Delta E > 2$. Yannikakis et al.,[25] on the other hand, stated that values below $\Delta E = 3.7$ are "acceptable" and values above that are "unacceptable". Most of the studies on this subject were carried out *in vitro*. In their *in vivo* study, Johnston and Kao[26] found that ΔE value should be below 3.7 for an optimal color match within the mouth. In this study, it was observed that discolorations in all the groups evaluated during 0 to 7 days were acceptable or close to acceptable, and in longer evaluations, only composite specimens had a discoloration above the acceptable level. This situation is in line with the data in the literature.

According to Ertas et al.,[27] the maximum holding time of the materials in solutions is 4 weeks. This period is equivalent to 2.5 years of use. In their study, Crispin and Caputo[28] reported that tea and coffee solutions caused high discoloration after 1 month. For this reason, we limited our study to 28 days. Furthermore, since composite resins are reported to have a significant discoloration within the first 7 days,[28,29] the measurement of 7-day values was also included in the study.

Studies on discolorations of many restorative materials are available in the literature. In a study on the discolorations of different composite resins, it was reported that the solutions in which they were kept affected the discoloration of materials, the most discoloration occurred in the specimens kept in red wine, the discoloration in mouthwashes was acceptable, and dual-polymerized resins had the highest discoloration values.[30] In another study conducted with composite resins, the 7-day evaluation showed that the most discoloration occurred in red wine, then in tea and coffee. Moreover, specimens kept in coke and water were reported to have the least discoloration.[31] In another study, it was observed that grape juice caused the discoloration in composite specimens within 1 week, while coffee and yerba mate did not cause any discoloration.[32]

In a study on discolorations of lithium disilicate ceramics, it was reported that the most discoloration occurred in the specimens kept in coke and orange juice, and coffee caused the highest opacity and lowest translucency in the specimens.[33] It was reported that the discoloration created by the coffee thermal cycle applied to zirconia-reinforced ceramics and lithium disilicate ceramics was acceptable.[34] Another study reported that the coffee thermal cycle caused the discoloration in monolithic and veneer zirconia, but these discolorations were also at clinically acceptable levels.[35] In a study on zirconia ceramics, it was reported that the materials were not affected by acidic drinks, although their ΔE values were affected by coffee.[36] According to the results of this study, when the discolorations during 0 to 7 days were examined, it was observed that the most discoloration occurred in the Grandio composite, and the least discoloration occurred in Prettau zirconia. When the discolorations during 7 to 28 days belonging to the groups were examined, it was observed that the most discoloration occurred in Grandio composite, and the least discoloration occurred in Prettau zirconia. When the discolorations during 0 to 28 days belonging to the groups were examined, it was observed that the most discoloration occurred in Clearfil composite this time, and the least discoloration occurred in Prettau Zirconia specimens. It is thought that the discoloration occurred at a higher level in composite specimens than the other materials compared due to the internal structure of the materials, their surface properties, and higher liquid absorption.

In their study, Guler et al.[37] reported that drinks causing the most discoloration in various restorative materials were red wine, coffee, coffee with the milk powder, and tea with sugar, respectively. In various studies in which the coloring effect of coke was tested, it was thought to have low pH due to the citric acid in its content and cause the matrix to soften, leading to deterioration in the composite surfaces, and high ΔE values were expected.[28,38] In studies related to mouthwashes, Baig et al.[39] stated that Listerine caused less discoloration in nanocomposites than non-alcohol chlorhexidine, Soygun et al.[40] stated that mouthwashes with high alcohol content increased the discoloration of bioceramics, and Derafshi et al.,[41] on the other hand, stated that the discolorations of monolithic zirconia and feldspathic porcelain in Listerine and chlorhexidine were clinically acceptable. Although there was a statistical difference between the discolorations during 0 to 7 and 7 to 28 days in the comparison of the solutions in which they were kept according to the results of this study, there was no statistically significant difference between the discolorations during 0 to 28 days. It was observed that the most discoloration was in the mouthwash and the least discoloration was in tea during 0 to 7 days, and the most discoloration was in the mouthwash and the least discoloration was in coke during 7 to 28 days. On the other hand, there was no significant difference between solutions during 0 to 28 days. It is considered that the different results acquired in three different time periods were caused by factors, such as, the temperature of the solutions in which the specimens were kept, the room temperature, or the darkness of the holding environment.

While it was expected that different polishing processes would create a significant difference in the discoloration of restorative materials in the study, no statistical difference was found between different polishing processes during 0 to 7, 7 to 28, and 0 to 28 days. It is assumed that this is because different polishing processes have a similar effect on the surfaces of materials, or the polishing process affects only the outer surface of the material.

One of the limitations of the study is that the surface roughness of the materials was not evaluated while polishing the materials. Thus, the relationship between surface roughness and discoloration was not evaluated. Another limitation is that the study is an *in vitro* study, so it cannot fully reflect oral conditions.

Conclusion

Within the limits of this study, the following conclusions were reached:

- There were differences between the discolorations of different restorative materials during 0 to 7, 7 to 28, and 0 to 28 days. The most discoloration occurred in composite specimens, and the least discoloration occurred in zirconia specimens.
- Different polishing processes did not affect the discoloration of the materials.
- There was a difference between the discolorations of the solutions in which the specimens were kept during 0 to 7 and 7 to 28 days. In both time periods, the most discoloration was found in the specimens that were kept in the mouthwash, and the least discoloration was found in the specimens that were kept in tea for 0 to 7 days and coke for 7 to 28 days.

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