A study on the characteristics of resin composites for provisional restorations

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In this study, we evaluated the characteristics of five commercial resin composites used for provisional restorations. The inorganic filler contents of the resins were measured, and three-point bending, wear, surface hardness, water absorption, and staining tests were performed. The specimens underwent additional three-point bending tests after water storage and undergoing thermal stresses at 5°C and 55°C (10,000 cycles). Data were analyzed using one- or two-way analysis of variance and Bonferroni *post-hoc* tests. Pearson's correlation coefficient was used for pairwise comparisons. Each resin composite presented with different mechanical properties, based on variations in the inorganic filler content. The flexural strength of each resin composite was significantly decreased after water storage. There has a positive correlation between flexural strength and dynamic hardness but a negative correlation between flexural strength and maximum wear depth. The types and contents of the inorganic fillers, the composition of the monomer in the resin matrix, and the addition of plasticizers can affect the properties of the material.

Keywords: Provisional restoration, Resin composite, Mechanical property, Water absorption, Staining

INTRODUCTION

Provisional restorations, including crowns and fixed partial dentures made from acrylic resin, protect and recover the abutment tooth esthetics for a certain amount of time before the final coronal restorations are delivered¹⁾. Furthermore, a good provisional restoration contributes to the design of the final coronal restoration via their harmonization with the periodontal tissues²⁾. Conventionally, methyl methacrylate-based cold cure resins have been frequently utilized for provisional restorations due to the low cost and ease of use in daily clinical practice. However, cold cure resins are associated with certain disadvantages, such as an irritating odor, polymerization shrinkage, and low wear resistance³⁾. For long-term provisional restorations, physical properties that contribute to maintaining the mechanical strength and resisting stain formation after water absorption are required⁴⁾. Further, considering the increase in the application of glass-ceramics and zirconia to coronal restorations, the materials used for provisional restorations are expected to have the same level of function and esthetics. Currently, the application of bis-acryl resin as an alternative to cold cure resin is on the rise. Bis-acrylic resins with inorganic fillers show superior physical properties compared to cold cure resins⁵⁻⁷⁾. In addition, the injection type of resin composite for provisional restorations is less technique sensitive⁸⁾ relative to the conventional hand-mixed resin. The catalyst and base are uniformly auto-mixed; hence, it presents with stable mechanical properties. Consequently, bis-acrylic resin is more suitable for medium to long-term provisional restorations compared to cold cure resin. Nevertheless, few studies have

reported the durability of resin composites for provisional restorations.

In the present study, we measured the inorganic filler content and performed three-point bend, two-body wear, dynamic hardness, water absorption, and staining tests of five commercially available resin composite products for provisional restorations. In addition, the characteristics, durability and color stability of each product were compared and evaluated. The null hypotheses to be tested were that inorganic filler content does not affect the characteristics of five commercially available resin composite products for provisional restorations.

MATERIALS AND METHODS

Materials

The five resin composites for provisional restorations (Luxacrown [LC], Luxatemp automix plus [LT], Luxatemp Star [LS], Tempsmart [TS], and Protemp 4 [P4]) used in the present study and their composition are described in Table 1.

Methods

1. Measurement of inorganic filler content

Each resin composite was placed in a metal mold that was 25 mm in length, 2 mm in width, and 2 mm in thickness ($n=4$ for each group). Cover glasses were placed on the top and bottom of the specimen and a load of 1 kg weight was applied on both sides for one minute. The specimen was removed from the mold after polymerization, according to the manufacturers' instructions in the laboratory at room temperature of 23°C. After that, each specimen was cut (length, 3 mm) using an automatic

Table 1 Resin composite for provisional restorations used in this study

Materials	Lot No.	Color	Manufacturer	Code	Contents	Filler contents (wt%)*
Luxacrown	785251	A2	DMG	LC	Bis-GMA, DDDMA, HDDMA, UDMA, TEGDMA, 2-HEMA, ethoxylated bisphenol-A-dimethacrylate, silanised glass-powder, stabilisor, food-pigments	46
Luxatemp automix plus	783358	A2	DMG	LT	TEDMA, HEMA, UDMA, ethoxylated bisphenol-A-dimethacrylate, polymethyl-methacrylate, silanised glass powder, paraffine, food-pigments	44
Luxatemp Star	798343	A2	DMG	LS	TEDMA, HEMA, ethoxylated bisphenol-A-dimethacrylate, urethan-acrylate oligomers and polymers, silanized glass powder, food-pigments	42
Tempsmart	1809031	A3	GC	TS	Bis-GMA, UDMA, dimethacrylate, silica filler, photo initiator, pigment	N/A
Protemp 4	4258600	A2	3M ESPE	P4	dimethacrylate, methacrylate, inorganic filler, catalyst, polymerization initiator	N/A

*Manufacturer's published value

cutting machine (Isomet, Buehler, Lake Bluff, IL, USA) and polished with #1000-grit silicone carbide paper, followed by cleaning in an ultrasonic bath filled with distilled water for 30 min. The specimens were dried with a three-way syringe and left at 23°C for 24 h. After heating at 800°C for 3 h (rate of increase in temperature, 10°C/min), the specimens were cooled down to room temperature, and the residual weight was measured using a thermogravimetric analyzer (TG/DTA6300, Seiko Instruments, Chiba, Japan). The residual weight was divided by the weight before thermal loading and multiplied by 100 to obtain the inorganic filler content (wt%).

2. Three-point bending test

Three-point bending tests were conducted according to ISO 4049. Each resin composite was placed in a metal mold (25 mm in length, 2 mm in width, and 2 mm in thickness) and polymerized as described earlier ($n=10$). After polishing with #1000-grit silicone carbide paper, the specimens were cleaned in an ultrasonic bath for 30 min. The specimens were dried and left at room temperature for 24 h. The groups stored at room temperature were determined the control group. The three-point bending test was conducted using a universal testing machine (EZ test, Shimadzu, Kyoto, Japan) at a crosshead speed of 1 mm/min with a span length of 20 mm. We determined the flexural strength and the elastic modulus from the stress-strain curve using computer software (TRAPEZIUM2, Shimadzu) linked to the testing instrument. The specimens as a water storage group were stored in distilled water at 37°C for 7 days

in the incubator. We prescribed the thermal cycle group that 10,000 thermal cycles between 5 and 55°C with a dwell time of 40 s.

3. Two-body wear test

Two-body wear tests were conducted according to former studies^{9,10}. Each resin composite was placed in a disk mold (15 mm in diameter and 2 mm in thickness; $n=10$). After compression with a load of 1 kg weight for one minute, each specimen was polymerized as same as “measurement of inorganic filler content”. Then, both surfaces were polished up to #2000 grit silicone carbide paper, and the specimens were cleaned in an ultrasonic bath for 15 min. Subsequently, the specimens were attached to a sliding impact wear testing machine (K655, Tokyo Giken, Tokyo, Japan), and wear testing was conducted for 10,000 cycles in the water at 37°C with a load of 5 kg and 3 mm of the sliding distance; a stainless hemispherical rod was used as an antagonist. This antagonist for a sliding impact wear testing machine was a stainless-steel ball bearing (radius=2.0 mm) set inside a collet assembly. The maximum wear depth was measured using a laser scanning microscope (VR-5000, Keyence, Osaka, Japan).

4. Dynamic hardness test

Dynamic hardness tests were conducted according to former studies¹¹. Resin composite specimens ($n=5$) were fabricated following the method and dimensions used for the wear test in the present study. Both sides of each specimen were polished up to #600-grit silicone carbide paper. A dynamic ultra microhardness tester (DUH211,

Shimadzu) fitted with a Berkovich indenter tip was used to measure the dynamic surface hardness of each resin composite with a peak load of 196.1 mN at 13.32 mN/s of the load rate for 15 s of the hold time.

5. Water absorption test

The resin composite specimens for water absorption testing were fabricated in the same manner and dimension as for the wear test ($n=5$). The specimens were polished up to #600-grit silicone carbide paper and cleaned in an ultrasonic bath for 15 min. Each specimen was stored in a desiccator at 37°C for 22 h and then moved to another desiccator, where it was stored for 2 h at 23°C. A weight loss of less than 0.1 mg was confirmed after 24 h. Then, the specimen was stored in water at 37°C for 28 days. The surface water was removed with a white filter paper after rinsing with water until no residual water was visible. The specimen was thoroughly waved in air for 15 s, and the weight was measured 1 min after removal from water. The constant weight after water storage was not measured; however, the difference in weight before and after water storage was used to calculate the water absorption per volume. We used a Precision Scale (AUW120D, Shimadzu) to measure the water absorption per volume.

6. Staining test

Each resin composite specimen was fabricated following the method and dimensions described for the wear test ($n=5$). The specimens were polished up to #4000-grit silicone carbide paper and a buff polishing followed by a 15-min ultrasonic bath cleaning. Each specimen was soaked in 15 mL of premade coffee (NESCAFÉ Gold Blend, Nestlé Japan, Kobe, Japan) and shaken 60 times/min at 37°C for 28 days. The solution was replaced every day. Color measurements were obtained in a measurement area of 1.8 mm using a chromameter (CR241, Konica Minolta, Tokyo, Japan) 0, 1, 2, 3, 7, 14, and 28 days after water storage. Each specimen was dried with air prior to the color measurement, and three different areas were measured to obtain the mean value of $L^*a^*b^*$ based on the CIE $L^*a^*b^*$ color system. The color differences expressed as ΔL^* , Δa^* , and Δb^* before and after staining were calculated. Setting Day 0 as the standard, we calculated the color difference using the following equation: $\Delta E^*_{ab}=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$.

7. Scanning electron microscope (SEM) surface observation

Each resin composite specimen was fabricated in the same manner and dimensions as for the wear test. The specimens were polished up to #2000-grit silicone carbide paper, and a mirror finish was accomplished using 9 μ m and 3 μ m lapping film sheets (3M, Tokyo, Japan). Argon ion beam etching (EIS-200ER, Elionix, Tokyo, Japan) was performed on the specimens at an accelerating voltage of 1 kV and a current density of 1.2 mA/cm² for 40 s. After gold-sputter coating using an ion coater (Quick Coater Type SC-701, Sanyu Electron, Tokyo, Japan), the surfaces of the specimens were observed using a SEM

(JCM-6000 Plus NeoScope, JEOL, Tokyo, Japan) at an accelerating voltage of 10 kV.

8. Statistical analysis

The mean values and standard deviations were obtained from the data. One-way analysis of variance (ANOVA) was conducted on the data obtained from the inorganic filler content, wear, and dynamic surface hardness tests. Two-way ANOVA and Bonferroni's multiple comparison tests were used to analyze the data from the three-point bend, water absorption, and staining tests. Pearson's correlation coefficient was used to analyze the correlations between the filler content, flexural strength, and elastic modulus of the specimens stored at room temperature and their maximum wear depth as well as dynamic surface hardness. SPSS version 23.0 (IBM SPSS Statistics for Windows, IBM, Armonk, NY, USA) was used for the analyses.

RESULTS

Measurement of inorganic filler content

The inorganic filler content (wt%) of each resin composite for provisional restorations is presented in Fig. 1. Significant differences in inorganic filler content were observed among the resin composites ($p<0.05$). LC presented with the highest filler contents, whereas TS had the lowest filler contents (24%).

Three-point bending test

The flexural strengths and elastic moduli of each resin composite are presented in Table 2, Figs. 2 and

Fig. 1 Inorganic filler content of each resin composite for provisional restorations.

A significant difference in inorganic filler content was observed among all groups ($n=4$; $p<0.05$). LC and TS exhibited the highest and lowest inorganic filler contents, respectively.

Table 2 Result of each composite resin for provisional restorations by three-point bending test

	Flexural strength (MPa)			Elastic modulus (GPa)		
	Control	Water immersion for 7 days	Thermal cycle	Control	Water immersion for 7 days	Thermal cycle
LC	110.4 (5.9)	91.3 (7.6)	110.9 (6.7)	4.2 (0.3)	3.2 (0.3)	4.7 (0.2)
LT	110.6 (6.0)	102.8 (7.3)	110.3 (14.1)	4.0 (0.3)	3.5 (0.3)	4.7 (0.1)
LS	113.4 (10.9)	101.8 (6.0)	115.5 (11.5)	4.2 (0.4)	3.6 (0.4)	4.5 (0.2)
TS	98.4 (5.4)	80.2 (3.7)	87.9 (11.1)	3.5 (0.3)	2.7 (0.3)	3.6 (0.4)
P4	91.2 (5.4)	74.9 (8.4)	85.1 (7.3)	2.9 (0.2)	2.1 (0.3)	3.2 (0.3)

Mean (SD)

Fig. 2. Flexural strength of each resin composite for provisional restorations.

A significant difference was observed between each resin composite and the control ($n=10$; $*p<0.05$). LS exhibited the highest flexural strength. The flexural strength of all resin composite after water storage was significantly lower than that of the control ($p<0.05$).

3, respectively. LS presented with the highest flexural strength. All specimens showed significantly lower flexural strength values after water storage relative to the control group ($p<0.05$). On the other hand, no significant differences in flexural strength were observed in the specimens after thermal cycling when compared to those in the control group ($p>0.05$). In the control groups, LC and LS showed the highest values for the elastic modulus; after water storage, the values of all specimens were significantly lower than those in the control group ($p<0.05$). An increasing tendency in the elastic modulus after thermal cycling was observed

Fig. 3. Elastic modulus of each resin composite for provisional restorations.

A significant difference from control in each resin composites from control ($n=10$; $*p<0.05$). LC and LS exhibited the highest elastic modulus. The elastic modulus of all resin composite after water storage was significantly lower than that of the control ($p<0.05$).

relative to the control group.

Two-body wear test

The maximum wear depth of each resin composite is presented in Fig. 4; significant differences were observed among all resin composites ($p<0.05$). And the wear marks of each resin composite captured by the microscope is presented in Fig. 5. LS showed the lowest value, whereas the highest value was noted in the P4 specimens.

Fig. 4 Maximum wear depth of each resin composite for provisional restorations. Significant differences were observed among the five groups ($n=10$; $p<0.05$). LS exhibited the lowest maximum wear depth, and P4 exhibited the highest maximum wear depth.

Fig. 6 Dynamic hardness of each resin composite for provisional restorations. Different superscript letters represent significant results ($n=5$; $p<0.05$). LS exhibited the highest dynamic hardness in the control for each resin composite. P4 showed a significantly lower dynamic hardness than LC, LT and LS ($p<0.05$).

Fig. 5 Images of water marks of each resin composite for provisional restorations by two-body wear test. The gradient from red to blue indicates the wear depth, with LS having the lowest maximum wear depth and P4 having the highest maximum wear depth.

Fig. 7 Amount of water sorption of resin composite for provisional restorations. A significant difference was observed from Day 1 in each resin composite for provisional restorations ($n=5$; $p<0.05$). LS exhibited the lowest water absorption, and TS exhibited the highest water absorption.

Dynamic hardness test

The dynamic hardness test results of each resin composite for provisional restorations are presented in Fig. 6. The dynamic hardness of LS, LC, LT, and TS have no significant difference ($p>0.05$). On the other hand, the dynamic hardness of P4 was significantly lower than those of LC, LT, and LS ($p<0.05$).

Water absorption

After 28 days, a significant difference in water absorption was noted among all the resin composites ($p<0.05$; Fig.

7). LS presented with the lowest values, whereas TS showed the highest water absorption among the five specimens.

Staining test

The color differences among the resin composites are presented in Table 3 and Fig. 8. Significant increases in color differences in LT and LS were observed after Day 2 compared to those on Day 1 ($p<0.05$). Only TS showed a significant decrease in the color difference after 28 days ($p<0.05$).

Table 3 Result of each composite resin for provisional restorations by staining test

	ΔE^*_{ab}					
	1 day	2 days	3 days	7 days	14 days	28 days
LC	1.3 (0.2)	1.7 (0.2)	2.0 (0.3)	2.7 (0.3)	2.9 (0.4)	3.3 (0.3)
LT	2.8 (0.3)	3.5 (0.4)	4.0 (0.3)	5.2 (0.5)	5.7 (0.2)	6.0 (0.4)
LS	2.0 (0.3)	2.5 (0.3)	2.5 (0.3)	3.7 (0.2)	3.7 (0.4)	4.0 (0.3)
TS	1.9 (0.3)	1.6 (0.3)	1.6 (0.4)	1.7 (0.2)	1.8 (0.3)	1.4 (0.3)
P4	1.8 (0.2)	1.7 (0.1)	1.8 (0.2)	2.5 (0.3)	3.0 (0.4)	3.4 (0.4)

Mean (SD)

Fig. 8 The color difference (ΔE^*_{ab}) of resin composite for provisional restorations.

A significant difference from Day 1 in each resin composite for provisional restorations ($n=5$; $p<0.05$). LT exhibited the highest ΔE^*_{ab} values after 28 days, and TS the lower ΔE^*_{ab} values after 28 days.

Fig. 9 SEM images of each resin composite for provisional restorations.

Irregularly-shaped filler particles (20 nm–1.5 μ m) were observed in LC, LT, and LS. Likewise, particles up to 2.5 μ m in size were observed in LS. Nano-sized spherical fillers were uniformly observed in TS and P4.

Table 4 Interrelationship by Pearson's correlation coefficient

	Inorganic filler content	Flexural strength (control group)
Flexural strength	$r=0.87$ ($p=0.06$)	—
Elastic modulus	$r=0.83$ ($p=0.08$)	$r=0.98$ ($p<0.01$)
Wear loss values	$r=-0.87$ ($p=0.05$)	$r=-0.98$ ($p<0.01$)
Dynamic surface hardness	$r=0.56$ ($p=0.33$)	$r=0.89$ ($p=0.04$)
Amount of water sorption	$r=-0.70$ ($p=0.20$)	$r=-0.38$ ($p=0.53$)

*Bold indicates $p<0.05$.

SEM surface observations

Images of the resin composite surfaces observed using a SEM are presented in Fig. 9. Irregularly shaped filler particles (diameter, 20 nm–1.5 μ m) were observed in LC, LT, and LS. Furthermore, irregularly shaped fillers up to 2.5 μ m in diameter were observed in LS. TS and P4 consisted of uniformly distributed nano-sized spherical fillers.

Correlations

The correlation analyses comparing the filler content and flexural strengths with the elastic modulus of the control groups, maximum wear depth, and dynamic hardness are presented in Table 4. No significant correlation was observed between the inorganic filler content and the other material properties ($p>0.05$). The flexural strength was positively correlated with the elastic modulus and dynamic hardness ($p<0.05$), and negatively correlated with the maximum wear depth.

DISCUSSION

In general, provisional restorations for fixed prosthetics using temporary restorative materials are expected to function for a few days to several weeks. In complicated situations like full mouth reconstruction, it can vary from 6 to 12 weeks^{12,13}; both dentists and patients require provisional restorations that can be utilized for a short duration. However, the duration of provisional restorations varies depending upon the surrounding periodontal tissues and other factors. Furthermore, the long-term use of provisional restorations is a matter of concern for vital teeth due to the adverse effects, such as the onset of hypersensitivity, on the pulp tissue. Therefore, provisional restorative materials with properties that stably protect the abutment teeth are required.

Several previous studies have reported that the increase in filler contents improves the mechanical strength and wear resistance and reduces the polymerization shrinkage of resin composites^{14,15}. Therefore, recent resin composites contain inorganic fillers of various types, sizes, shapes, contents, and surface modifications. The containing of inorganic fillers of the commercially available resin composites for provisional restorations is lower than that in the

restorative resin composites. Still, the characteristics are identical to those in the restorative resin composites. Hence, correlations between the inorganic filler content and flexural strength, maximum wear depth, dynamic hardness, and water absorption were evaluated in the present study. However, no correlations were observed between the inorganic filler content and most of the tested properties. Thus, the null hypothesis was accepted in this study. The inorganic filler content was obtained by measuring the weight of the residue after heating each resin composite to eliminate the organic filler; this process of excluding the organic composite fillers is considered to affect the results. The inorganic filler contents of LC, LT, and LS were generally consistent with the manufacturer's published values. Likewise, the inorganic filler contents of TS and P4 were similar to the results in previous studies^{7,16}. Furthermore, the amount of inorganic fillers content in the resin composites for provisional restorations in the current study was less than 50%, suggesting that they might have a limited effect on the mechanical properties. The inorganic fillers included in each resin composite for provisional restorations were divided into two groups (glass and spherical) based on the SEM surface findings. The glass fillers in LC, LT, and LS were larger in diameter and irregularly shaped relative to the spherical fillers in TS and P4, thus contributing to the increase in the filler contents.

The results of the two-way ANOVA on the flexural bending test are presented below. The main effects of the types of resin composites ($F=34.185$; $p<0.001$) and storage conditions ($F=34.220$; $p<0.001$) were statistically significant, as well as the interaction effects ($F=2.524$, $p=0.008$) in flexural strength. In elastic modulus, the main effects of types of resin composites ($F=757.394$, $p<0.001$) and storage conditions ($F=40.24$, $p<0.001$) are statistically significant, as well as the interaction effects ($F=28.297$, $p<0.001$). The flexural strength and elastic modulus of the specimens in the water storage group showed a significant decrease relative to those in the control group. Water absorption has been shown to cause the hydrolysis of the silane-treated layer in inorganic fillers, resulting in the detachment of the fillers¹⁷. Additionally, it has been reported that the quantity of monomers such as bisphenol A-glycidyl methacrylate (Bis-GMA) and triethyleneglycol dimethacrylate

(TEGDMA) affects the mechanical properties, including the flexural strength and elastic modulus¹⁸. Variations in the type and amount of monomers and the filler content in each resin composite are considered to be related to the flexural strength. However, no significant decrease in flexural strength and elastic modulus values was observed after thermal cycling. The effects of thermal stress and water absorption by thermal cycling on the flexural strength and elastic modulus have been reported previously^{10,17,19,20}. A majority of the resin composites for provisional restorations used in the present study were of the self-cure type. Mei *et al.*²¹ reported that the flexural strength of bis-acryl resins increases at a polymerization temperature of 60°C. Thus, the difference in polymerization in the current study may be attributed to the promotion of heat polymerization in a hot water bath.

Mair *et al.*²² classified wear into four types: adhesive, abrasive, fatigue, and corrosive wear. Wear behavior should be evaluated, considering multiple factors such as the media and tooth wear, in the oral cavity²³. In the present study, a two-body wear test that simply observes the fatigue wear, excluding the effects of the media, was used. LC, LT, and LS showed significantly lower maximum wear depth relative to the other resin composites. No correlation between maximum wear depth and inorganic filler content was noted. Since the inorganic filler content of LC, LT, and LS was higher than 40%, their wear resistance was higher than those of the other resin composites. As reported previously, the maximum wear depth showed a strong negative correlation with flexural strength and elastic modulus¹⁹.

The dynamic hardness tests were conducted using a dynamic ultra microhardness tester in the present study. This testing method repeatedly measures the process of hitting an indenter on the specimen surface with impact²⁴. The effectiveness of this method in evaluating resin composite surface hardness has been reported previously¹¹. It is well known that the surface hardness of a resin composite is associated with the inorganic filler content and the wear depth; nonetheless, no significant correlations were observed in the present study. Hu *et al.*²⁵ reported that the coefficient of friction, the bond strength between the filler and resin matrix, and the resin matrix surface's integrity are essential in determining the wear resistance of resin composite in two-body wear tests. Therefore, differences in the types, shapes, content, and size of the fillers in the composite resins used in this study may have affected the correlation between wear depth and surface hardness. Also, as suggested by Hirayama *et al.*¹¹, the composition and viscosity of the resin matrix were found to affect the surface hardness in the present study.

Resin composite materials show water-absorbing properties, which are known to affect the mechanical properties and cause color changes. Clinically, water absorption affects the bonding surface, resulting in dislodgement. In general, the amount of water sorption is dependent on the contents of the resin matrix. Thus,

an increase in filler contents will lead to a decrease in the amount of the resin matrix, resulting in a decrease in water absorption. The main effects of resin composite types ($F=2807.831$, $p<0.001$), and storage conditions ($F=3451.643$, $p<0.001$) showed a statistical significance. Likewise, the interaction effects ($F=182.996$, $p<0.001$) showed a statistical significance. Hydrophilic monomers, Bis-GMA, and TEGDMA are known to have high water absorbability. Both Bis-GMA and urethane dimethacrylate (UDMA) have high viscosity; hence, TEGDMA needs to be frequently added as a diluent material. TEGDMA consists of ethylene glycol as the main chain and is, therefore, highly flexible and water absorbable²⁶⁻²⁸. On the other hand, although UDMA is a hydrophobic monomer, it has a hydrophilic isocyanate group. Some studies have reported that UDMA affects water absorbability²⁹⁻³¹. The resin composites for provisional restorations in the present study contained various types of monomers. Thus, water absorption could be affected not only by the inorganic filler contents but also by other factors, such as the various types of monomers in the resin composite.

Several studies reported staining problems after long-term use of conventional resin composite materials³²⁻³⁴. In addition to the mechanical properties, the esthetics of the provisional restorations during middle- to long-term use is essential. In the present study, the staining of the resin composites was compared and evaluated using the color difference measurement. There are several reports on the staining of resin composites^{35,36}. In the present study, we selected coffee that is universally consumed by people across a wide age range. Moreover, the stainability of coffee is the second-highest after red wine³⁷. Guler *et al.*³⁸ reported that sugar in coffee or tea accelerated the color changes. Therefore, we used premade coffee with a relatively constant concentration to exclude the effects of other ingredients. In the present study, the soaking duration in coffee to evaluate the staining of medium to long-term provisional restorations was 28 days. Previous *in vitro* studies have shown that 28 days of soaking is equivalent to about 2.5 years in the oral cavity³⁹⁻⁴¹. However, it is challenging to simulate the oral environment *in vitro*. Thus, it is suggested that the color difference in the oral cavity could be greater than the values obtained in the experiment. International Commission on Illumination (CIE) defined the standard definition of color difference to ΔE^*_{ab} . ΔE^*_{ab} 0.6 determined 1st-grade limits practical tolerances when various error factors are considered. ΔE^*_{ab} 1.2 defined 2nd grade that most people can easily recognize the color difference when judged by comparing them. ΔE^*_{ab} 2.5 determined 3rd grade almost identical when evaluated at a distance. ΔE^*_{ab} 5.0 defined 4th grade that Almost identical when compared over time. Vichi *et al.*⁴² divided the values of ΔE^*_{ab} into three categories, wherein " $\Delta E^*_{ab}<1.0$ ", " $1.0<\Delta E^*_{ab}<3.3$ ", and " $\Delta E^*_{ab}>3.3$ " denoted "not appreciable by the human eye", "appreciable by skilled operators", and "clinically not acceptable", respectively. Douglas *et al.*⁴³ reported that a ΔE^*_{ab} of 2.6 was denoted as "not acceptable by

50% of dentists". In one study, a ΔE^*_{ab} of "<1.0" was considered as "not appreciable by the human eye"⁴⁴⁾, whereas in two other studies, a " ΔE^*_{ab} of 3.3" was set as the "clinically acceptable limit"^{45,46)}. There seems to be no certain standard for color difference and tolerance. The main effects of resin composite types ($F=91.879$, $p<0.001$), and storage conditions ($F=153.668$, $p<0.001$) showed a statistical significance, and the interaction effects ($F=157.584$, $p<0.001$) also showed a statistical significance. Furthermore, the color difference was significantly increased in all the resin composites over time, except for TS. TS did not show a significant increase in the color difference regardless of the soaking time probably due to the lack of a plasticizer. A plasticizer is often included in bis-acryl resins to add flexibility and plasticity. However, since it is not chemically bonded to monomers^{47,48)}, it may affect the deterioration of the resin composite during polymerization or storage in a solution.

In medium to long-term provisional restorations, the characteristics required by clinicians vary depending upon the treatment location and the oral environment. Esthetic anterior provisional restorations should present with high stain resistance. On the other hand, posterior restorations need mechanical strength and provide medium- to long-term services.

CONCLUSIONS

In the present study, we evaluated the characteristics of commercially available resin composites for provisional restorations. After comparing and evaluating the characteristics and durability of commercially available resin composites for provisional restorations, the following conclusions were reached:

1. The flexural strength significantly decreased after water storage.
2. There was no correlation between inorganic filler content and the results of each test.
3. Wear depth showed a negative correlation with flexural strength.
4. The inorganic filler content is not the only factor that affects the amount of water absorption.
5. A significant increase in color difference was observed with the increase in the soaking time in coffee in all groups, except for TS.

These findings indicate that the types and contents of inorganic fillers, the composition of the monomer in the resin matrix, and the addition of plasticizers could affect the properties of the material. The characteristics of provisional restorations can change depending on the composition of each ingredient. Thus, understanding the characteristics of each product is of importance in clinical practice.

CONFLICTS OF INTEREST

The authors have no conflict of interest to declare.

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