

## Effects of contemporary orthodontic composites on tooth color following short-term fixed orthodontic treatment: a controlled clinical study

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**Background/aim:** To determine the color alterations of natural teeth associated with different orthodontic composites used in comprehensive short-term treatment.

**Materials and methods:** Twenty-two patients were treated with fixed appliances and 22 untreated subjects were also evaluated. Lower incisors were bonded with different orthodontic composites: 42 with Grelgloo, 41 with Light Bond, 31 with Kurasper F, and 32 with Transbond XT. The color parameters of the Commission Internationale de l'Eclairage (CIE) were measured for each tooth with a spectrophotometer. Color assessment in relation to time, adhesive material, and their interaction was made with 2-way mixed analysis of variance (ANOVA) and 1-way ANOVA for the color differences ( $\Delta E^*$ ). Further analyses were done using Tukey's honestly significant difference tests and paired-samples t-tests.

**Results:** The color of teeth was affected by treatment. The mean  $L^*$  and  $a^*$  values increased, whereas the mean  $b^*$  values decreased. Total color differences of teeth demonstrated visible color changes clinically after treatment, ranging from 1.12 to 3.34  $\Delta E$  units. However, there were no significant differences for color of enamel.

**Conclusion:** Teeth may be discolored with fixed appliances during treatment. Moreover, contemporary orthodontic composites have similar effects of enamel discoloration.

**Key words:** Tooth color, discoloration, orthodontic composites

### 1. Introduction

Orthodontics is a unique science in dentistry since its workspace sets on the external surface of enamel when using fixed appliances for treatment. Orthodontists or patients may encounter unwanted changes on the enamel surface or structure, such as discoloration, white spots, microcracks, fractures, and abrasions during and after fixed orthodontic treatment (FOT) because of, e.g., diet, oral care, bonding materials and techniques, composites, appliances, debonding, and clean-up procedures (1–3). Bonding materials and composites of FOT are the most prominent factors responsible for enamel color alterations (3,4). Enamel discolorations may occur by direct absorption of food colorants and products arising from the corrosion of the orthodontic appliance into resin tags (5,6). The long-term presence of these residues in the enamel tags during fixed treatment makes the color stability of these materials critical for tooth color (7).

A great deal of orthodontic research has concentrated on the assessment of the physical and mechanical performances of the adhesive resins. However, comparatively few studies have investigated the effects of bonding materials used in brackets on enamel color (3,5,8–10) and only 2 clinical studies examined the color alterations of teeth associated with FOT (3,4). According to the findings of those studies, visible enamel color changes may occur with fixed appliances, which would be detected in clinical trials (3,4). Although enamel color was changed after orthodontic treatment, the light-cured composite was associated with lower discoloration rates than chemically cured resins (4). According to Karamouzos et al. (4), orthodontists may choose the use of no-mix and light-cured composites, whose effects on enamel color were the same. However, a recent in vitro study about discoloration of these types of orthodontic composites revealed that unsatisfactory color stability was

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observed for contemporary adhesive systems and also that discolorations of resins were very different (8).

At this point, the choice of orthodontic composite may be very clinically important in esthetically critical areas with FOT. An orthodontic resin must bond the bracket to the tooth very well, along with protecting its own color during its life span. Even then, discoloration of adhesives is especially problematic when adhesives are subjected to prolonged exposure to staining materials during long-term treatment. Therefore, the comparison of different contemporary composites in the same mouth will give very practical and useful information about discoloration of teeth to clinicians for FOT, and it is also especially needed because there is no further information about discoloration of the new generation of orthodontic composites in vivo in the literature.

The color of composites is known to change in the mouth over a certain period of time due to many extrinsic and intrinsic factors (4,11,12). Many factors influence the extent of discoloration of adhesives, such as incomplete polymerization, resin matrix composition, type of filler particles, light-curing devices, and irradiation times (4,5,7,8,11). Thus, irradiation time and composition of the adhesive are very important for color stability of the tooth/adhesive. Therefore, the color stability of teeth must be evaluated in a way different from the study of orthodontic composites in vivo. This prospective clinical trial was performed to determine the color alterations of teeth in vivo associated with 4 different contemporary composites used in orthodontic treatment using a spectrophotometer. Two of these materials must be cured for 20 s and the others for 40 s. The null hypothesis was that no statistically significant difference would be found in color performance of teeth bonded with different materials before and after orthodontic treatment.

## 2. Materials and methods

The study sample involved 28 consecutive patients who were treated in the Department of Orthodontics, Faculty of Dentistry, İnönü University, Malatya, Turkey, and 22 consecutive patients who were investigated as an untreated control group in the Department of Orthodontics, Faculty of Dentistry, Abant İzzet Baysal University, Bolu, Turkey. The present prospective clinical study was approved by the local clinical research ethics committee of İnönü University (Acceptance No. 2012/40), and an informed consent form was signed by the parents of the children included in the study.

The treatment group met the following inclusion criteria: 1) need for comprehensive orthodontic treatment by fixed appliances in the lower arch; 2) permanent dentition, no severe crowding (<4 mm); 3) no plaque accumulation or gingival inflammation before bracket bonding; 4) no

dental caries or restorations; 5) no smoking habit; and 6) no systemic disease. The untreated control group met one extra inclusion criterion: no crowding in the mandibular dentition. In a clinical study, total color differences ( $\Delta E$ ) between all measured teeth were found to be  $2.80 \pm 0.82$  (4). Sample size calculation to determine the number of teeth necessary to achieve 90% power with  $\alpha$  of 0.05 was based on  $\beta = 0.10$  meaningful difference (G Power Version 3.1.3). The calculation showed that a minimum of 22 teeth were required. Since 4 teeth of an individual were bonded, a minimum of 22 patients was necessary in this study.

Before treatment, patients were trained and informed to maintain oral hygiene with fixed appliances and to brush at least 3 times a day with white fluoride toothpaste. Patients were not permitted to routinely use staining mouth rinses or beverages during orthodontic treatment. Oral hygiene status was assessed at every treatment appointment, and, if necessary, supporting information and training were given. Moreover, there was no inflammation of the soft tissues adjacent to the lower incisors in the 2 groups. Six subjects were excluded from the treatment group because of cooperation and oral hygiene problems or repeated bracket failure. The treatment group ( $n = 22$  patients) included 11 females and 11 males (mean age:  $14.4 \pm 2.97$  years; range: 12.0–17.6 years) and the control group ( $n = 22$  patients) included 12 females and 10 males (mean age:  $15.1 \pm 2.55$  years; range: 12.4–17.8 years). The mean treatment and control times were  $6.8 \pm 1.2$  months and  $8.5 \pm 1.1$  months, respectively.

The treatment started with the upper teeth and, 2 or 3 months later, the lower teeth were bonded, because the lower incisors are most likely to present bracket failures due to eating habits or particular foods and beverages, especially at the beginning of the treatment, and such possible failures and rebondings might affect the study results. Thus, there were no bracket failures for the lower teeth and a possible major limitation was eliminated from the present study. Moreover, there was no inflammation of the soft tissues adjacent to the lower incisors.

The same examination room, facing north, and the same hours of the day were used to do in vivo spectrophotometric color measurements in order to ensure standardization. All measurements and oral hygiene scores were recorded for 3 weeks before starting the study by the same educated and experienced operator (FÖ) to ensure intraexaminer reliability for color measurement. At the end of the education period, 10 patients were randomly selected and reexamined (before starting FOT and from the untreated control group) by the same operator 1 week later. The differences between the measurements of tooth color were evaluated by Pearson correlation coefficient and paired t-test. Tooth color was analyzed using an intraoral spectrophotometer (VITA Easyshade Compact, VITA

Zahnfabrik, Germany) with a 5-mm probe and an infection control shield was utilized for every patient. The instrument was automatically calibrated using an integrated calibration plate on the base station of the device for every patient (13). The spectrophotometer's light sensor tip was placed at right angles to the central area of the middle third of the labial surface of the tooth's axis and measurement was performed in the 'tooth area' mode (middle) with an Essex gauge (13). The color measuring procedure was repeated 3 times for each tooth for a total of 12 times per patient before bracket bonding and also after debonding and cleaning (8,13). The color measurements of 2 patients in the treatment group were done immediately after 1 week, when inflammation was no longer present. The color measurements of the untreated control group were done with an interval of approximately 8 months by FÖ.

Bonding procedures were performed according to the manufacturer's instructions by another operator (ET; Table 1). Stainless steel brackets (Equilibrium 2, Dentaurem, Germany) were placed and firmly pressed onto the enamel surfaces and excess adhesive was removed from the bracket base periphery. Tooth number 42 was bonded with Grengloo, 41 with Light Bond, 31 with Kurasper F, and 32 with Transbond XT. Curing was carried out with an LED unit (Elipar S10, 3M ESPE). If a slight bit of excess adhesive was present after setting, it was removed (especially along the gingival margin) with burs. All brackets were ligated with steel ties to arch wire to minimize plaque accumulation for the duration of treatment.

At the end, brackets were mechanically debonded and adhesive residue was cleaned, first with a high-speed carbide bur and then with a low-speed carbide bur, and, finally, the enamel surface was polished with Sof-Lex finishing disks (3M Dental). The color measurements and

the treatments were done by different operators to produce a double-blind study.

Each value of 22 teeth of different patients with the same adhesive was averaged and the color difference was obtained from the average color values. The Commission Internationale de l'Eclairage (CIE) L\*a\*b\* color system was used for determination of color difference (14). The CIE L\*a\*b\* color system uses 3 dimensional colorimetric measurements, L\*, a\*, and b\*, where L\* values correspond to the brightness of a color [ranging from 0 (black) to 100 (white)], a\* values to the redness (positive a\*) and greenness (negative a\*) content, and b\* values to the yellowness (positive b\*) and blueness (negative b\*) content. The total color difference, ΔE\*ab, between 2 color stimuli, each given in terms of L\*, a\*, and b\*, is calculated from the following formula:

$$\Delta E^* = [(L1^* - L2^*)^2 + (a1^* - a2^*)^2 + (b1^* - b2^*)^2]^{1/2}.$$

A perceptible color change of ΔE\* > 1.0 (default value) is referred to as acceptable up to the value of ΔE\* = 3.7 in subjective visual determinations made in vitro under optimal lighting conditions (4).

The data were entered into a spreadsheet (Excel 2007; Microsoft, USA) for calculation of descriptive statistics. Color assessment in relation to time, adhesive material, and their interactions was made with 2-way mixed analysis of variance (ANOVA) for the L\*, a\*, and b\* parameters and with 1-way ANOVA for ΔE\*. The assumptions of univariate normality were tested and verified with the Kolmogorov-Smirnov test (P > 0.05). Afterwards, the obtained data were analyzed between different groups by Tukey's honestly significant difference (HSD) test. Intergroup comparisons (L1\*-L2\*, a1\*-a2\*, b1\*-b2\*) were tested with the paired-samples t-test. These statistical analyses were conducted with SPSS 17.0 (SPSS Inc., USA). The level of significance was set at 0.05.

**Table 1.** Bonding system used for patients in orthodontic treatment.

Materials	Curing time	Material type	Manufacturer
Grengloo Light Cure	20 s	Uncured methacrylate ester monomers (20%–38%), inert mineral fillers, fumed silica, activators, and preservatives	Ormco Corporation, Glendora, CA, USA
Light Bond Light Cure	40 s	UDMA (15%–19%), bis-GMA (3%–7%), silica-crystalline, fused silica, amorphous silica, sodium fluoride	Reliance Orthodontic Products, Itasca, IL, USA
Kurasper F Light Cure	40 s	bis-GMA (5%–25%), TEG-DMA (6%), silanated barium glass filler, colloidal silica, DL-camphorquinone, catalysts, accelerators	Kuraray Europe GmbH, Frankfurt, Germany
Transbond XT Light Cure	20 s	bis-GMA (5%–10%), bis-EMA (10%–20%), TEG-DMA (5%–10%), silane-treated quartz, silane-treated silica	3M Unitek Orthodontics, Monrovia, CA, USA

38% phosphoric acid was applied for 30 s; light curing time was selected according to manufacturer's instructions.

UDMA: Urethane dimethacrylate, bis-GMA: bisphenol A diglycidyl methacrylate, bis-EMA: Bisphenol A bis-(2-hydroxyethyl ether) dimethacrylate, TEG-DMA: triethylene glycol dimethacrylate.

**3. Results**

In terms of method error, significant correlations between the first and second readings were found for the operators (0.812 and 0.785, respectively) and, according to the paired t-test ( $P = 0.736$  and  $P = 0.834$ , respectively), there was no significant difference between the first and second readings.

According to the present investigation, the color of teeth is affected by FOT when the CIE color system is used as a criterion. After progressive therapy, the mean  $L^*$  and  $a^*$  values increased by  $0.47 \Delta L^*$  units ( $P > 0.05$ ) and

$0.04 \Delta a^*$  units ( $P > 0.05$ ), respectively, whereas the mean  $b^*$  values decreased by  $-0.38 \Delta b^*$  units ( $P > 0.05$ ), but all of those findings were statistically insignificant. After a certain period of time in the untreated control group, the mean  $L^*$ ,  $a^*$ , and  $b^*$  values slightly changed, and those were also statistically insignificant (Table 2). Moreover, 2-way ANOVA showed that adhesive type had a significant effect on all color parameters, whereas time was significant with respect to parameter  $a^*$  and the interaction of time and adhesive type was insignificant for all color parameters (Table 3).

**Table 2.** The differences of CIE values of all measured teeth before and after orthodontic treatment and also within the untreated control group.

Product (tooth no. <sup>a</sup> )	n	$\Delta L^*$ (Mean $\pm$ SD)	$\Delta a^*$ (Mean $\pm$ SD)	$\Delta b^*$ (Mean $\pm$ SD)
Grengloo (42)	22	$0.77 \pm 1.97$	$-0.41 \pm 0.64^*$	$-0.04 \pm 1.58$
Light Bond (41)	22	$0.86 \pm 1.73^*$	$-0.57 \pm 0.76^*$	$-0.05 \pm 1.63$
Kurasper F (31)	22	$0.29 \pm 1.51$	$-0.34 \pm 0.62^*$	$0.26 \pm 1.55$
Transbond XT (32)	22	$-0.07 \pm 1.55$	$-0.21 \pm 1.757^*$	$0.01 \pm 1.75$
Total	88	$0.47 \pm 1.71$	$-0.38 \pm 0.63$	$0.04 \pm 1.59$
Untreated control	88	$0.23 \pm 0.11$	$-0.17 \pm 0.13$	$0.03 \pm 0.29$

Paired-samples tests; \*:  $P < 0.05$ . <sup>a</sup>: Tooth numbering according to the FDI system.

**Table 3.** Results of 2-way ANOVA for color parameters with respect to the effects of time and adhesive materials.

Effects	Type III sum of squares	df	Mean square	F	Significance (P-value)
Parameter $L^*$					
Time (T)	9.505	1	9.505	2.534	0.113
Adhesive (A)	200.054	3	66.685	17.778	0.000
Interaction (T $\times$ A)	6.335	3	2.112	0.563	0.640
Error	630.180	168	3.751		
Parameter $a^*$					
Time (T)	6.607	1	6.607	13.313	0.000
Adhesive (A)	13.645	1	4.548	9.165	0.000
Interaction (T $\times$ A)	0.740	3	0.247	0.497	0.685
Error	83.377	168	0.496		
Parameter $b^*$					
Time (T)	0.091	1	0.091	0.013	0.908
Adhesive (A)	628.288	3	209.429	30.578	0.000
Interaction (T $\times$ A)	0.759	3	0.253	0.037	0.990
Error	1150.640	168	6.849		

Two-way mixed analysis variance.

The  $\Delta E^*$  of teeth demonstrated clinically visible color changes after FOT, ranging from 1.12 to 3.34  $\Delta E$  units in the treatment group, and the  $\Delta E^*$  of teeth in the untreated control group did not demonstrate clinically visible color changes (Table 4). Furthermore, all adhesive materials showed the same color alterations on enamel and there were no significant differences for color of enamel among them. They were sorted from the lowest to highest values as follows: Kurasper F, Transbond XT, Grengloo, and Light Bond, respectively.

After the in vivo experimental orthodontic treatment with adhesive materials, unsatisfactory color stability or visible color changes were observed for 12.50% of the bonded teeth ( $\Delta E^* \geq 3.7$ ), and if these teeth were distributed among the subjects, almost 45.44% of the patients had at least 1 tooth with unacceptable color changes.

#### 4. Discussion

In the present study, the color alterations of the natural tooth before and after FOT were evaluated using a spectrophotometer. The results indicated no statistically significant unacceptable differences in CIE color values of teeth before and after FOT. However, all adhesive materials showed the same color alterations (in acceptable ranges) on enamel and so the color of teeth was changed compared to the baseline and also to the untreated control group. Thus, the null hypothesis was rejected.

The most common limitations of clinical research related to spectrophotometric instruments and natural tooth color measurement systems are associated with assessment of measurement uncertainties (1,12,13). Evaluation of measurement uncertainties of spectrophotometers by means of systematic and random errors are the main faults for precision and accuracy (13). Accuracy, with limitations usually originating from systematic errors, which are difficult to manage,

is affected mainly by spectrophotometric instruments and calibration techniques, fluorescence, instrument metamerism, and variations in measurement geometry. Precision, with limitations originating from random errors, which are main parts of the uncertainty of the evaluation process, could be tested by determination of repeatability (same method, operator, or instrument) and reproducibility (different method, operator, and/or instrument) (1,13). In the present study, the color of teeth was evaluated with the same operator, method, environmental conditions, and instrument, and also by using a gauge with multiple measurements and averaging of the obtained data, in order to decrease the random errors. In the literature, some comparison studies showed that the Vita Easyshade provided the best precision in vivo as compared to other instruments (15) and also had high reliability (reproducibility) and variability in accuracy (1). Furthermore, almost the same color coordinate ranges of natural teeth were achieved using the Vita Easyshade (1,15). The Vita Easyshade Compact was utilized in the present investigation as a spectrophotometer while considering these many advantages.

In the current study, mandibular incisors were selected for color comparisons of 4 orthodontic composites. First, sample size calculation was determined by power analysis. Second, teeth were in the same spontaneously visible region of the mouth. Third, more than 2 adhesives could be compared for investigations using 4 teeth, which were relatively similar in the range of color and size. Moreover, the duration of the present investigation ranged from 5.9 to 8.8 months. This was a relatively short-term treatment compared to the general duration of FOT. However, study of a long-term treatment would be difficult in light of the patient's oral hygiene, motivation, compliance with treatment, and many other factors that may cause staining. Here the authors wanted to investigate

**Table 4.** The total color differences ( $\Delta E$ ) between all measured teeth before and after orthodontic treatment and Tukey's HSD grouping, and also for the untreated control group.

Product (tooth no. <sup>a</sup> )	n	$\Delta E$ (Mean $\pm$ SD)	Tukey's HSD grouping <sup>b</sup>
Kurasper F (31)	22	2.11 $\pm$ 0.79	A
Transbond XT (32)	22	2.13 $\pm$ 0.97	A
Grengloo (42)	22	2.29 $\pm$ 1.44	A
Light Bond (41)	22	2.37 $\pm$ 1.22	A
Total $\Delta E$	88	2.23 $\pm$ 1.11	
Total $\Delta E$ of untreated control group	88	0.29 $\pm$ 0.17	

<sup>a</sup>: Tooth numbering according to the FDI system.

<sup>b</sup>: Means with the same letter are not significantly different at the  $\alpha = 0.05$  level.

effects of the composites on tooth color while minimizing other influencing factors. Color shifts of these teeth may be more pronounced owing to small anatomical size, as compared to studies of other teeth in short-term FOT (1). Furthermore, the properties of orthodontic composites are very similar to traditional dental composites, and in this way their color may easily change in a few months of use and exposure to different varieties of diets and lighting conditions. For these reasons, the authors assumed that the treatment duration was long enough for comparison of materials in vivo. In addition, no cases of bracket failure, plaque accumulation, or gingival inflammation were observed, and braces were also bonded at the beginning and debonded at the end of treatment. Therefore, the color of teeth may be affected only by resins or debonding procedures.

The perceptible threshold level of  $\Delta E^*$  values was set at 1 and the acceptable threshold level of  $\Delta E^*$  was set at 3.7 (4,5,8,9,16). Thus, color changes below or above the value of  $\Delta E^* = 3.7$  were determined as 'acceptable' or 'unacceptable', respectively. Furthermore, the acceptable threshold level of the  $\Delta L^*$  values among the enamel color variables was set at 2.0 because the human eye can detect changes in  $\Delta L^*$  (17). In the current study, 12.50% of the bonded teeth showed visible and clinically important color alterations using  $\Delta E^*$ . Moreover, individual or total brightness ( $\Delta L^*$ ) values of treated teeth were acceptable (Table 3). If discolored teeth were distributed among the subjects, approximately 45.34% of the patients had at least 1 tooth with unacceptable discoloration. Therefore, the enamel will show discoloration with FOT.

Limited data are available from only a few in vitro studies on the related effects of bonding and debonding procedures on enamel color (5,9,10,18). Two of these in vitro investigations reported that if the bonding and debonding procedures were evaluated alone, these applications did not appear to have a significant effect on the tooth of bovine and human enamel (9,10). Comparison research on bonding materials concluded that the color shift of enamel varied from invisible ( $\Delta E^* = 0.85$ ) to visible ( $\Delta E^* = 1.51$ ), but, in the end, discoloration of teeth was on an acceptable spectrum (10). Two other studies indicated that debonding and cleaning procedures significantly affected all color variables of teeth beyond the clinically acceptable borderline ( $\Delta E^* > 3.7$ ), with values ranging from  $5.27 \pm 2.21$  to  $13.7 \pm 4.7 \Delta E^*$  units, respectively (5,18).

A clinical study indicated that the color of mandibular incisors after treatment showed significant changes, ranging from 2.38 to 3.61  $\Delta E^*$  units, and teeth treated with Transbond XT showed the lowest color changes ( $\Delta E^* = 2.58 \pm 0.74$ ) (4). The individual color variables ( $L^*a^*b^*$ ) of teeth were changed such that the  $\Delta L^*$  value decreased, whereas the  $\Delta a^*$  and  $\Delta b^*$  values increased. The results of

the current study similarly suggest that the color of natural teeth did seem to be influenced by FOT; the  $\Delta E^*$  values were  $2.11 \pm 0.79$ ,  $2.13 \pm 0.97$ ,  $2.29 \pm 1.44$ , and  $2.37 \pm 1.22$  with Kurasper F, Transbond XT, Grengloo, and Light Bond, respectively. Moreover, the mean  $L^*a^*b^*$  values indicated that minimal and acceptable discolorations of teeth had occurred. Some possible explanations exist for the lower  $\Delta E^*$  values in our study compared to the other in vivo study: the duration of FOT in our subjects was shorter than in the previous study, though this may not be statistically important, and the materials investigated were different between the 2 studies. In particular, the use of chemically cured resin showed greater color changes.

Secondary optical properties of the tooth (i.e. translucency, opacity, and surface gloss) may be affected by several factors including quality and quantity of light reflection at the surface, dispersion, diffraction and interference of light at the surface, roughness and anatomical morphology of surface, properties and structures of enamel and dentin (2,17–19), and variations of blood flow in the dental pulp (20,21). Light also affects the gum and lip color (22). The  $L^*$  value is directly associated with the opacity of enamel and is affected by the roughness of the surface (21,22). The  $L^*$  values in the present study were not increased in any of the teeth except those treated with Light Bond, and tooth color in all groups seemed to have a whiter or more opaque appearance. The preferred procedure for resin removal in the present study, using Sof-Lex disks, showed a decrease in surface irregularities (21). Thus, a flat, smooth tooth surface allows more specular reflection and more precise color measurement.

Surface gloss is an indicator of vitality and is affected by age (17,23,24). In the present study, the lower incisors had flat, smooth surfaces and were very young. Additionally, the duration of treatment was short, and thus the impact of age may not be a reason for the color shifts of teeth. The alterations in color of the investigated teeth could be explained by the resins used, because the optical properties were fairly similar to the baseline characteristics of the teeth. Furthermore, the color measurements must be taken from the middle part of tooth instead of the incisal part, which affected translucency, and the cervical part, which affected gingival light scattering (17,25,26). It was suggested that the magnitude of  $L^*$  was the brightest in the middle area of the labial surface (17,25). Furthermore, wetting the tooth provides more precise measurements of color because dryness may cause lighter and less saturated color for the tooth (27). For these reasons, the measurements were taken from the middle of the labial surface of the tooth and teeth were wetted in the current investigation. The color measurement technique of the present study was based on reflection of light from the surface, which is dependent on characteristics of the surface of the enamel (17,24).

Acid etching affects the enamel in some ways including an increase in surface porosity, enamel loss of about 10–20  $\mu\text{m}$  by dissolution of the apatite crystallites, small enamel cracks and fragments, and additional enamel loss at debonding (5,7). Thus, these problems may cause adverse effects in the optical properties of enamel. Furthermore, there might be fracture and cracking of the enamel with removal techniques, resulting in diffuse reflection of light and shifting of the color variables of the enamel. To minimize the enamel color shifts, it has been suggested that adhesive residue must first be cleaned by a carbide bur handpiece at a slow speed, then secondly by a new high-speed tungsten carbide finishing bur (28), and, finally, after elimination of the surface roughness, the enamel surface must be polished with a series of composite disks (21). In the present study, this debonding sequence of burs and Sof-Lex disks was used in order to reduce damage to enamel.

Resin tags used for bracket bonding could reach a depth of 50  $\mu\text{m}$  in the enamel structure, and debonding and cleaning protocols could not reverse adhesive resin impregnation into the enamel (6). Thus, the color of the enamel might be affected in 2 ways in these conditions: surface alterations or the inability of resin to protect its own color during its lifespan (7,8,11,12,14,17). The color changes of polymers may be due to external (e.g., superficial adsorption or absorption of color pigmentation from the diet) or internal (the chemical structure) influences (2,8,9,11,12,24). Thus, the color of the enamel may be affected by the instability of resin during its life span. Resin derivatives in the enamel may affect  $a^*$  and  $b^*$  values (5,17,19,23). In the current study,  $a^*$  values of composites were significantly increased and discoloration of adhesives was linked to changes in  $a^*$  values toward less greenness. Visible color changes (89.78%) were observed in this in vivo study with all composites and that may be explained by matrix compositions, oxidation of the

polymer matrixes, inorganic filler contents, water sorption characteristics, or insufficient polymerizations of the various composites. Because of resin tags, the longitudinal tooth color changes must be evaluated after patients have undergone FOT procedures in further studies.

In the present study, organic and inorganic content percentages of the resins were different (Table 1), and the curing time of Light Bond and Kurasper F was 40 s while that of the others was 20 s, but this may not be a crucial factor in color alteration because we used a powerful LED unit. Although total color changes were not significantly different between resins, Light Bond showed the highest degree of color change, similar to the findings of a previous in vitro evaluation (8). Not only curing time and amount of filler content but also the type of filler and monomer, the connection capacity of monomer to filler, and the oxidation of the polymer matrix must be taken into account with regard to discoloration of composites. In addition, resins of the present study were flowable and were not highly filled polymers, and so they may have easily absorbed staining substances from the oral environment (7,11,17). Further studies are required to evaluate the longitudinal tooth color changes for different types of resin as well as illumination times or sources after the patient has undergone FOT procedures.

In conclusion, teeth will show discoloration with fixed appliances during the treatment period. Moreover, the contemporary orthodontic composites have similar effects of enamel discoloration. The color shifts and optical properties of enamel are complex phenomena that are affected by not only color pigmentation of dietary factors and instability of resin, but also by the types of filler and monomer and by the connection capacity of the monomer before and after FOT. Further clinical studies are required to determine longitudinal tooth color changes as evaluated with different types of resin as well as illumination times or sources in patients that have undergone FOT procedures.

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