The impact of in vitro aging on the mechanical and optical properties of indirect veneering composite resins

Stawarczyk, Bogna ; Egli, Roger ; Roos, Malgorzata ; Özcan, Mutlu ; Hämmerle, Christoph H F

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Abstract

Statement of Problem. Flexural strength, hardness, surface roughness, discoloration, and abrasion resistance are important properties of veneering composite resins. Recently introduced veneering resins are purported to have enhanced mechanical properties due to their composition, but their long-term durability is not known.

Purpose. This study tested the impact of aging on 3 different veneering composite resins.

Material and methods. Indirect composite resins, GC Gradia, VITA VM LC, and 3M ESPE Sinfony were prepared for flexural strength (N=495, n=165 per group), Martens hardness (N=30, n=10), surface roughness (N=30, n=10), discoloration measurement (N=90, n=30), and abrasion resistance (N=18, n=6) testing. After initial flexural strength measurement, the remaining specimens were stored in water or subjected to thermocycling for 1, 7, 28, 90, or 180 days, and hardness and surface roughness (water stored: n=5 and thermocycling: n=5 of each group) were tested. The discoloration specimens were randomly divided into 3 groups: coffee, black tea, and red wine; n=10), and age and discoloration were measured. Abrasion resistance was determined after 120,000, 240,000, 640,000 and 1,200,000 mechanical thermocycling loading. One-way ANOVA was used, followed by a post hoc Scheffé test and t-test. The longitudinal observations were analyzed using linear mixed models (α=.05).

Results. When considering all 5 of the properties tested, Sinfony revealed the best results, followed by GC Gradia and VITA VM LC.

Conclusion. The veneering composite resin, Sinfony, showed the most stable properties.

Clinical Implication. The long-term stability of the veneering composite resins tested was judged to be acceptable. Sinfony was found to have the most stable results after undergoing the aging conditions tested.

INTRODUCTION

A fixed dental prosthesis (FDP) typically consists of a high-strength substructure such as metal, and an esthetic veneer, which is currently either ceramic or composite resin. Veneering with ceramic is an established and successful technology for the anterior and posterior regions.[1] The flexural strength of the veneering ceramic ranges between 55 and 150 MPa.[2] Veneering ceramics provide excellent biocompatibility, color stability,[3] and abrasion resistance.[4] However, ceramic-veneered restorations have numerous undesirable characteristics, such as time-consuming fabrication. They are technically demanding and may damage the opposing natural tooth structure.[5] Some clinical studies have reported chipping of the veneering ceramic, particularly when used with zirconia substructures, despite the reported mechanical properties of ceramics.[6-11]

As a result, improved, indirectly-fabricated composite resins have been developed. The composition of these indirect, veneering composite resin systems is similar to that of the direct composite resins, but they differ in additional polymerization.[12] The mechanical and physical properties of veneering composite resins are based on their chemical composition: resin matrix,[13,14] filler particle type,[14] filler size,[15] filler percentage,[15,16] and filler-matrix bonding (silane coupling agent).[16,17] Temperature,[17,18] environmental conditions,[19] and light intensity of

the polymerization unit are all important factors.[14] In addition, longer light exposure and post-curing by heating have been found to improve the properties of prosthetic composite resin materials in laboratory studies.[20-22] It has been shown that the failure probability of composite resin-veneered restorations was not significantly different from that of metal ceramic restorations.[23] One in vitro study reported that CAD/CAM composite resins provided better fracture resistance for non-retentive occlusal veneers than ceramic.[24]

However, some problems, such as different degrees of flexural strength reduction with aging depending on the material type,[25,26] changing veneer surface texture,[27-29] and a tendency for discoloration,[30-36] have been reported. Discoloration in such composite resins may result in the need to replace the restorations. Color differences (ΔE) more than 3.3 units reflect clinically significant visual discoloration.[31,32]

The polymerization process could be improved with an increased conversion rate, resulting in fewer unpolymerized molecules.[18] The increased practice of using a veneering technique with indirect composite resins is due to recent improvements in the composite resins.[27,37] These new composite resins have an approximately 66% volume percentage of inorganic ceramic fillers, which results in improved mechanical properties with a flexural strength of between 120 and 160 MPa and an elastic modulus of 8.5-12 GPa.[12] Most veneering composite resins are applied with a post-curing process through heat and photo-polymerization, which results in superior flexural strength to veneering ceramic, minimal polymerization shrinkage, and a wear rate comparable to tooth enamel.[38,39] So far, chipping of veneering composite resin has not been reported in short-term clinical studies.[33] In the future, veneering ceramic could be replaced with veneering composite resins for single crowns and multiple-unit

posterior FDPs because of their similar mechanical properties and abrasion features. In addition, the use of veneering composite resin for zirconia frameworks might be considered.

Intraorally, restorative materials are subject to mechanical, chemical, and thermal influences through eating, drinking, and breathing.[40,41] Therefore, the purpose of this study was to test and compare the impact of aging on 3 indirect veneering composite resins, with different compositions aged in water (37°C) and with thermocycling (5°C/55°C) up to 180 days, on flexural strength, hardness, surface roughness, and color stability. Furthermore, the abrasion resistance was determined with mechanical-thermal cyclic loading upto 1.2 million cycles after aging. The null hypothesis for this investigation was that there would be no difference between the properties of the 3 tested composite resins before and after aging.

MATERIAL AND METHODS

Three different light-polymerizing veneering composite resins were tested for in vitro stability (Table I). The distribution of specimens per test method and the aging conditions are presented in Figure 1.

Veneering composite resins were polymerized according to each manufacturer's instructions in their corresponding light-polymerizing units. For GRD, the LABOLIGHT LV-III (GC Europe; Leuven, Belgium) was used for a polymerization time of 5 minutes. For VVL, the SPEED LABOLIGHT (Hager & Werken; Duisburg, Germany) was used for a polymerization time of 10 minutes, and for SFN, the Visio Alfa together with the Visio Beta (3M ESPE; Seefeld, Germany) were used. SFN was pre-polymerized for 5 seconds with the Visio Alfa and then polymerized in the Visio Beta device for 16 minutes under vacuum. All polymerization devices were used according to the manufacturers' instructions.

All veneering composite resins were prepared and polymerized according to manufacturers` instructions with their corresponding polymerizing light. The specimens were divided per test method by one person, blinded to the objectives of the study.

Flexural strength

For each tested veneering composite resin, 165 specimens (25×2×2 mm) were fabricated in a special stainless steel mold according to ISO 10477:2004.[43] The initial flexural strength of all 3 veneering composite resins (n=15) was measured. The remaining 150 specimens of each veneering composite resin were randomly divided into 2 subgroups: (1) 75 specimens were stored in distilled water at 37 °C in an incubator (ED 240; Binder; Tuttlingen, Germany); and (2) 75 specimens were placed in a thermocycling machine (5 °C/55°C/dwell time: 20seconds; Thermocycler; Willytec; Feldkirchen-Westerham, Germany). In both subgroups, 15 specimens were selected after 1, 7, 28, 90, and 180 days for flexural strength measurements. The 3-point flexural strength was measured using a universal testing machine (1 mm/min, Z010, Zwick, Ulm, Germany). The specimens were placed on 2 rollers with a diameter of 2 mm and set at a distance of 20 mm. The specimens were loaded axially with a cylinder (diameter of 2 mm) until fracture.

Martens Hardness

The production of the specimens (n=10 per composite resin) was the same as previously described. The surface of the specimens was first polished with silicon carbide abrasives P400 through P1200 in an automatic polishing device (PlanoPol-2; Struers; Ballerup, Denmark) for 60 seconds each. The specimens of each veneering composite resin were divided into 2 subgroups: (1) 5 specimens were stored in distilled water at 37 °C in the incubator; and (2) 5 specimens were placed in the thermocycling machine (5°C/55°C/dwell time: 20 seconds). Every specimen was tested before aging and after 1, 7, 28, 90, and 180 days for Martens hardness (ZHU 2.5; Zwick;

Ulm, Germany). The diamond indenter of the hardness tester was used on the polished surface of the specimen with a load of 10 N for 20 seconds.

Surface roughness

For each veneering composite resin, 10 disc-shaped specimens (diameter: 10 mm, thickness: 2 mm) were fabricated in a silicone mold (Dublisil 10; Dreve; Unna, Germany). The veneering composite resins were directly inserted and polymerized. The specimen surface was polished as described for the Martens hardness specimens. Ten specimens of each veneering composite resin group were divided into 2 subgroups: (1) 5 specimens were stored in distilled water at 37 °C in the incubator (ED 240); and (2) 5 specimens were placed in the thermocycling machine (5 °C/55°C/dwell time: 20seconds). The surface roughness of each specimen was determined with a surface measuring unit (Perthometer S2 with feed unit GD25; Mahr GmbH; Göttingen, Germany). Each specimen was measured 5 times with a measuring track of 1.75 mm. The distance between the tracks was 0.25 mm. Both subgroups were measured before aging and after 1, 7, 28, 90, and 180 days.

Discoloration

Specimens were prepared (N=90, n=30 per veneering composite resin) with a diameter of 15 mm and a thickness of 1 mm, following the ISO 4049 specification.[44] A plastic split ring that rested on a glass slab was used to fabricate the specimens. The split ring between the 2 glass slabs was filled with veneering composite resin, polymerized, and then embedded in acrylic resin (ScandiQuick; SCAN-DIA; Hagen, Germany) with 25 mm diameter cylindrical molds. The surface of all specimens was uniformly polished (P400, P1200, P2400) on a polishing device (LaboPol-21; Struers) and examined under a light microscope (×25; Wild M3B; Heerbrugg, Switzerland). The 30 specimens of each veneering composite resin were divided into 3

subgroups: (1) 10 specimens were stored in coffee (Mastro Lorenzo Classico; Kraft Foods; Glattpark, Switzerland) at 37 °C; (2) 10 specimens were stored in black tea (Lipton Yellow Label; Unilever GmbH; Thayngen, Switzerland) at 37 °C; and (3) 10 specimens were stored in red wine (Rioja, Spain) at 37 °C. The discoloration of each specimen was measured before aging and after 1, 7, 28, 90, and 180 days. The initial measurement of each group was used as a reference point. The measurements were performed with a calibrated (white standard SRS-99-010-7698-a) spectrophotometer (CM-508d; Minolta; Tokyo, Japan). The resulting parameters (L, h, a, b) were examined with a 2-degree standard observer and illuminant D65 with the manufacturer's software (SpectraMagic; Minolta), and then the ΔE-values were calculated with the following equation: $\Delta E = \sqrt{\Delta a^2 + \Delta b^2 + \Delta L^2}$. After 180 days of storage in coffee, tea, and red wine, all specimens were polished for 60 seconds with a prophylaxis paste (Cleanic; KerrHawe SA; Bioggio, Switzerland) and the discoloration was measured.

Abrasion resistance

Specimens of each veneering composite resin were made in a stainless steel mold (N=18, n=6) and polymerized. The specimens were polished with silicon carbide paper P400, P1200, and P2400 (LaboPol-21; Struers). All specimens were aged in a computer-controlled, mechanical thermocycling machine (University of Zurich). Thermo-mechanical loading was applied during cyclic loading; an occlusal load of 50 N at 1.7 Hz and simultaneous thermal stress with temperature changes from 5 °C to 50 °C every 120 seconds. Palatal cusps from nearly identical maxillary human molars fixed in amalgam (Dispersalloy; Dentsply; Konstanz, Germany) acted as antagonists. The profiles of the specimens were measured with a 3D wear-measuring device (University of Zurich) before aging and after 120,000, 240,000, 640,000, and 1,200,000 masticatory cycles. The veneering composite resin loss of each specimen was calculated with the

software (3DS software; University of Zurich) by overlaying the profiles with congruent points and subtracting initial measurements from subsequent measurements.

Descriptive statistics were computed. To detect differences in the flexural strength means, 1-way analysis of variance (ANOVA), together with Scheffé's post hoc test, was applied. For hardness, surface roughness, discoloration, and abrasion resistance measurements, linear mixed models with random intercept were applied to investigate the influence of the different aging levels, different veneering composite resins and the interaction between aging levels and veneering composite resins. Akaike information criterion (AIC) and Bayesian information criterion (BIC) were used for the model choice. The data set was analyzed with statistical software (SPSS Version 17; SPSS INC, Chicago, Ill) (α=.05). In summary, a subjective assessment of all measured properties was made to provide an outline of the aging stability for the 3 different composite resins.

RESULTS

Flexural strength

Table II provides descriptive statistics on flexural strength measurement of both aging types for each veneering composite resin and aging level. For flexural strength of the 3 veneering composite resins at a specific aging level with water storage, no significant differences between the veneering composite resins were observed after 1 day (P=.295) and 7 days (P=.085) of aging (Table II). After 28 days (P<.001), the highest flexural strength was obtained for GRD and SFN, and both veneering composite resins showed better values than VVL. After 90 days, GRD presented significantly lower (P=.001) values than SFN, and after180 days, SFN showed significantly higher (P<.001) flexural strength than GRD and VVL.

After 1 day of thermocycling, GRD showed significantly higher (P=.026) flexural strength than VVL, and after 7 days, the highest (P<.001) flexural strength was obtained from VVL and SFN (Table II). After 28 days of thermocycling, the results for SFN were significantly higher (P=.026) than VVL. After 90 days, GRD revealed the lowest (P<.001) mean flexural strength, and SFN was higher than VVL. VVL had significantly higher results compared to than SFN after 180 days (P=.040).

The results for long-term flexural strength stability for each veneering composite in water storage showed the highest flexural strength after 1 day and 7 days of water storage within the GRD groups (P<.001) (Table II). The lowest results were observed initially and after 180 days of aging. VVL showed initially significantly higher (P<.001) values than after 7, 28, and 180 days. In the last aging level (180 days), flexural strength was lowest. Within the SFN group, after 1 day, a significantly higher flexural strength (P<.001) was observed than initially and after 7 and 180 days of water aging. The specimens aged for 180 days showed significantly lower values than after 28 days and 90 days.

After thermocycling, GRD showed significantly lower (P<.001) flexural strength after 90 and 180 days than initially or after 1, 7 and 28 days of aging (Table II). In VVL, the lowest results were observed after 180 days of aging (P<.001). The highest flexural strength was observed initially. Within SFN, the specimens showed the lowest results (P<.001) after 180 days of aging. Significantly higher flexural strength values were obtained after 7, 28, and 90 days of aging than after l day.

Martens hardness

VVL showed higher (P=.004) initial Martens hardness than SFN and GRD after water storage. All 3 veneering composite resins showed an increase in Martens hardness (P=.016), but

correction of the slope for SNF and GRD were not significant (Table III, Fig. 2a). After thermocycling, the veneering composite resins showed no differences in the initial mean Martens hardness values level (between SFN and GRD: P=.060, between SFN and VVL: P=.075). All veneering composite resins showed an increase in Martens hardness during aging (P=.001). VVL showed a less pronounced increase (P=.045) than SFN and GRD (Table III, Fig. 2b).

Surface roughness

With water storage, the 3 veneering composite resins showed significant differences (P<.001). The initial mean Ra for SFN showed lower values than for GRD (P=.005) and VVL (P=.002). No changes due to aging (p=.475) were observed for all 3 veneering composite resins (Table III, Fig. 3a). The lowest initial mean Ra value for SFN was obtained after thermocycling and was significantly different from VVL (P=.019). GRD showed an increase in Ra values (P=.002) during aging with respect to SFN and VVL (P=.532; P=.14) (Table III, Fig. 3b).

Discoloration

All 3 veneering composite resins, at all levels of aging, had ΔE values significantly higher than zero, indicating color change (Tables IV-VI). A similarly significant initial mean coffee discoloration (P<.001) was found in all 3 veneering composite resins while the corrections for GRD and VVL with respect to SFN were P=.770 and P=.356, respectively. The discoloration increased according to the aging level (P=.001). GRD (P=.002) and VVL (P<.001) showed a higher increase than SFN (Fig. 3a). After polishing with prophylaxis paste, the ΔE values of GRD and SFN showed similar discoloration, but VVL presented higher ΔE values after 1 day of coffee storage (Table IV). All 3 veneering composite resins discolored within the same range for tea storage (between SFN and GRD: P=.104; between SFN and VVL: P=.720). The increase in discoloration was higher for GRD (P<.001) and VVL (P=.01) than for SFN (Fig. 4b). After

polishing, the discoloration of all 3 tested veneering composite resins was removed and was within the values range of 1 day in black tea storage (Table V). Over time, all composite resins showed a strong increase in discoloration after red wine storage. No difference in the increase in discoloration was found between the 3 veneering composite resins (between SFN and GRD: P=.538; between SFN and VVL: P=.306) regardless of storage time (Table VI, Fig. 4c). After polishing, the ΔE values demonstrated higher discoloration than after 1 day of wine storage for all veneering composite resins (Table VI).

Abrasion resistance

All veneering composite resins showed a mean loss of material that was significant (P<.001). VVL showed a higher material loss than GRD and SFN (P=.002) (Table VII, Fig. 5). SFN and GRD were similar regarding the level of material loss. With increased mechanical thermocycling, there was a significantly higher loss of material in VVL (P<.001) than in SFN and GRD, both of which showed (P=.002) only a slight increase in material loss at all remaining aging levels, indicating good abrasion resistance.

DISCUSSION

Differences were observed between the properties of the 3 tested composite resins before and after aging. Hence, the null hypothesis is rejected. According to the manufacturers, the 3 veneering composite resins have different compositions. GC Gradia is a fine hybrid composite resin composed of UDMA and EDMA; VITA VM LC is a microfilled composite resin with EDMA, TEGDMA and DMAEMA; and Sinfony is a microhybrid composite resin containing a resin matrix composed of HEMA and octahydro-4,7-methano-1H-indenediyl-bis(methacrylate). Only Sinfony includes a post-polymerizing process. Their composition and polymerization

parameters play a major role in providing the needed properties of veneering composite resin.[21] Although Sinfony had lower filler content (50 wt%) its optical and mechanical stability were more favorable than the other resins, which were more highly filled. This composite resin required longer polymerization time, which might have improved the surface properties. Therefore, not only the filler content but also the polymerization mode might have affected the mechanical and optical properties.

The highest flexural strength after water storage and thermocycling was observed with Sinfony. The flexural strength of all tested veneering composite resins was reduced after water storage and thermocycling. Other studies have observed similar results after aging.[25,26] Clinically, veneering composite resins are subjected to complex mastication forces and a considerable amount of flexural stress. For restorations that are subjected to high masticatory stress, high and long-term stable flexural strength is desired to avoid fractures.[41]

The veneering composite resin VITA VM LC showed stable Martens hardness, whereas the results for GC Gradia and Sinfony showed an increase parallel to the aging level. Therefore, it can be stated that throughout the entire observation period of 180 days, no negative effect of aging occurred on the surface layer. The increase in hardness during the aging time might be explained by additional, continued polymerization. An increase in the Martens hardness of direct placement composite resins has been reported previously.[26] Hardness can be used to evaluate the relative degree of the conversion of a composite resin.[44] Therefore, it can be concluded that additional conversion occurred during aging procedures in GC Gradia and Sinfony.

Despite the uniform polishing of the specimens, differences of surface roughness were detected. Compared to the other 2 materials, Sinfony had a smoother surface, represented by significantly lower Ra values. During the aging process with water storage, the surface

roughness was stable for all veneering composite resins. With the addition of thermocycling, the surface of Sinfony remained stable while the surface roughness of VITA VM LC was reduced. With GC Gradia the surface roughness increased with aging. This could be attributed to possible water sorption during water storage and thermocycling, which may have caused swelling on the surface of this composite resin.

After 180 days, the discoloration increased from black tea to coffee to red wine. After polishing, the ΔE values for black tea, coffee (except VITA VM LC), and red wine (except VITA VM LC) decreased to below 3.3 ΔE and were clinically acceptable. These findings of acceptable color stability have been confirmed in another study.[35]

In the current in vitro study, Δb values represented a yellowish shade. Authors of an in vivo study reported that the tested material became darker and more yellowish after 18 months.[34] Another clinical study reported a statistically significant yellow discoloration of resin veneered telescopic dentures after 2 years.[33] This phenomenon was attributed to the presence of residual camphorquinone, which is added to the composite resin materials as a photo-initiator.[31] In general, color stability is influenced by the intensity and duration of polymerization and consequently by the degree of conversion.[32] Therefore, it is important to adhere to the polymerization parameters and the corresponding timing. Prolonged polymerization duration may increase the degree of conversion and thereby decrease discoloration composite resins containing TEGDMA.[32] Although VITA VM LC contains TEGDMA, color was not stable compared to other materials. This composite resin could benefit from longer polymerization, a possibility which warrants further research.

The veneering composite resins Sinfony and GC Gradia showed significantly less wear than VITA VM LC after 1,200,000 cycles, which is equivalent to 5 years of clinical wear.[28] The

involvement of thermocycling in the mechanical loading might have contributed to and increased the effect of aging.[29] The loss of material resulted in a rougher surface, which is a predisposing factor for bacteria adhesion, plaque maturation, periodontal disease, and extrinsic staining.[29] In the current study, 2 veneering composite resins (Sinfony and GC Gradia) showed, after 1,200,000 masticatory cycles, abrasion resistance similar to human enamel (55.5 ± 40.6 μm) and better than amalgam (157.5 ± 29.9 μm) (data obtained with the Zurich wear simulator).[24]

Theoretically, no deterioration in either optical or mechanical properties is clinically desirable. Yet, these properties of the tested materials varied depending on the material after aging. For some of the tests in this study, aging procedures were performed on each specimen, and measurements were made on the same specimens at different time points (0-180 days, or 0-1,200,00 chewing cycles). For the Martens hardness test, surface roughness, discoloration, and abrasion resistance specimens were repeatedly used and longitudinal data were, therefore, available. Consequently, the measurements from one particular specimen were correlated with one another. Thus linear mixed models with random intercept were applied to investigate the influence of different aging times. The Akaike information criterion and Bayesian information criterion were used for the model choice. Linear mixed models allow for correlated responses by including random effects in the linear predictor. However, for the flexural strength test, 1-way ANOVA, followed by the post hoc Scheffé test, was used. For this test, specimens could not be used repeatedly since the specimens were destroyed during each test. Therefore, for this test method, longitudinal observations could not be made as in other test methods. The data for flexural strength test were normally distributed, and so parametrical statistics, such as ANOVA, were used.

The objective assessment of the properties of the 3 tested veneering composite resins after aging indicated that the veneering composite resin, Sinfony, had the highest stability. The use of veneering composite resin with a metal framework FDP is well documented. The newer veneering composite resins yielded superior mechanical properties, and the results of this study showed superior long term stability for the tested materials. Further studies are needed to evaluate their performance on ceramic frameworks in terms of long-term adhesion, wear, color, and mechanical stability.

One limitation of this study was the lack of power analysis. A pilot study was also not feasible because of the long, 180-day thermocycling procedure. To calculate the optimal sample size, the data were treated as if they were from a pilot study. For flexural strength and Martens hardness, the difference in standard deviation was considered to be 25% of the initial values and 25% of the maximum value of the veneering composite resins at 180 days. For surface roughness and abrasion resistance, 50% of the initial values, and 50% of the maximum value at 180 days was considered as the difference in means. However, for discoloration ΔE values under 3 were considered as the difference in standard deviations after 180 days of aging and after polishing. Therefore, the sample size and the data used for this study could be considered as a pilot and used as a reference for future studies.

The other limitation of this study is the lack of positive and negative control groups. However, standardization of enamel or ceramic specimens, for instance, for all test types would have been difficult. Particularly, the flexural strength test would have been difficult to perform on enamel because of the required geometry. Due to the variations of enamel surfaces in human teeth, no control group was used in this study nor for the other testing methods.

CONCLUSION

Within the limits of this study, the following conclusions can be drawn regarding the 3 veneering composite resins evaluated:

1. Aging with water storage and thermocycling showed a decrease in flexural strength.

2. All veneering composite resins showed an increase in Martens hardness during aging.

3. Water storage showed no effect on the surface roughness but varied depending on the material after thermocycling.

4. After 180 days of aging with coffee, black tea, and red wine the discoloration values of the polished specimens were less than the clinically acceptable level, except for VVL where a significant color change was observed.

5. Overall, SFN showed the highest stability after aging.

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Table I. Summary of composite resins evaluated

Composite resin type	Product name (code)	Manufacturer	Composition	Curing light used*	Shade	Lot
Fine hybrid	**GC Gradia (GRD)**	GC Europe, Leuven, Belgium	UDMA, EDMA, (75 wt% filler: Ceramic, Prepolymer, SiO_2)	LABOLIGHT LV-III (GC Europe, Leuven, Belgium) for 5 min	A3	0805122, 0807151
Microfilled	**VITA VM LC (VVL)**	VITA Zahnfabrik, Bad Säckingen, Germany	EDMA, TEGDMA, DMAEMA, (45-48 wt% filler 40 nm: Prepoly-merized Splinters, SiO_2)	SPEED LABOLIGHT (Hager & Werken, Duisburg, Germany) for 10 min	1M2	10030, 20281
Microhybrid	**Sinfony (SFN)**	3M ESPE, Seefeld, Germany	HEMA, Octahydro-4,7-methano-1H-indenediyl-	Pre-polymerization: Visio Alfa (3M ESPE) for 5 s End-	A3	335152, 351464

			bis(methylene-diacrylate), (50 wt% filler 0.5-0.7 µm: Sr-Ba-Al-Si glass, pyrogenic silica)	polymerization: Visio Beta Vario (3M ESPE) for 16 min under vacuum		
* All polymerization lights were chosen according to manufacturer's specific instructions						

Table II. Descriptive statistics for flexural strength (MPa) of each aging type and level and veneering composite resins

Veneering composite	Aging type	Mean ± SD					
		initial	1 day	7 days	28 days	90 days	180 days
GRD	**Water storage (37°C)**	66.6 ± 12.4^{a,A,I}	142.7 ± 26.1^{a,C}	126.8 ± 14.3^{a,C}	122.6 ± 17.1^{b,BC}	104.5 ± 18.9^{a,B}	73.8 ± 10.8^{a,A}
	Thermocycling (5°C/55°C)		113.2 ± 10.9^{b,II}	99.1 ± 13.6^{a,II}	95.5 ± 18.9^{ab,II}	63.3 ± 12.3^{a,I}	66.6 ± 16.0^{ab,I}
VVL	**Water storage (37°C)**	136.6 ± 23.9^{c,D,X}	131.1 ± 15.8^{a,CD}	109.1 ± 24.3^{a,BC}	104.7 ± 20.2^{a,B}	118.9 ± 16.3^{ab,BCD}	79.4 ± 10.7^{a,A}
	Thermocycling (5°C/55°C)		97.4 ± 14.9^{a,II}	134.2 ± 23.0^{b,III}	90.9 ± 20.9$^{a,I/II}$	106.0 ± 13.6^{b,II}	71.6 ± 11.9^{b,I}
SFN	**Water storage (37°C)**	117.2 ± 14.0^{b,AB,YX}	141.7 ± 23.4^{a,C}	116.3 ± 23.9 (103.0,129.5)^{a,AB}	138.5 ± 13.8 (130.8,146.1)^{b,BC}	134.1 ± 25.6 (119.9,148.2)^{b,BC}	99.7 ± 9.5 (94.4,105.0)^{b,A}
	Thermocycling (5°C/55°C)		105.4 ± 19.1^{ab,II}	137.4 ± 19.8^{b,III}	112.7 ± 24.3$^{b,II/III}$	132.7 ± 24.7^{c,II}	56.6 ± 16.6^{a,I}

Lower case superscripted letters reflect significant difference value levels from 1-way ANOVA (P<.05) within same aging levels and aging types among 3 veneering composite resins

Upper case superscripted letters reflect significant difference value levels after water storage from 1-way ANOVA (P<.05) within same veneering composite resins among 6 aging levels

Superscripted roman numerals reflect significant difference value levels after thermocycling from 1-way ANOVA (P<.05) within same veneering composite resins among 6 aging levels

Table III. Descriptive statistics of mean Martens hardness and surface roughness Ra values of each aging type and level for all veneering composite resins

Aging level (days)	**Martens hardness**		**Surface roughness**	
	Water storage (37 °C)	**Thermocycling (5 °C/55 °C)**	**Water storage (37 °C)**	**Thermocycling (5 °C/55 °C)**
	mean + SD	mean + SD	mean + SD	mean + SD
GRD				
Initial	158.7 ± 17.9	169.9 ± 17.8	0.099 ± 0.013	0.112 ± 0.016
1	193.2 ± 39.8	178.4 ± 37.3	0.099 ± 0.013	0.119 ± 0.021
7	209.6 ± 38.0	239.7 ± 30.2	0.117 ± 0.016	0.128 ± 0.023
28	221.9 ± 34.8	214.5 ± 21.3	0.114 ± 0.026	0.137 ± 0.025
90	239.6 ± 17.5	257.5 ± 22.7	0.115 ± 0.032	0.172 ± 0.067
180	243.0 ± 17.9	241.1 ± 21.1	0.098 ± 0.020	0.165 ± 0.051
VVL				
Initial	223.2 ± 25.2	221.8 ± 46.5	0.094 ± 0.028	0.101 ± 0.028
1	218.3 ± 19.3	193.6 ± 20.7	0.113 ± 0.019	0.118 ± 0.026
7	202.6 ± 32.7	176.1 ± 25.7	0.112 ± 0.035	0.141 ± 0.017
28	194.9 ± 29.7	208.3 ± 15.3	0.129 ± 0.034	0.157 ± 0.024
90	211.8 ± 17.2	202.9 ± 34.9	0.134 ± 0.034	0.144 ± 0.016
180	217.0 ± 11.0	208.6 ± 32.9	0.089 ± 0.021	0.077 ± 0.009
SFN				
Initial	144.2 ± 26.0	139.8 ± 16.5	0.064 ± 0.008	0.073 ± 0.017
1	173.0 ± 24.8	161.7 ± 24.1	0.064 ± 0.012	0.082 ± 0.036

7	185.0 ± 11.6	201.7 ± 34.7	0.067 ± 0.013	0.097 ± 0.020
28	208.5 ± 14.3	207.2 ± 20.7	0.069 ± 0.009	0.113 ± 0.025
90	192.4 ± 29.0	217.3 ± 26.2	0.070 ± 0.006	0.112 ± 0.014
180	203.0 ± 9.2	218.1 ± 6.9	0.058 ± 0.007	0.070 ± 0.017

Table IV. Descriptive statistics for coffee discoloration of each aging level for all 3 veneering composite resins

Aging level (days)	**ΔL**	**Δa**	**Δb**	**ΔE**
	mean ± SD	mean ± SD	mean ± SD	mean ± SD
GRD				
1	-0.70 ± 0.39	0.31 ± 0.19	1.25 ± 0.49	1.52 ± 0.49
7	-1.65 ± 0.46	0.70 ± 0.28	2.09 ± 0.59	2.79 ± 0.65
28	-2.80 ± 0.39	0.73 ± 0.20	1.81 ± 0.48	3.44 ± 0.44
90	-3.22 ± 0.63	0.89 ± 0.32	2.89 ± 0.63	4.44 ± 0.79
180	-3.02 ± 0.64	0.92 ± 0.31	3.27 ± 0.85	4.60 ± 0.80
after polishing	-1.20 ± 0.86	0.16 ± 0.23	0.96 ± 1.03	1.86 ± 0.80
VVL				
1	-0.38 ± 1.24	0.10 ± 0.26	1.77 ± 0.54	2.17 ± 0.55
7	-0.78 ± 1.60	0.22 ± 0.24	3.35 ± 0.56	3.76 ± 0.66
28	-2.63 ± 1.53	0.19 ± 0.43	2.85 ± 1.11	4.22 ± 0.81
90	-2.36 ± 1.63	0.19 ± 0.27	4.78 ± 0.95	5.59 ± 0.69
180	-2.13 ± 1.54	-0.14 ± 0.24	5.69 ± 1.02	6.24 ± 1.09
after polishing	-0.97 ± 2.03	-0.50 ± 0.28	3.62 ± 1.11	4.29 ± 0.91
SFN				
1	1.29 ± 3.30	0.07 ± 0.25	1.08 ± 0.93	2.52 ± 2.82
7	0.57 ± 3.02	0.15 ± 0.31	1.73 ± 0.89	2.71 ± 2.36

28	-0.38 ± 2.54	0.42 ± 0.30	1.65 ± 0.76	2.87 ± 1.16
90	0.48 ± 3.25	0.40 ± 0.25	2.47 ± 0.72	3.51 ± 2.16
180	1.14 ± 3.01	0.48 ± 0.15	2.78 ± 0.84	3.64 ± 2.32
after polishing	2.46 ± 3.55	0.03 ± 0.24	0.19 ± 0.76	2.76 ± 3.39

Table V. Descriptive statistics for black tea discoloration of each aging level for all 3 veneering composite resins

Aging level (days)	**ΔL**	**Δa**	**Δb**	**ΔE**
	mean ± SD	mean ± SD	mean ± SD	mean ± SD
GRD				
1	-0.50 ± 0.49	0.24 ± 0.18	0.66 ± 0.48	1.02 ± 0.42
7	-0.96 ± 0.59	0.31 ± 0.21	0.85 ± 0.55	1.45 ± 0.53
28	-1.43 ± 0.43	0.31 ± 0.27	0.51 ± 0.62	1.68 ± 0.42
90	-1.21 ± 0.42	0.23 ± 0.30	2.75 ± 1.30	3.12 ± 1.11
180	-2.04 ± 0.76	0.64 ± 0.38	2.86 ± 1.41	3.71 ± 1.26
after polishing	-0.29 ± 0.87	0.06 ± 0.29	0.82 ± 1.43	1.40 ± 1.24
VVL				
1	-0.32 ± 1.40	0.23 ± 0.15	0.67 ± 0.35	1.37 ± 0.84
7	-0.11 ± 1.41	0.39 ± 0.16	1.68 ± 0.65	2.08 ± 0.98
28	-1.37 ± 1.59	0.23 ± 0.37	1.33 ± 1.06	2.50 ± 0.98
90	-2.03 ± 1.71	0.59 ± 0.49	2.72 ± 1.17	3.87 ± 1.05
180	-1.61 ± 1.40	0.67 ± 0.37	3.04 ± 0.98	3.82 ± 0.69
after polishing	0.08 ± 1.55	0.04 ± 0.25	0.94 ± 0.93	1.44 ± 1.42
SFN				
1	0.97 ± 1.50	0.14 ± 0.23	0.79 ± 0.51	1.69 ± 1.07

7	0.86 ± 1.37	-0.01 ± 0.33	0.95 ± 0.85	1.79 ± 0.99
28	-0.15 ± 2.18	0.23 ± 0.39	0.24 ± 1.15	2.30 ± 0.71
90	0.68 ± 1.44	0.21 ± 0.44	1.49 ± 0.91	2.16 ± 0.97
180	0.69 ± 0.91	0.60 ± 0.32	2.34 ± 0.88	2.71 ± 0.79
after polishing	1.76 ± 1.56	0.28 ± 0.27	-0.42 ± 0.59	2.18 ± 1.13

Table VI. Descriptive statistics for red wine discoloration of each aging level for all 3 veneering composite resins

Time of aging (d)	**ΔL**	**Δa**	**Δb**	**ΔE**
	mean ± SD	mean ± SD	mean ± SD	mean ± SD
GRD				
1	-0.90 ± 0.28	0.20 ± 0.22	-0.13 ± 0.48	1.04 ± 0.33
7	-2.56 ± 0.47	0.67 ± 0.28	-0.02 ± 0.76	2.75 ± 0.47
28	-10.10 ± 3.13	3.59 ± 1.49	-0.87 ± 1.74	10.93 ± 3.27
90	-18.12 ± 7.80	7.87 ± 4.12	2.16 ± 1.90	19.96 ± 8.77
180	-19.19 ± 6.22	10.50 ± 3.74	6.80 ± 2.58	23.02 ± 7.29
after polishing	-1.93 ± 0.92	0.53 ± 0.32	1.86 ± 1.16	2.90 ± 1.12
VVL				
1	-1.66 ± 0.70	0.49 ± 0.37	0.07 ± 0.90	1.96 ± 0.71
7	-2.82 ± 1.17	0.39 ± 0.55	1.25 ± 1.73	3.61 ± 0.95
28	-17.33 ± 4.97	6.73 ± 1.93	0.56 ± 1.82	18.69 ± 5.29
90	-24.41 ± 7.66	12.21 ± 4.27	4.42 ± 2.73	27.78 ± 8.73
180	-25.31 ± 7.08	14.08 ± 3.65	8.32 ± 2.44	30.30 ± 7.60
after polishing	-1.54 ± 0.69	0.24 ± 0.46	2.79 ± 1.38	3.35 ± 1.20
SFN				
1	0.54 ± 0.62	0.59 ± 0.44	0.11 ± 0.75	1.19 ± 0.54

7	1.16 ± 1.66	0.50 ± 0.26	0.14 ± 0.46	1.83 ± 1.04
28	-8.67 ± 5.13	5.89 ± 2.53	2.02 ± 1.49	10.84 ± 5.58
90	-15.89 ± 6.51	10.78 ± 3.49	7.39 ± 2.72	20.69 ± 7.51
180	-17.52 ± 6.55	12.89 ± 3.60	11.47 ± 2.78	24.78 ± 7.27
after polishing	1.59 ± 0.74	0.37 ± 0.22	0.05 ± 0.63	1.75 ± 0.74

Table VII. Mean ± SD abrasion resistance values of each aging level for all veneering composite resins in μm

Masticatory cycles	**GRD**	**VVL**	**SFN**
120,000	26.2 ± 7.5	40.8 ± 11.1	35.3 ± 6.9
240,000	29.8 ± 7.0	59.3 ± 21.0	38.5 ± 8.3
640,000	33.2 ± 8.5	77.2 ± 23.5	44.5 ± 10.6
1,200,000	38.2 ± 11.9	111.2 ± 31.5	50.3 ± 15.8

LEGENDS

Fig. 1. Test methods depending on aging-type and aging-time for each veneering composite resin.

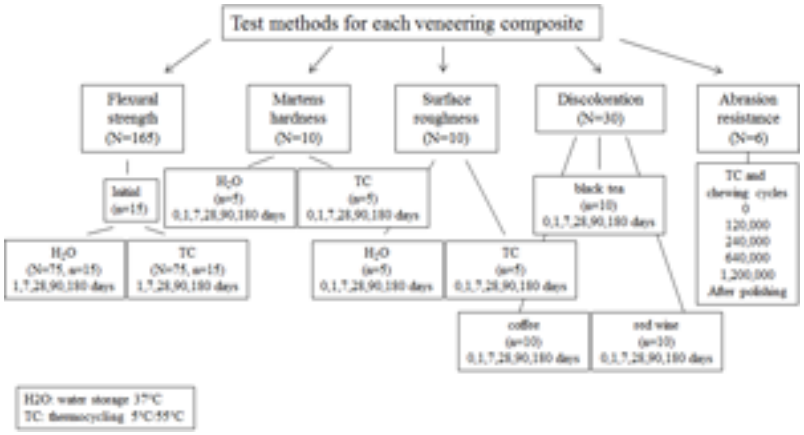
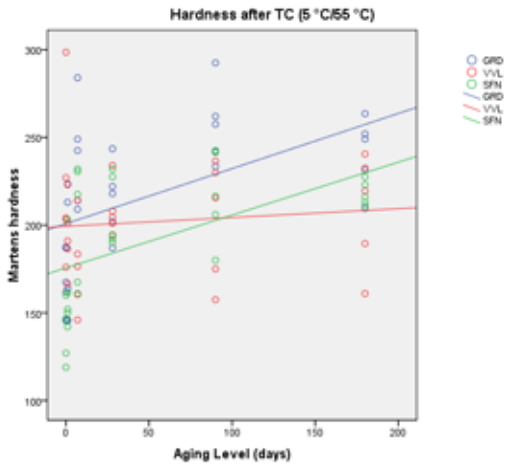
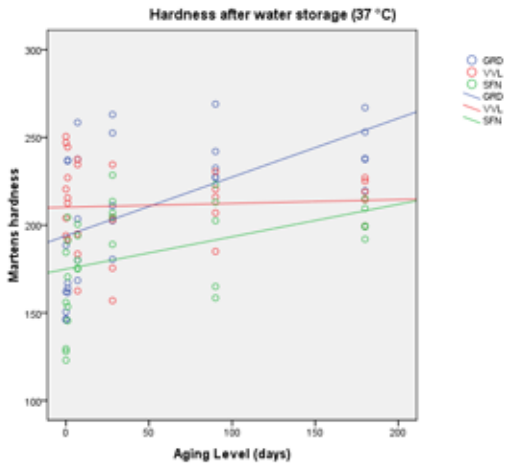


Fig. 2. A. Diagram of Martens hardness after water storage for each veneering composite resin at each aging level (GRD = GC Gradia, VVL = VITA VM LC and SFN = Sinfony).

B. Diagram of Martens hardness after thermocycling for each veneering composite resin at each aging level (GRD = GC Gradia, VVL = VITA VM LC and SFN = Sinfony).



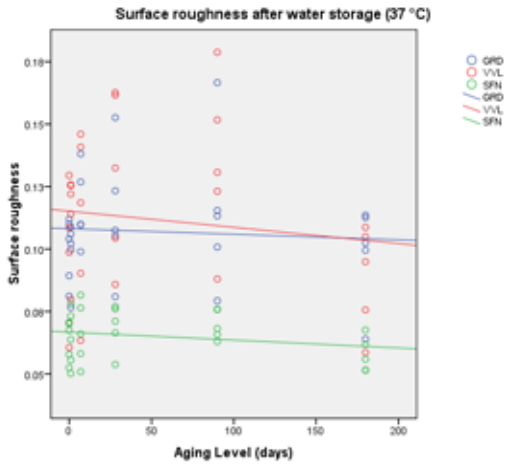
A



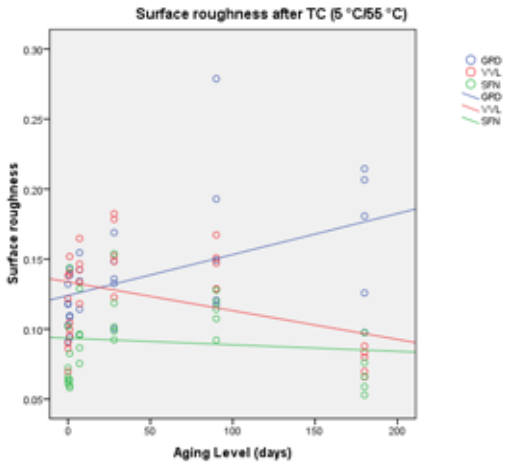
B

Fig. 3. A. Diagram of surface roughness after water storage for each veneering composite resin at each aging level (GRD = GC Gradia, VVL = VITA VM LC and SFN = Sinfony).

B. Diagram of surface roughness after thermocycling for each veneering composite resin at each aging level (GRD = GC Gradia, VVL = VITA VM LC and SFN = Sinfony).



A

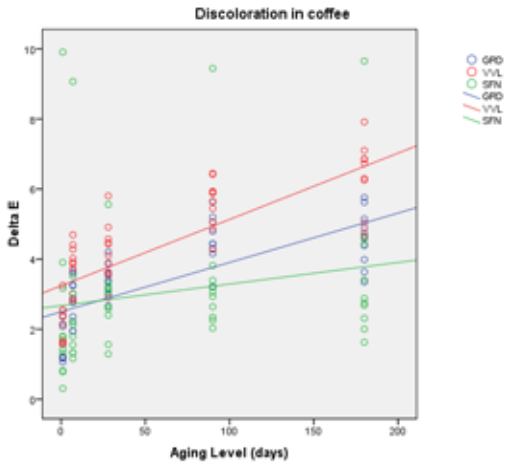


B

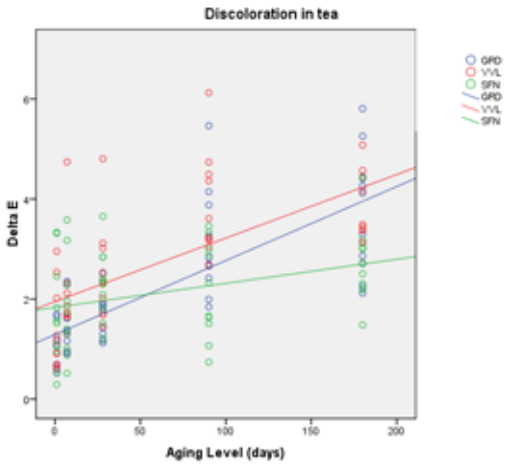
Fig. 4. A. Diagram of discoloration after coffee storage for each veneering composite at each aging level (GRD = GC Gradia, VVL = VITA VM LC and SFN = Sinfony).

B. Diagram of discoloration after black tea storage for each veneering composite at each aging level (GRD = GC Gradia, VVL = VITA VM LC and SFN = Sinfony).

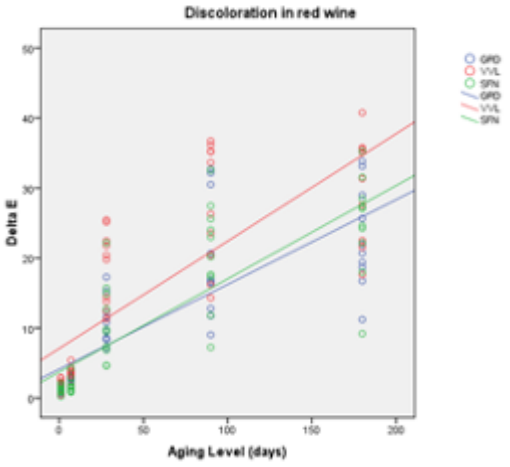
C. Diagram of discoloration after red wine storage for each veneering composite at each aging level (GRD = GC Gradia, VVL = VITA VM LC and SFN = Sinfony).



A

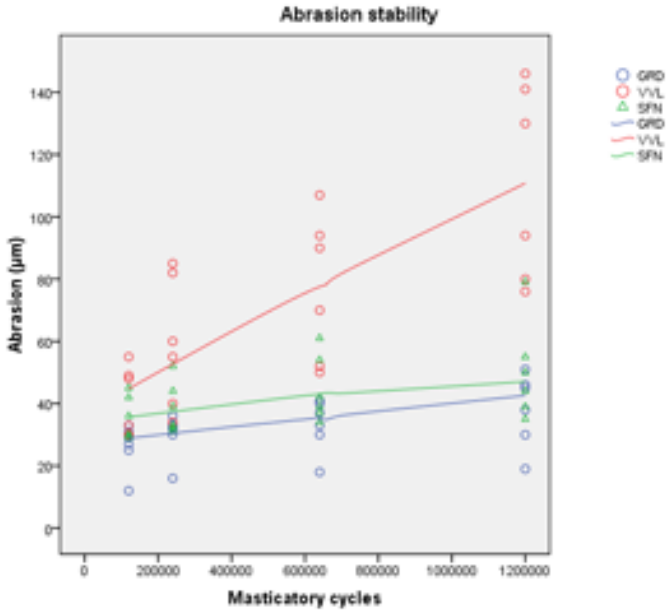


B



C

Fig. 5. Diagram of material loss after mechanical thermocycling loading (abrasion resistance) for each veneering composite at each aging level (GRD = GC Gradia, VVL = VITA VM LC and SFN = Sinfony).


Abrasion stability
Abrasion (µm)
Masticatory cycles
0
20
40
60
80
100
120
140
0
200000
400000
600000
800000
1000000
1200000
GRD
VVL
SFN
GRD
VVL
SFN