Original

Surface properties of an indirect composite polymerized with five laboratory light polymerization systems

Mahoko Murakami

Division of Applied Oral Sciences, Nihon University Graduate School of Dentistry, Tokyo, Japan

Abstract: A study was conducted to evaluate the influence of laboratory light polymerization systems on the post-curing properties of a composite. An indirect composite (Sinfony) was polymerized with five polymerization systems (Visio system, Hyper LII, Pearlcure Light, Twinkle MIII, and UniXS II) using nine polymerization modes. After light exposure, Knoop hardness number, wear depth, and changes in gloss were determined. The highest hardness number was recorded with the use of the Hyper LII (120 s) and Pearlcure Light (120 s) units, whereas the lowest value was obtained with the Visio system and UniXS II (60 s). Six groups demonstrated comparable as well as higher wear resistance to toothbrush abrasion (Hyper LII 60 and 120 s, UniXS II 120 s, Pearlcure Light 60 and 120 s, and Twinkle MIII 120 s), and two groups exhibited lower wear resistance (Visio system and UniXS II 60 s). Gloss of the composite was not dependent on the polymerization mode used before wear testing. However, surface gloss was significantly reduced by toothbrush dentifrice abrasion. Within the limitations of the present experiment, it can be concluded that the Sinfony composite can be polymerized sufficiently with high-intensity light polymerization units. (J Oral Sci 51, 215-221, 2009)

Correspondence to Dr. Mahoko Murakami, c/o Dr. Hideo Matsumura, Department of Fixed Prosthodontics, Nihon University School of Dentistry, 1-8-13 Kanda-Surugadai, Chiyoda-ku, Tokyo 101-8310, Japan
Tel: +81-3-3219-8145
Fax: +81-3-3219-8351
E-mail: matsumura@dent.nihon-u.ac.jp

Introduction

Indirect composites are used as veneering agents for cast restorations, super-structures of implant-supported prostheses, and denture teeth (1,2). Although the properties of composites have improved substantially, several problems including discoloration, wear, and disappearance of gloss have been reported (3-9). Dentifrices that include hard abrasives tend to induce excessive surface change of composites (10-13), and the roughened surface of restorations promotes plaque accumulation and affects their esthetic appearance. Several heat-polymerized composites exhibited insufficient resistance to wear and roughening of the surface. Both the mechanical and esthetic properties of composites, however, have improved over the last two decades (14-16), and a number of studies have been conducted to improve the properties of indirect composites. Matsumura et al. (17) reported that application of a high-intensity light source considerably improved the properties of a microfilled composite material. Other studies have demonstrated that depth of cure, hardness, wear resistance, water sorption, and solubility are influenced by the type of laboratory polymerization units employed (18-23).

Although the association between the light intensity of polymerization units and post-cure properties of direct composites has been studied by many researchers (24-26), only limited information is available on the relationship between the energy delivered by laboratory polymerizing units and the properties of indirect composites. The purpose of this study was to evaluate the influence of light sources and their energy on Knoop hardness, abrasion resistance, and change in gloss of an indirect composite (Sinfony, 3M ESPE, Seefeld, Germany). The working hypothesis was that Knoop hardness, abrasion resistance, and change in gloss of the composite would be positively influenced by use of high-intensity light sources.

Materials and Methods

Composite material and polymerizing units

An indirect composite (Sinfony, Lot No. 245550, 253243) designed for inlays, onlays, and restoration veneers was selected. The Sinfony composite is composed of aliphatic and cycloaliphatic monomers and inorganic fillers: aluminum glass and SiO_2 with an average particle size of 0.6 μm (27). The E3 shade for the enamel portion was selected for the current experiments. Five laboratory light polymerization systems were assessed. The Visio system, designed for polymerizing the Sinfony composite, consisted of two polymerization units: Visio-Alfa and Visio-Beta Vario (3M ESPE). The light source of the former was a halogen lamp, whereas that of the latter was fluorescent tubes (27,28). The polymerization mode of the Visio-Beta Vario unit was 1-min irradiation under atmospheric pressure followed by 14-min irradiation under reduced pressure. The light sources of the other units were two metal halide lamps for the Hyper LII unit (Toho Dental Products, Saitama, Japan) (17,20), a mercury lamp for the Pearlcure Light unit (Tokuyama Dental Corp., Tokyo, Japan), two halogen lamps and a metal halide lamp for the Twinkle MIII unit (Toho Dental Products) (20,21), and two xenon stroboscopic tubes for the UniXS II unit (Heraeus Kulzer GmbH, Wehrheim, Germany) (19,20). Table 1 summarizes the details of the polymerization systems, their power, and energy densities (range: 400-500 nm) determined using a spectroradiometer (USR-40D, Ushio Inc., Tokyo, Japan) equipped with a ND10 filter.

Knoop hardness measurements

The composite was packed into a split polytetra-fluoroethylene mold with a cylindrical opening 10 mm in diameter and 2 mm in height, and covered with a glass plate (1.3 mm thickness, Micro Slide Glass, Matsunami Glass, Osaka, Japan). Polymerization was performed under the conditions shown in Table 1 using the five polymerization systems. After polymerization, the top surface of each specimen was wet-ground with a series of silicon carbide papers (#800-2,000, WetorDry Tri-M-ite, 3M Corp., St. Paul, MN, USA) and polished with felt (TexMet 1500, Buehler Ltd., Lake Bluff, IL, USA) and alumina (0.05 μm, Baikalox 0.05CR, Baikowski International Corp., Charlotte, NC, USA). The height of reduced surface was approximately 500 μm. All specimens were stored in distilled water at 37°C for 24 h. Knoop hardness number (KHN) was determined with a universal indenter (Micro Hardness Tester, Akashi Ltd., Yokohama, Japan) by application of a 0.49-N load for 30 s.

Toothbrush dentifrice abrasion

The composite material was packed into a stainless steel mold ($25.0 \times 18.0 \times 2.0$ mm) and covered with a glass plate. The specimens were polymerized using the nine modes shown in Table 1 for the five polymerization systems. After polishing in the same manner as described in the previous section, all specimens were stored in distilled water at 37°C for 14 days. Each specimen was fixed on a specimen holder attached to a toothbrush

Table 1 Light polymerizing units assessed

Polymerizing unit	Light source	Exposure time	Power density ($\mu W\ cm^{-2}$)	Energy density ($mJ\ cm^{-2}$)	Distance (light-specimen)
Visio-Alfa	Halogen lamp *	15 s	8,600	129	10 mm
9010546	100W×1, 400-550 nm				
Visio-Beta Vario	Fluorescent tubes *	15 min	300	270	40 mm
9110125	250W×2, 400-550 nm				
Hyper LII	Metal halide lamp **	60 s	5,400	324	80 mm
160908	150W×2, 250-600 nm	120 s		648	
Pearlcure Light	Mercury lamp	60 s	10,100	606	70 mm
L06G088	150W×1, 380-550 nm	120 s		1,212	
Twinkle MIII	Halogen lamp	60 s	4,800	288	80 mm
15030305	150W×2, 400-600 nm	120 s		576	
	Metal halide lamp **				
	150W×1, 250-600 nm				
UniXS II	Xenon stroboscopic tube **	60 s	1,000	60	45 mm
22764	100W×2, 350-520 nm	120 s		120	

* Gohring et al. (28), ** Tanoue et al. (20)

abrasion testing machine (K236, Tokyo-Giken Co., Ltd, Tokyo, Japan) (13,18). A dentifrice containing abrasives of conventional silica (16,29) (Crest Tartar Protection Regular Paste, RDA-Value 136, Procter & Gamble Co., Cincinnati, OH, USA) was used as an abrasive slurry with a paste-to-water ratio of 1:1. The vessel of the machine was loaded with 150 g of slurry. A toothbrush (Bee King, Bee Brand Medico Dental Co., Ltd., Osaka, Japan) with nylon filaments (Tynex, Dupont Japan, Tokyo, Japan) was fixed in the toothbrush holder of the machine, and moved back and forth on the specimen at 140 strokes per minute. A consistent load of 3.4 N was applied to the top of the toothbrush holder with a steel weight (13,18). The specimens were abraded with a total of 20,000 reciprocal strokes. The toothbrush and slurry were replaced for the testing of each specimen. Six specimens were tested for each polymerization mode. After the testing, specimens were removed from the machine, ultrasonically cleaned in distilled water for 10 min, and gently air-dried.

The vertical loss of each specimen in μm was determined with a confocal scanning laser microscope (1LM21W, Lasertec Corp., Yokohama, Japan) equipped with a He-Ne (Wavelength: 633 nm) laser light source. The resolution performance of the microscope was approximately 0.03 μm. The distance from the original specimen surface to the deepest abraded point was defined as the wear depth. Diagrams of the wear depth determination are shown in Fig. 1.

Gloss

The surface gloss of the specimens before and after abrasion testing was measured with a gloss meter (GM-26D, Murakami Color Research Laboratory Co., Ltd., Tokyo, Japan). Gloss was expressed in gloss units (GU). The gloss meter was calibrated before each recording session using a standard black board with a reference value of 92.1 at 60° incidence angle (5). The specimens were rinsed with distilled water and air-dried, then placed on the specimen stage at the top stage of the device. The specimen was covered with a black plate to prevent reflection from the backside of the specimen and external light. The average of three measurements was recorded per surface.

Scanning electron microscopic observation

The specimens polymerized with the Visio system and the specimens polymerized with the Hyper LII unit for 120 s were observed with a scanning electron microscope (ERA-8800FE, Elionix Inc., Tokyo, Japan). Typical specimens were mounted on stubs, adequately dried in a vacuum desiccator for 24 h, and vacuum-coated with osmium (HPC-1S, Vacuum Device Inc., Mito, Japan) for 30 s. The surfaces before and after abrasion testing were observed with the microscope operated at 15 kV.

Statistical analysis

Statistical analyses were performed with the SPSS software package version 15.0 (SPSS Inc, Chicago, IL, USA). For the three tests, mean values and standard deviations of six specimens were calculated for nine groups. Data distribution was evaluated by the Kolmogorov-Smirnov test. The results of KHN, wear depth, and gloss were primarily analyzed by the Levene test for evaluation of equality of variance. When the results of the Levene test showed homoscedasticity for all categories, one-way analysis of variance (ANOVA) and the Tukey HSD test were further performed with the value of statistical significance set at $P = 0.05$.
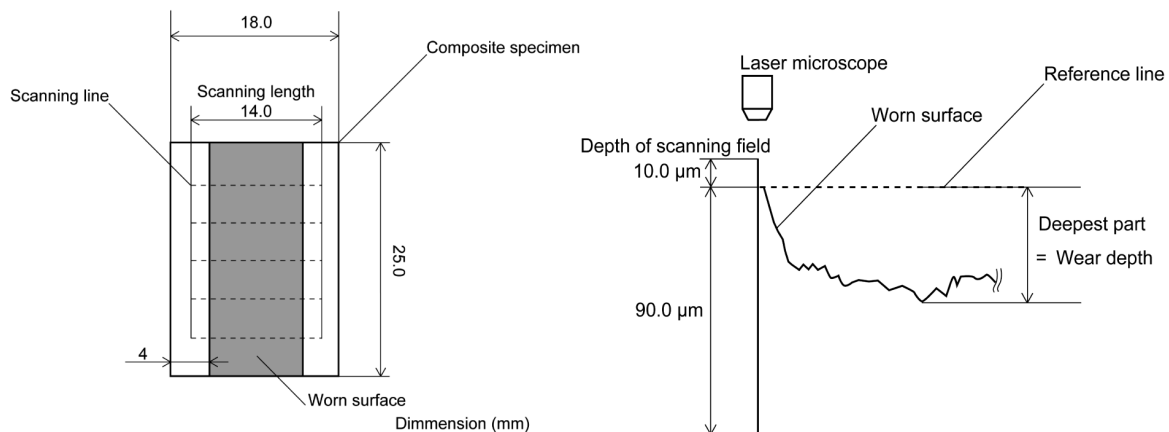

Fig. 1   Specimen design and location of the laser microscope scanning for evaluation of wear depth of the composite specimens.

Results

The Kolmogorov-Smirnov test run on the results of KHN, wear depth, and worn surface gloss revealed a normal distribution for each of the categories. Also, the Levene test run on the experimental results showed P-values greater than 0.05 for all tests, i.e., 0.367 for KHN, 0.641 for wear depth, and 0.713 for gloss. The results of the three tests were therefore analyzed by one-way ANOVA, and this revealed that the KHN ($P < 0.01$), wear depth ($P < 0.01$), and worn surface gloss ($P < 0.01$) were influenced by the polymerization mode. The results were finally analyzed with the post-hoc Tukey HSD test, and the mean values were categorized alphabetically.

The results of the hardness testing are presented in Table 2. KHN varied from 17.8 to 30.0, and was divided into five categories (a, b, c, d, and e) according to the post-hoc Tukey HSD test. Two groups polymerized either with the Hyper LII unit for 120 s (KHN 30.0) or with the Pearlcure Light unit for 120 s (KHN 28.6) showed the highest hardness values (category a). The hardness value of the specimens polymerized with the Visio system (KHN 19.5) was categorized into the lowest group (category e). For all polymerization units, the hardness value after 120 s light exposure was higher than that after 60 s exposure.

The results of toothbrush dentifrice abrasion testing (i.e., wear depth values) are shown in Table 3. Wear depth varied from a low of 26.2-32.7 μm (category f) to a high of 38.1-41.2 μm (category i). Tukey HSD test divided the results into four categories (f-i). Six groups (category f) demonstrated the lowest wear depth. For the Pearlcure Light and Hyper LII units, no significant differences in wear values were found between the 60 s and 120 s exposure periods. The wear depth value of the specimens polymerized with the Visio system (38.1 μm) was categorized into the most worn group (category i), although no significant difference was found among the three groups (category h) and between the two groups (category i).

Table 4 summarizes the gloss units determined before and after the toothbrush dentifrice abrasion test. The surface gloss of specimens before the abrasion test ranged from 82.2 to 85.9, and they were not significantly different from each other. The gloss of the worn surface varied from 28.0 to 46.3. Two categories (j and k) were generated after the wear testing. Two groups polymerized with the UniXS II unit for 60 s (GU 29.3, category k) and the Visio system (GU 28.0, category k) showed significantly lower gloss values than the other seven groups (GU 38.9-46.3, category j). Wilcoxon signed-rank tests run on the pre- and

Table 2 Knoop hardness test results

Polymerization mode	Median	Mean	SD	Category				
Hyper LII 120 s	30.0	30.0	1.6	a				
Pearlcure Light 120 s	28.2	28.6	1.3	a	b			
Twinkle MIII 120 s	26.7	26.7	1.0		b			
Hyper LII 60 s	24.8	24.6	1.2			c		
Pearlcure Light 60 s	24.3	24.0	1.1			c		
Twinkle MIII 60 s	23.9	23.7	0.7			c		
UniXS II 120 s	20.8	20.8	0.7				d	
Visio system	19.6	19.5	0.8				d	e
UniXS II 60 s	18.0	17.8	0.7					e

SD, standard deviation; Category, Values with identical letters are not statistically different at $P = 0.05$ (Tukey HSD test).

Table 3 Wear test results after toothbrush dentifrice abrasion (μm)

Polymerization mode	Median	Mean	SD	Category			
Hyper LII 120 s	25.9	26.2	2.5	f			
UniXS II 120 s	26.0	26.5	3.0	f			
Pearlcure Light 120 s	28.6	28.3	2.6	f	g		
Twinkle MIII 120 s	28.4	28.6	3.9	f	g		
Pearlcure Light 60 s	28.8	30.3	3.4	f	g		
Hyper LII 60 s	33.0	32.7	4.0	f	g	h	
Twinkle MIII 60 s	32.3	33.0	3.3		g	h	
Visio system	37.5	38.1	3.1			h	i
UniXS II 60 s	42.0	41.2	4.9				i

SD, standard deviation; Category, Values with identical letters are not statistically different at $P = 0.05$ (Tukey HSD test).

Table 4 Gloss results before and after toothbrush dentifrice abrasion

Polymerization mode	Before abrasion testing			After abrasion testing			Category	P-value
	Median	Mean	SD	Median	Mean	SD		
Twinkle MIII 120 s	84.6	83.1	3.3	46.7	46.3	3.9	j	0.028*
Hyper LII 120 s	82.8	82.9	0.6	44.4	43.9	2.5	j	0.028*
Pearlcure Light 120 s	84.4	84.5	2.0	44.4	43.5	4.1	j	0.028*
Twinkle MIII 60 s	86.0	85.9	1.2	41.9	42.3	3.2	j	0.028*
UniXS II 120 s	82.0	82.2	0.7	41.6	41.7	4.4	j	0.028*
Pearlcure Light 60 s	85.0	84.4	2.5	40.2	40.4	3.6	j	0.028*
Hyper LII 60 s	83.5	83.5	0.4	39.3	38.9	6.7	j	0.028*
UniXS II 60 s	83.6	83.6	0.6	31.5	29.3	5.5	k	0.028*
Visio system	86.6	85.3	3.3	28.7	28.0	4.9	k	0.028*

SD, standard deviation; Values with identical letters are not statistically different at $P = 0.05$ (Tukey HSD test). *Significant difference between the pre- and post-abrasion testing was found (Wilcoxon signed-ranks test; $P < 0.05$).
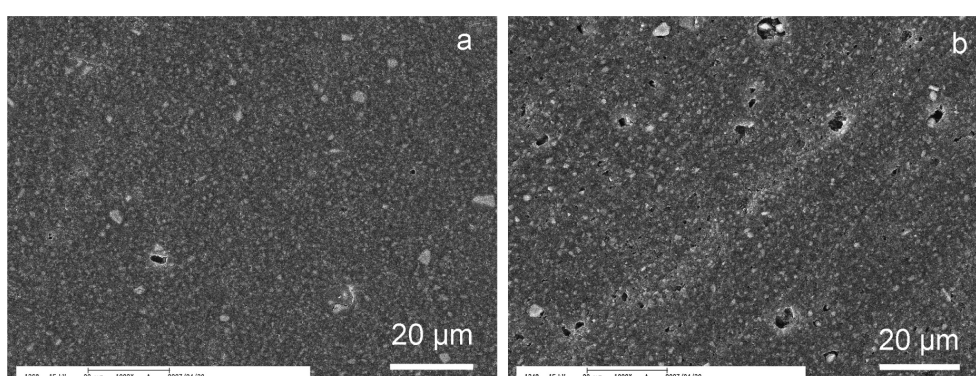

Fig. 2 Scanning electron micrographs (×1,000, bar = 20 μm) of the Sinfony surface polymerized with the Visio-Alfa and Beta Vario units. (a) before abrasion testing; (b) after abrasion testing.
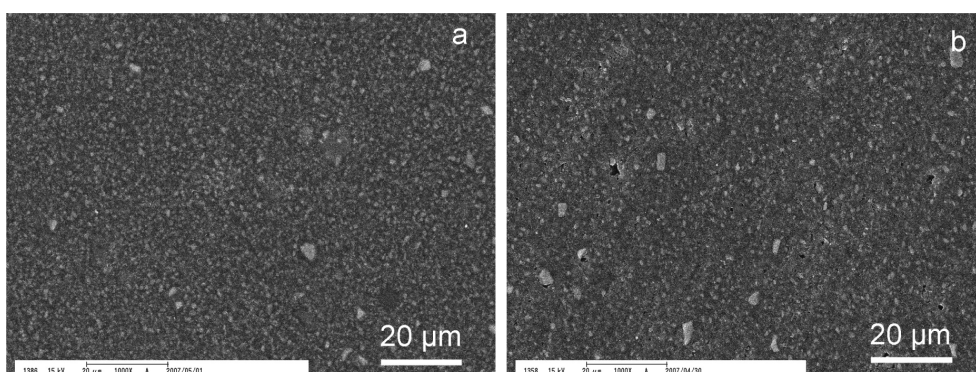

Fig. 3 Scanning electron micrographs (×1,000, bar = 20 μm) of the Sinfony surface polymerized with the Hyper LII unit for 120 s. (a) before abrasion testing; (b) after abrasion testing.

post-wear gloss values revealed that gloss was negatively affected by application of reciprocal brushing with dentifrice ($P = 0.028$) for all groups.

Figures 2 and 3 show electron micrographs before and after toothbrush abrasion testing. The abraded specimen polymerized with the Visio system exhibited multiple voids or detachment of macrofiller particles (Fig. 2b) as compared with the post-abrasion specimen polymerized with the Hyper LII unit (Fig. 3b).

Discussion

Knoop hardness testing is useful for evaluating the properties of composites in relation to wear resistance (12,15,16). The present results demonstrated that Knoop

hardness was influenced considerably by both the type of polymerization unit and light exposure period. As shown in Table 2, hardness values after 120 s of light exposure were significantly greater than those after 60 s of exposure for the four polymerization units. These results indicate that the hardness of the Sinfony composite can be increased by extension of the light exposure period (i.e., energy density) of the four units. Also, the rank order of the polymerization units provided from Knoop hardness testing was almost comparable with the rank order of the polymerization units provided from the power density of each unit. Although the power density of a unit is affected by the distance between the light source and the specimen, as well as the set-up position of the light source, the present results suggest a positive relationship between the power or energy density of the light source and the hardness number of the composite material (30). The present results agree with those of previous studies that have examined the relationship between the hardness of direct composites and the energy of hand-held curing units (24-26).

Wear resistance is an important characteristic of indirect composite materials. This study demonstrated improvement of the wear resistance of the Sinfony composite by application of four different light polymerization units. These units have a stronger irradiation power than the Visio system. The results suggest that the wear resistance of the Sinfony composite can be improved by application of a high-energy light polymerization unit with a shorter light exposure period. However, evaluation of wear resistance showed that six polymerization modes recorded comparable wear depth values. The author speculates that the indentation generated by a hardness tester represents a substantial mechanical property of the material surface rather than the depth of the surface abraded by a toothbrush and dentifrice. As shown in the post-abrasion micrographs, wear was related to surface roughness or loss of filler particles of the composite. The results in Tables 2 and 3 show the characteristics of the polymerization units: greatest hardness and wear resistance with the Hyper LII and Pearlcure Light units (120 s) and low hardness and wear resistance with the Visio system (15 min). The association between hardness and wear resistance of a composite under different conditions, shown in this study, agrees in part with other reports that have discussed the relationship between the hardness and wear resistance of various composites (16,31).

The gloss of the Sinfony composite was determined before and after the toothbrush abrasion test. No significant differences in the gloss of the composite among poly-merization modes was evident before the abrasion test. This was probably due to compatibility between the polishing method and composition of the composite. The gloss of the composite was significantly reduced for all polymerization modes by toothbrush dentifrice abrasion. These results suggest that reduction of the gloss cannot be avoided for the Sinfony composite when using the Crest Tartar Protection dentifrice. The use of dentifrices with strong abrasive is not recommended in patients with restorations and dentures made of the Sinfony composite. The two polymerization modes including the Visio system produced lower gloss values after abrasion as compared with the other seven modes. It is reasonable to consider that the composite material should be polymerized with sufficient energy to maintain the original surface characteristics.

The working hypothesis proposed in the Introduction section was accepted through the three types of property test. Clinicians and dental laboratory technicians should be aware that properties of indirect composite materials are affected considerably by the characteristics of light polymerization units.

References

1. O'Neal SJ, Leinfelder KF, Barrett CB (1989) Clinical evaluation of Dentacolor as a posterior veneering agent. J Esthet Dent 1, 29-33.
2. Matsumura H, Nakamura M, Tanoue N, Atsuta M (2000) Clinical evaluation of an urethane tetramethacrylate-based composite material as a prosthetic veneering agent. J Oral Rehabil 27, 846-852.
3. O'Brien WJ, Johnston WM, Fanian F, Lambert S (1984) The surface roughness and gloss of composites. J Dent Res 63, 685-688.
4. Stanford WB, Fan PL, Wozniak WT, Stanford JW (1985) Effect of finishing on color and gloss of composites with different fillers. J Am Dent Assoc 110, 211-213.
5. Paravina RD, Roeder L, Lu H, Vogel K, Powers JM (2004) Effect of finishing and polishing procedures on surface roughness, gloss and color of resin-based composites. Am J Dent 17, 262-266.
6. Lee YK, Lu H, Oguri M, Powers JM (2005) Changes in gloss after simulated generalized wear of composite resins. J Prosthet Dent 94, 370-376.
7. Watanabe T, Miyazaki M, Moore BK (2006)

Influence of polishing instruments on the surface texture of resin composites. Quintessence Int 37, 61-67.

8. Heintze SD, Forjanic M, Rousson V (2006) Surface roughness and gloss of dental materials as a function of force and polishing time in vitro. Dent Mater 22, 146-165.

9. Kakaboura A, Fragouli M, Rahiotis C, Silikas N (2007) Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. J Mater Sci Mater Med 18, 155-163.

10. Kanter J, Koski RE, Martin D (1982) The relationship of weight loss to surface roughness of composite resins from simulated toothbrushing. J Prosthet Dent 47, 505-513.

11. Cannon ML, Marshall GW Jr, Marshall SJ, Cooley RO (1984) Surface resistance to abrasion of preformed laminate resin veneers. J Prosthet Dent 52, 323-330.

12. Jones RM, Goodacre CJ, Moore BK, Dykema RW (1989) A comparison of the physical properties of four prosthetic veneering materials. J Prosthet Dent 61, 38-44.

13. Tanoue N, Matsumura H, Atsuta M (2000) Wear and surface roughness of current prosthetic composites after toothbrush/dentifrice abrasion. J Prosthet Dent 84, 93-97.

14. Matsumura H, Leinfelder KF (1993) Localized three-body wear of six types of composite resin veneering materials. J Prosthet Dent 70, 207-213.

15. Yamaga T, Sato Y, Akagawa Y, Taira M, Wakasa K, Yamaki M (1995) Hardness and fracture toughness of four commercial visible light-cured composite resin veneering materials. J Oral Rehabil 22, 857-863.

16. Mandikos MN, McGivney GP, Davis E, Bush PJ, Carter JM (2001) A comparison of the wear resistance and hardness of indirect composite resins. J Prosthet Dent 85, 386-395.

17. Matsumura H, Tanoue N, Atsuta M, Kitazawa S (1997) A metal halide light source for laboratory curing of prosthetic composite materials. J Dent Res 76, 688-693.

18. Tanoue N, Matsumura H, Atsuta M (2000) Analysis of composite type and different sources of polymerization light on in vitro toothbrush/dentifrice abrasion resistance. J Dent 28, 355-359.

19. Tanoue N, Atsuta M, Matsumura H (2003) Properties of a new photo-activated composite polymerized with three different laboratory photo-curing units. J Oral Rehabil 30, 832-836.

20. Tanoue N, Atsuta M, Kitazawa S, Koizumi H, Matsumura H (2005) A new laboratory polymerizing apparatus equipped with halogen and metal halide light sources. Dent Mater J 24, 43-48.

21. Satsukawa H, Koizumi H, Tanoue N, Nemoto M, Ogino T, Matsumura H (2005) Properties of an indirect composite material polymerized with two different laboratory polymerizing systems. Dent Mater J 24, 377-381.

22. Tanoue N, Murakami M, Koizumi H, Atsuta M, Matsumura H (2007) Depth of cure and hardness of an indirect composite polymerized with three laboratory curing units. J Oral Sci 49, 25-29.

23. da Silva GR, Simamoto-Júnior PC, da Mota AS, Soares CJ (2007) Mechanical properties of light-curing composites polymerized with different laboratory photo-curing units. Dent Mater J 26, 217-223.

24. Peutzfeldt A, Asmussen E (2005) Resin composite properties and energy density of light cure. J Dent Res 84, 659-662.

25. Ramp LC, Broome JC, Ramp MH (2006) Hardness and wear resistance of two resin composites cured with equivalent radiant exposure from a low irradiance LED and QTH light-curing units. Am J Dent 19, 31-36.

26. Gritsch K, Souvannasot S, Schembri C, Farge P, Grosgogeat B (2008) Influence of light energy and power density on the microhardness of two nanohybrid composites. Eur J Oral Sci 116, 77-82.

27. Kakaboura A, Rahiotis C, Zinelis S, Al-Dhamadi YA, Silikas N, Watts DC (2003) In vitro characterization of two laboratory-processed resin composites. Dent Mater 19, 393-398.

28. Göhring TN, Gallo L, Lüthy H (2005) Effect of water storage, thermocycling, the incorporation and site of placement of glass-fibers on the flexural strength of veneering composite. Dent Mater 21, 761-772.

29. Rice DE, Dhabhar DJ, White DJ (2001) Laboratory stain removal and abrasion characteristics of a dentifrice based upon a novel silica technology. J Clin Dent 12, 34-37.

30. Botte G, Krejci I, Lutz F (1996) Charakterisierung von handelsublichen kompositvergutungsgeraten. Acta Med Dent Helv 1, 125-133. (in Germany)

31. Lappalainen R, Yli-Urpo A, Seppä L (1989) Wear of dental restorative and prosthetic materials in vitro. Dent Mater 5, 35-37.