Mechanical and optical properties of indirect veneering resin composites after different aging regimes

Bogna STAWARCZYK¹, Michael BRAUNEIS¹, Benedikt LANGWIEDER¹, Sebastian SPINTZYK², Marlis EICHBERGER¹ and Anja LIEBERMANN¹

¹ Department of Prosthetic Dentistry, University Hospital, LMU Munich, Goethestrasse 70, 80336 Munich, Germany

² Section Medical Materials Science and Technology, University Hospital Tübingen, Osianderstraße 2-8, 72076 Tübingen, Germany

Corresponding author, Anja LIEBERMANN; E-mail: Anja.Liebermann@med.uni-muenchen.de

This study tested and compared properties of six modern indirect veneering resin composites (VRC), namely Ceramage (Shofu), dialog Vario (Schütz Dental), Gradia Plus (GC Europe), in:joy (Dentsply), Signum composite (Heraeus Kulzer), and SR Nexco (Ivoclar Vivadent). Specimens were fabricated from dentin and enamel pastes and following properties were analyzed: (1) two-body wear (TB), (2) surface roughness (SR), (3) Martens hardness parameters (HM and E_{IT}), and (4) translucency (T). The highest impact on HM and E_{IT} was exerted by VRC brand (HM: $\eta_P^2=0.960$ / E_{IT} : $\eta_P^2=0.968$; $p<0.001$), followed by VRC paste material (HM: $\eta_P^2=0.502$ / E_{IT} : $\eta_P^2=0.580$; $p<0.001$), and aging duration (HM: $\eta_P^2=0.157$ / E_{IT} : $\eta_P^2=0.112$; $p<0.001$). Lowest and highest TB were measured for Signum composite and dialog Vario, respectively ($p<0.001$). Highest T was showed Signum composite and Ceramage ($p<0.001$). VRCs should be individually selected with respect to the indication area, due to different surface properties.

Keywords: Veneering resin composite, Two-body wear, Martens hardness, Surface roughness, Translucency

INTRODUCTION

Modern indirect veneering resin composites are indicated for extraorally made restorations, *e.g.* inlays, onlays, or so-called “chips” (ultra-thin occlusal onlays) as a non- or minimally invasive therapy option or for implant-supported removable dentures as well as veneering material in fixed dental prostheses (FDP)^{1,2}. Veneering resin composites are comparable to direct filling resin composites concerning their chemical structure. A three-dimensional matrix network of polymerized organic monomers surrounds inorganic fillers. In today's dental practice, mostly homogenous and inhomogeneous microfiller resin composites as well as hybrid resin composites are used. Macrofiller resin composites —*e.g.* those containing milled fillers of quartz, glass, borosilicate, or ceramic with an average size of 0.1 to 100 μm — are difficult to polish and therefore play a minor role. Among other things, the filler selected and its silanization quality have an influence on the surface roughness and Martens hardness parameters as well as the resulting two-body wear of composites. Microfilled resin composites further seem to be inferior to hybrid composites in terms of surface hardness, elastic modulus, and two-body wear³⁻⁷. Compared to direct filling resin composites, indirect veneering resin composites are treated with a longer polymerization time, or even additional heat or pressure treatment, depending on the setting of the initiator system⁸. Properties such as hardness parameters or two-body wear of resin composites presumably increase with the conversion rate —as the actual rate of reaction— as more chemical bonds

are formed and fewer free double bonds are present, which may be responsible for degenerative processes^{8,9}. During this polymerization process, however, tensions can arise within the composite structure, possibly leading to cracking and water absorption, which have mostly been investigated in direct composites¹⁰⁻¹⁴. This might also negatively affect the material's properties.

Concerning optical properties, the more inorganic fillers in the composite, the opaquer the material¹⁵. The translucency of dental material —ceramics and resin composites— is influenced by factors such as ceramic particles, grain size, and pigments, as well as the number, size, and distribution of defects, and porosity^{16,17}. If the crystals are smaller than the wavelength of visible light (400 to 700 nm) the glass will appear transparent; however, in the case of light scattering and a diffuse reflection, the material will appear opaque¹⁵. For nanofillers, the particle sizes can lead to greater translucency —often analyzed by spectrophotometers— because particles with a diameter smaller than the wavelength of visible light cause less light scattering and absorbance^{18,19}. However, very few studies on properties of veneering resin composites are currently available.

The present *in vitro* investigation therefore assessed various properties of six modern indirect veneering resin composites, as well as the different veneering pastes (dentin/enamel): two-body wear after chewing simulation (TB), surface roughness (SR), Martens hardness (HM) and elastic indentation modulus (E_{IT}) after thermal cycling, as well as the translucency (T). The null hypothesis of this investigation is that all veneering resin composites tested are comparable with respect to all surface properties tested.

Color figures can be viewed in the online issue, which is available at J-STAGE.

Received Sep 12, 2019; Accepted Apr 8, 2020

doi:10.4012/dmj.2019-307 JOI JST.JSTAGE/dmj/2019-307

MATERIALS AND METHODS

The veneering resin composites (Table 1) were manually pressed into a silicone form (picodent twinduo extrahart, picodent, Wipperfurth, Germany) fabricated in advance on the basis of a specimen prototype, and disc-shaped specimens (diameter: 12 mm, thickness: 1.4 ± 0.01 mm) were manufactured. Except for SR Nexco which was fabricated just with enamel-based specimens, specimens of the materials tested were fabricated from both dentin and enamel paste to analyze possible differences in their surface properties. The veneering resin composites were polymerized according to manufacturer's instructions (Table 1). The TB specimens were embedded in an acrylic resin (Scandiform/ScandiQuick, SCAN-DIA, Hagen, Germany). All specimens were ground and polished with a series of silicon carbide (SiC) papers up to P1200 (HM/ET) and P4000 (TB, R_a, T) at 150 rpm for each paper for 10 s under constant water cooling (Struers Abramin, Struers, Ballerup, Denmark). Specimen thickness was controlled with a digital micrometer with a sensitivity of 0.001 mm (IP65, 0–25 mm; Mitutoyo, Aurora, IL, USA). The specimens were cleaned in an ultrasonic bath (Transistor/Ultrasonics, L&R, Kearny, NJ, USA) in distilled water for 10 min. Specimens for TB, SR, and T measurements were stored in distilled water for 24 h at 37°C and then tested.

TB was measured for all enamel pastes (N=96, $n=16$ per enamel veneering resin composite). As antagonists, extracted human molars (optically healthy teeth, predominantly third molars) from various dental practices in Munich were collected and assessed optically with the naked eye. After extraction, the teeth were stored for seven days at room temperature at 23°C in chloramine T (0.5%, Sigma-Aldrich Laboratory Chemicals, Seelze, Germany) and then in distilled water at 4°C in a refrigerator for a maximum of 6 months. The mesiobuccal cusp tip was separated from the rest of the tooth crown with a diamond cutting disc on a dental handpiece (4 mm thick). The base was designed to have an approximately 90° angle to the bump axis and was provided with horizontal retention grooves to achieve the subsequent fixation with amalgam (Dispersalloy, Dentsply Sirona, York, PA, USA) in the holders provided (Fig. 1). The cusp tip was given the shape of a lying hemisphere on a drill press with a diamond-tipped profile drill (40 µm) under constant wetting and low pressure in order to create standardized initial conditions. Specimens were aged for 480,000 cycles with a load of 50 N and a frequency of 1.2 Hz in a chewing simulator (Chewing Simulator CS-4, SD Mechatronics, Feldkirchen-Westerham, Germany). To determine material loss, the surfaces of the specimens and antagonists were digitized before aging (baseline) and after 480,000 chewing cycles (LASERSCANNER LAS-20, SD Mechatronics). All datasets before (baseline) and after wear simulation were superimposed using a three-notch alignment and match-3D procedure, and images were generated to display the differences. The volume material and antagonist loss were computed using

Fig. 1 Set-up of enamel antagonists for TB measurements: mesiobuccal cusp tip separated from tooth embedded in amalgam.

the 3D inspection and mesh processing software GOM (GOM Inspect 2016). Qualitative surface observations were made using scanning electron microscopy (SEM; LEO 1430, Zeiss, Oberkochen, Germany). The SEM images were taken three times, operating at 10 kV with a working distance of 18–21 mm. All specimens were sputter-coated with gold–palladium using a sputter coater (SCD 005, Bal-Tec, Balzers, Liechtenstein).

SR measurements were determined profilometrically (MarSurf M400, Mahr, Göttingen, Germany). The specimens (N=60, $n=10$ per enamel veneering resin composite) were placed under the measuring needle so that the needle scanned the specimen about midway with a length of 5 mm. This process was carried out three times on each specimen in the longitudinal direction and three times in the transverse direction. Each specimen was displaced by approximately two millimeters between each measurement to avoid double-scanning any measured length.

The HM and E_{IT} measurements (N=110, $n=10$ per enamel and dentin veneering resin composite) were conducted using a Universal Hardness Testing Machine (Zwick/Roell ZHU 0.2/Z2.5, Zwick, Ulm, Germany) immediately after fabrication (initial), as well as after 4 h (250 cycles) and 1 (1,500 cycles), 7 (10,500 cycles), 14 (21,000 cycles), and 28 days (42,000 cycles) of aging in a thermocycler filled with distilled water (Aqua Bidest, Kerndl, Weissenfeld, Germany) with changing of baths between 5°C and 55°C. The diamond indenter pyramid ($\alpha=136^\circ$) of the hardness-testing machine was pressed vertically into the specimen with a load of 10 N for 20 s with a maximum penetration depth of 0.05 mm. The HM was calculated as follows:

Table 1 Summary of veneering resin composites used with type of composite paste, color shade, lot. no., composite type, manufacturer, composition, and curing procedure with irradiance as well as wavelength of curing unit in alphabetical order

Product name	Paste type	Color shade	Lot.No.	Type of veneering resin composite	Manufacturer	Composition	Curing unit/time* (Watt/W)	Irradiance curing unit (Watt/W)	Wavelength curing unit (nm)
Ceramage Incisal	enamel	59	101671	Microhybrid	Shofu, Kyoto, Japan	5–15% UDMA; 73 wt% ZrSiO ₄ filler	Solidilite V (Shofu) for 3 min	600	400–500
Ceramage Body	dentin	A3B	111688						
dialog Vario Occlusal	enamel	A59	2017002801	Microhybrid	Schütz Dental, Rosbach, Germany	UDMA, Bis-GMA, BDMA; 74 wt% glass filler, pyrogenic silica	HiLite (Kulzer) for 3 min	3 (LED)	peak: 405
dialog Vario	dentin	A3	2017002799						
Gradia Plus Heavy Body Enamel	enamel	HB-ED	1703131	Nanohybrid	GC Europe, Leuven, Belgium	1–5% Bis-GMA, 5–10% TEGDMA, 1–5% UDMA; ceramic filler	Labolight Duo (GC Europe) for 3 min	—	380–510
Gradia Plus Heavy Body Dentine	dentin	HB-DA3	1703141						
in.joy incisal	enamel	medium	10055979	Microhybrid	Dentsply Sirona, Konstanz, Germany	≤5% Decandiol-DMA, ≤5% TEGDMA; 55 wt% prepolymer filler, pyrogenic silica, glass	Eclipse Junior 10 min Program „final“	150	400–500
in.joy dentine	dentin	A3	10055359						
Signum composite enamel	enamel	EL	010516A	Microhybrid	Kulzer, Hanau, Germany	Decandiol-DMA, TEGDMA; 74 wt% SiO ₂ filler, polymerisate splitter	HiLite for 3 min	3 (LED)	peak: 405
Signum composite dentine	dentin	DA3	010530A						
SR Nexco Paste Incisal	enamel	I3	W04319	Nanohybrid	Ivoclar Vivadent, Schaan, Liechtenstein	3–10% Decandiol-DMA, 1–2.5% UDMA, 1–2.5% TCDMMA; 82–83 wt% prepolymer filler, SiO ₂ , Micro-Opal-filler	HiLite for 3 min	3 (LED)	peak: 405

$$HM = \frac{F}{A_s(h)} = \frac{F}{26.43xh^2}$$

where HM : Martens hardness (N/mm²); F : test force (N); $A_s(h)$: surface area of the indenter at distance h from the tip (mm²).

E_{IT} was calculated with the following equation:

$$E_{IT} = (1 - \nu_s^2) \left(\frac{2\sqrt{A_p(h_c)}}{\sqrt{\pi s}} - \frac{(1 - \nu_i^2)}{E_i} \right)^{-1}$$

where E_{IT} : elastic indentation modulus of the indenter (Vickers pyramid) (kN/mm²); ν_s : Poisson ratio of the specimen; ν_i : Poisson ratio of the indenter.

For T measurements, the Martens hardness specimens before the aging procedure were used. T was determined ($N=60$, $n=10$ per enamel veneering resin composite) using a Lambda 35 UV/VIS Spectrometer (PerkinElmer, Waltham, MA, USA) and the corresponding PerkinElmer UV WinLab software (UV Win Lab™ 2.8; Perkin Elmer). The measurement was carried out within the visible light spectrum between 400 and 700 nm wavelength with the following settings: ordinate mode: T%; slit width (nm): 2; scan speed (nm/min): 480; date interval (nm): 1; cycle number: 1; “cycle as fast as possible”. The light quantity was measured with no specimen in the optical path (L_{source}) before each measurement and served as the baseline value. Then the luminance (L_{specimen}) was recorded and calculated for each specimen:

$$T\% = (L_{\text{specimen}} / L_{\text{source}}) \times 100.$$

Statistical Package for the Social Sciences Version 25 (IBM SPSS, Chicago, IL, USA) was used for calculating the descriptive statistics. The normality of

data distribution for each parameter was tested with the Kolmogorov–Smirnov test, separately. For analysis of Martens hardness parameters, TB values, and SR, non-parametric tests such as Kruskal–Wallis, Mann–Whitney U , and Wilcoxon tests were used. T data was analyzed parametrically using one-way ANOVA followed by Scheffé *post hoc* test. Correlations were determined using Spearman's rho test. Results of statistical analyses with p -values less than 0.05 were interpreted as statistically significant.

RESULTS

The TB results presented significant differences between the materials tested within the veneering resin composite side ($p<0.001$), enamel antagonist side ($p<0.001$), and within the pooled data (veneering resin composite and enamel antagonist; $p<0.001$) (Table 2). For Signum composite, less material loss on the veneering resin composite side was seen compared to dialog Vario ($p=0.008$) and Gradia Plus ($p=0.011$). Within the enamel antagonist side, dialog Vario ($p<0.001$ – $p=0.005$) showed the greatest material loss, however with no difference to that observed for Gradia Plus ($p=0.089$). Signum composite ($p<0.001$), in:joy ($p<0.001$), and SR Nexco ($p<0.001$) revealed less material loss than Ceramage, Gradia Plus, and dialog Vario. Ceramage presented less material loss than dialog Vario ($p=0.005$), but more than Signum composite ($p<0.001$), in:joy ($p<0.001$), and SR Nexco ($p=0.001$) (Fig. 2). Within the pooled data (both sides, material and antagonist), the smallest material loss was observed for Signum composite ($p<0.001$), in:joy ($p<0.001$), and SR Nexco ($p=0.001$ – $p=0.038$) and the highest values were observed for dialog Vario ($p<0.001$), followed by Gradia Plus ($p<0.001$ – $p=0.038$). The qualitative characterization of wear for all veneering

Table 2 Descriptive statistics [mean±SD (standard deviation)] for two-body wear (TB), surface roughness (SR), and translucency (T) results for all enamel pastes

Enamel paste of veneering resin composite	TB of veneering resin material surface (μm ³)	TB of enamel antagonist surface (μm ³)	TB of veneering resin composite surface+enamel antagonist surface (μm ³)	Surface roughness (μm)	Translucency (%)
Ceramage	0.261±0.084 ^{ab}	0.212±0.062 ^{*b}	0.559±0.133 ^{*ab}	0.043±0.007 ^{*b}	49.0±0.4 ^b
dialog Vario	0.331±0.058 ^b	0.286±0.063 ^c	0.616±0.109 ^c	0.050±0.009 ^{*b}	44.5±0.3 ^a
Gradia Plus Heavy Body	0.328±0.084 ^b	0.231±0.063 ^{bc}	0.473±0.137 ^{bc}	0.051±0.009 ^b	45.2±0.5 ^a
in:joy	0.238±0.072 ^{ab}	0.124±0.024 ^a	0.362±0.086 ^a	0.031±0.006 ^a	48.5±0.6 ^b
Signum composite	0.219±0.068 ^a	0.122±0.031 ^a	0.341±0.089 ^a	0.030±0.005 ^a	54.6±0.8 ^c
SR Nexco Paste	0.291±0.092 ^{ab}	0.127±0.035 ^{*a}	0.418±0.116 ^a	0.029±0.005 ^a	48.5±0.6 ^b

* non-normally distributed data

^{abc} letters presented significant differences between the veneering resin composites tested. Different letters showed different homogeneous groups.

resin composites is summarized in Fig. 3. The evaluations with SEM showed damage in the form of cracks on the Ceramage and in:joy surfaces.

After polishing, SR Nexco, Signum composite, and in:joy presented significantly lower SR than Ceramage, dialog Vario, and Gradia Plus ($p<0.001$) (Table 2).

The strongest influence on HM and E_{IT} was exerted by the veneering resin composite brand (partial eta squared HM: $\eta_p^2=0.960$; E_{IT} : $\eta_p^2=0.968$; $p<0.001$), followed by the resin composite paste material (HM: $\eta_p^2=0.502$; E_{IT} : $\eta_p^2=0.580$; $p<0.001$) and aging duration (HM: $\eta_p^2=0.157$; E_{IT} : $\eta_p^2=0.112$; $p<0.001$). The effect of the binary combination was significant only for the combinations veneering resin composite coupled with resin composite paste (HM: $\eta_p^2=0.589$; E_{IT} : $\eta_p^2=0.663$; $p<0.001$), and veneering resin composite coupled with aging duration (HM: $\eta_p^2=0.272$; E_{IT} : $\eta_p^2=0.214$; $p<0.001$). In general, comparable outcomes were observed for HM and E_{IT} (Tables 3 and 4).

No impact of veneering resin composite paste

Fig. 2 Two-body wear of different veneering resin composites (μm^3) as well as enamel antagonists (μm^3) in alphabetical order.

(enamel vs dentin) was observed for in:joy or Signum composite ($p=0.143$ – 0.971), regardless of the aging duration. Gradia Plus ($p<0.001$ – 0.015) and Ceramage ($p<0.001$ – 0.007) presented higher Martens hardness parameters for enamel than for dentin for all aging durations. From an aging duration of 250 thermocycles, dialog Vario also showed higher Martens hardness parameters for enamel than for dentin ($p=0.001$ – 0.024).

The lowest values of Martens hardness parameters were seen for in:joy with Signum composite, followed by SR Nexco, while dialog Vario and Ceramage presented the highest values ($p<0.001$). Detailed statistical differences are presented in Tables 3 and 4.

For dialog Vario ($p<0.001$), a decrease of Martens hardness parameters was observed after 10,500 thermocycles. in:joy specimens aged for 1,500 cycles presented higher Martens hardness parameters than specimens aged for 42,000 cycles (HM: $p=0.007$, E_{IT} : $p=0.001$). Signum composite specimens showed initial values higher than those after thermal cycling ($p<0.001$). In contrast, Gradia Plus initial values were lower than those after thermal cycling ($p<0.001$). SR Nexco (HM: $p=0.098$; E_{IT} : $p=0.389$) and Ceramage (HM: $p=0.191$; E_{IT} : $p=0.264$) presented no impact of aging duration on Martens hardness parameters.

Different T values were analyzed for the veneering resin composites tested ($p<0.001$). The highest T was measured for Signum composite, followed by those for Ceramage, SR Nexco, and in:joy. The lowest T values were observed for dialog Vario and Gradia Plus (Table 2).

Correlations were found for all parameters tested in this study. Positive correlations were calculated between TB results and SR ($R=0.446$; $p<0.001$), HM ($R=0.609$; $p<0.001$), and E_{IT} ($R=0.601$; $p<0.001$), between SR and HM ($R=0.690$; $p<0.001$) and E_{IT} ($R=0.707$; $p<0.001$), and between HM and E_{IT} ($R=0.982$; $p<0.001$). Negative

Fig. 3 SEM image for each veneering resin composite after aging in the chewing simulator.

Table 3 Descriptive statistics for Martens hardness (HM) in MPa of each veneering resin composite for different aging levels with enamel and dentin paste materials separately in alphabetical order

Veneering resin composite	Veneering resin composite paste	0 cycles	250 cycles	1,500 cycles	10,500 cycles	21,000 cycles	42,000 cycles
Ceramage	enamel	505±26.5 ^c	500±14.1 ^d	508±17.6 ^d	488±16.1 ^d	493±24.7 ^d	498±9.2 ^e
	dentin	489±18.9 ^e	468±20.0 ^d	473±22.5 ^d	451±48.0 ^{*c}	450±44.2 ^{*c}	456±16.0 ^d
dialog Vario	enamel	572±13.5 ^d	547±22.6 ^e	540±17.9 ^e	498±35.8 ^d	500±18.1 ^d	510±14.4 ^e
	dentin	441±19.4 ^d	427±17.1 ^c	424±10.5 ^c	401±25.2 ^{*c}	392±14.8 ^b	392±18.4 ^c
Gradia Plus Heavy Body	enamel	388±14.2 ^b	414±15.4 ^c	434±23.8 ^{*c}	418±8.7 ^c	418±7.7 ^c	413±4.5 ^d
	dentin	353±16.1 ^c	386±24.8 ^b	396±28.4 ^b	394±10.3 ^b	371±36.1 ^b	380±13.6 ^c
in:joy	enamel	278±21.8 ^a	275±12.3 ^a	283±8.9 ^a	274±9.5 ^a	268±11.4 ^a	264±9.5 ^a
	dentin	280±10.3 ^a	275±12.3 ^a	278±9.0 ^a	273±10.4 ^a	263±17.4 ^a	261±13.6 ^a
Signum composite	enamel	305±11.4 ^{*a}	296±11.0 ^a	294±13.8 ^{*a}	287±6.1 ^a	277±16.4 ^{*a}	288±5.6 ^b
	dentin	308±10.3 ^{*b}	295±11.0 ^a	299±6.6 ^a	294±5.6 ^a	290±7.5 ^a	289±5.1 ^a
SR Nexco Paste	enamel	367±17.3 ^b	357±7.8 ^b	371±9.8 ^b	364±10.3 ^b	367±10.5 ^b	360±10.6 ^c

* group not normally distributed

^{abc} letters presented significant differences between the resin composite pastes (enamel and dentin separately) of the six veneering resin composites tested, within one aging level. Different letters indicated different homogeneous groups.

Table 4 Descriptive statistics for elastic indentation modulus (E_{IT}) in kN/mm² of each veneering resin composite for different thermocycles number with enamel and dentin materials separately in alphabetical order

Veneering resin composite		0 cycles	250 cycles	1,500 cycles	10,500 cycles	21,000 cycles	42,000 cycles
Ceramage	enamel	12.4±0.5 ^d	12.1±0.5 ^d	12.4±0.4 ^d	12.0±0.4 ^d	12.0±0.4 ^d	12.1±0.4 ^d
	dentin	11.1±0.5 ^d	10.8±0.7 ^c	10.9±0.7 ^c	10.3±1.5 ^c	10.3±1.1 ^c	10.5±0.6 ^c
dialog Vario	enamel	13.5±0.3 ^e	13.1±0.4 ^e	12.6±1.1 ^{*d}	11.8±1.1 ^d	12.1±0.5 ^d	12.2±0.6 ^d
	dentin	9.8±0.3 ^c	9.7±0.2 ^b	9.6±0.2 ^c	9.1±0.5 ^{*b}	8.9±0.3 ^b	8.9±0.5 ^{*b}
Gradia Plus Heavy Body	enamel	9.5±0.3 ^c	10.0±0.4 ^{*c}	10.1±0.4 ^c	10.1±0.3 ^c	10.1±0.2 ^c	10.0±0.1 ^c
	dentin	8.8±0.3 ^b	10.0±0.4 ^b	9.8±0.4 ^b	9.8±0.2 ^{bc}	9.3±0.5 ^b	9.3±0.3 ^b
in:joy	enamel	6.0±0.5 ^a	5.9±0.2 ^a	6.0±0.2 ^{*a}	5.8±0.2 ^{*a}	5.7±0.2 ^{*a}	5.5±0.3 ^a
	dentin	6.0±0.2 ^a	275±12.3 ^a	5.9±0.2 ^a	5.8±0.2 ^a	5.7±0.2 ^a	5.6±0.2 ^a
Signum composite	enamel	6.4±0.2 ^a	6.0±0.3 ^a	6.2±0.3 ^a	6.0±0.1 ^a	5.8±0.2 ^a	5.9±0.2 ^a
	dentin	6.4±1.3 ^a	6.2±0.2 ^{*a}	6.3±0.2 ^{*a}	6.1±0.1 ^{*a}	6.1±0.1 ^{*a}	6.1±0.1 ^{*a}
SR Nexco Paste	enamel	8.3±0.4 ^b	8.2±0.2 ^{*b}	8.4±0.2 ^b	8.3±0.2 ^b	8.3±0.2 ^b	8.2±0.3 ^b

* group not normally distributed

^{abc} letter presented significant differences between the tested groups. Different letters showed different homogeneous groups.

correlations were observed between T values and TB ($R=-0.496$; $p<0.001$), SR ($R=-0.596$; $p<0.001$), HM ($R=-0.554$; $p<0.001$), and E_{IT} ($R=-0.590$; $p<0.001$).

DISCUSSION

The null hypotheses of this investigation, that all

veneering resin composites tested present comparable results with respect to TB, SR, HM, E_{IT} , and T, were rejected. All veneering resin composites tested presented differences in their properties. Signum composite and in:joy showed the highest material loss and caused the lowest material loss on the enamel antagonist. These results correlate with other studies in which differences between veneering resin composites²⁰ and/or CAD/CAM composites were determined^{21,22}. No precise cause for the increased material loss of the veneering resin composite itself and the enamel antagonist for dialog Vario could be found specifically from the composition. Influencing factors are generally the size, shape, and amount of fillers, the chemical composition, and the matrix as well as the silanization and incorporation of fillers within the matrix^{4,23–25}. A different influence of thermal load changes on the material is also conceivable²⁰. For the present investigation, the filler content of the veneering resin composites was apparently less decisive for their abrasive behavior, in contrast to other investigations^{23,25,26}. Signum composite, containing 74 wt% fillers, behaved similarly to in:joy with a filler content of only 55 wt%. Differences were additionally observed for dialog Vario with 74 wt% and SR Nexco with 82–83 wt% fillers, for example in having a higher material loss than the two veneering resin composites mentioned before (Table 2; Fig. 2). Consequently, this result shows that it is not only the filler content that is responsible for the resulting properties. For the abrasion resistance of nanofilled composites, a high filler content above a threshold value tends to have a negative effect on abrasion resistance²⁷. It is striking, however, that the veneering resin composites in:joy, Signum composite, and SR Nexco, being microfilled or filled with filler silicon dioxide and prepolymers, caused the slightest loss of substance in the opposing enamel antagonist. This tendency also coincides with another investigation²⁸. In addition, a correlation with hardness abrasion behavior was established in another investigation²⁹. It was shown that the higher the hardness values, the higher the volume loss of the tested material. However, that study cannot be directly compared to the present investigation as only CAD/CAM materials were analyzed. One explanation may be the porosity of the SiO₂ fillers, which ensures penetration of the matrix and thus a strong filler–matrix bond³⁰, so that the fillers are less soluble and can act as abrasive particles. The combination of low wear on the antagonist and moderate material wear on the veneering resin composite itself meant that Signum composite, in:joy, and Ceramage had less loss of height. Maintaining the vertical dimension of the teeth is critical to balancing the biomechanical, functional, and neuromuscular interactions of the stomatognathic system. Esthetic consequences and craniomandibular dysfunction may result from disturbance of this balance³¹.

An overview of the abrasions on the specimens was made visible using SEM images (Fig. 3), presented with different measuring bars. Evident are the abrasion troughs caused by the enamel antagonist. Depending

on the material, the geometry of the troughs varied. Use of a highly abrasive antagonist, such as dialog Vario or Gradia Plus, led to an increase in the contact surface due to the hemispherical design of the enamel antagonists. Consequently, the abrasion troughs became wider and flatter. Conversely, the antagonists of the antagonist-friendly materials were more likely to cause deeper wells of smaller diameter. However, it should be mentioned that the diameter of the troughs increased with increasing penetration depth of the antagonists due to geometry.

Concerning SR, the veneering resin composite values were well below the required value of 0.2 μ m described in the scientific literature^{32,33}. The results obtained can be partially compared with the results of other studies^{20,34}. Differences in the polishing processes, however, limit the comparability. The surface condition is dependent on the composition of the resin composite, in particular of the fillers it contains and their size, number, and distribution. In addition, the hardness, flexibility, and grain size of the polishing agents play a crucial role in polishing^{23,35–38}. In the case of resin composites, fillers are embedded in a polymer matrix, which is softer than the filling bodies and therefore tends to be removed during polishing, so that the filling bodies partially protrude. In the literature, a finer filler and a higher content are therefore described as decisive factors for lower SR³⁷. This hypothesis is in line with the results obtained in the present investigation, as the lowest SR values were observed for the nanohybrid composite SR Nexco with the highest packing content of 82–83 wt%. In contrast, in:joy, presenting a lower filler content of 55 wt%, also presented lower SR values with good abrasion resistance. This could perhaps be based on the microhybrid composite structure with a slightly increased filler size.

There are various test methods for the analysis of surface hardness, such as Vickers hardness, Knoop hardness or Martens hardness. Compared to the other static test methods, the analysis of Martens hardness has the advantage that the plastic-elastic properties of a dental material can be analyzed, especially for composite-based materials³⁹. This test method was therefore chosen in the present study.

Concerning Martens hardness parameters (HM and E_{IT}), it is interesting that the veneering resin composites behaved differently with aging. SR Nexco and Ceramage for example presented no influence of aging on Martens hardness parameters. In contrast, Gradia Plus exhibited higher, and dialog Vario as well as in:joy presented lower values after aging. The effect of aging on Gradia Plus can be compared with that observed in a previous study testing its predecessor Gradia²⁰. In the same investigation, the HM of three different veneering resin composites was analyzed initially and after aging, and generally presented lower HM values than observed in the present investigation. Despite the possibly improved composition and further development of the newer materials, however, these results might have been due to a different test method²⁰.

The translucency —the light transmission of a dental material— is determined by means of a spectrophotometer. The values may differ minimally when measured with devices from different manufacturers and therefore cannot be compared exactly on the basis of the value level in the literature. Besides the mentioned properties SR, TB, MH, and E_{IT} , the optical property T also presented significant differences between the veneering resin composites tested. The conclusion of another study, that an increasing amount of the composite fillers leads to increased opacity, however, cannot be confirmed¹⁵. In the present study, for example, SR Nexco with a high filler content (82–83 wt%) presented the same T as in:joy with a significantly lower filler content (55 wt%). It is clear that the translucency of dental composites is strongly influenced by further factors such as filler particles and pigments, as well as the number, size, and distribution of defects, and porosity^{16,17}. T decreased with increasing values of the other properties tested. The negative correlation of T and SR can be confirmed in the literature³⁷, as light is scattered more on a rougher material surface, decreasing translucency values. In addition, with a higher filler content and reduced matrix percentage, T decreases due to scattering as mentioned before, and the parameters MH and E_{IT} as well as TB increase. Further investigation with equal testing arrangements, parameters, and evaluation techniques should be conducted to allow the comparison of research results. Information derived from geometrical specimens needs to be verified in anatomical reconstructions simulating the clinical situation. Of course, clinical studies are necessary to support the use of the tested veneering resin composites for long-term restorations.

A limitation of the present investigation is the manual fabrication of the specimens, as bubbles may have remained in the upper layers of the material when the material was pressed inside the silicone form. These could have led to reduced properties or increased deviations in values. After polymerization, the surface was checked for defects with the naked eye and all specimens were sorted out; however, it was not possible to check slightly deeper layers within the specimen. A further limitation is based on the use of different polymerization units for curing of the six different veneering resin composites. This was done in the present investigation according to the manufacturer's recommendations and could also have influenced the results, in particular influencing the exact comparability of the materials tested.

To conclude, it can be stated that the indirect veneering resin composites tested showed partly significant differences in their properties. These differences need to be considered in the final selection of a veneering resin composite appropriate for the indication area —esthetic anterior or load-bearing posterior area.

CONFLICT OF INTEREST

All authors declare no conflict of interest. This research did not receive any specific grant from funding agencies

in the public, commercial, or not-for-profit sectors. The authors would like to thank the companies Dentsply Sirona, GC Europe, Ivoclar Vivadent, Kulzer, Schütz Dental, and Shofu for providing the investigation with the materials tested.

REFERENCES

- 1) Brunton PA, Cattell P, Burke FJ, Wilson NH. Fracture resistance of teeth restored with onlays of three contemporary tooth-colored resin-bonded restorative materials. *J Prosthet Dent* 1999; 82: 167-171.
- 2) Thordrup M, Isidor F, Hörsted-Bindslev P. A 5-year clinical study of indirect and direct resin composite and ceramic inlays. *Quintessence* 2001; 32: 199-205.
- 3) Rosentritt M, Ilie N, Lohbauer U. Material science in dentistry, part II: dental materials, Chapter 7 Direct and indirect composites. Stuttgart 2018, Thieme.
- 4) Rzanny A, Gobel R, Welker D. Moderne Verblendkunststoffe — eine werkstoffkundliche Studie. *Quintessenz Zahntechnik* 2003; 29: 58-73.
- 5) Ilie N, Kunzelmann K, Hickel R. Werkstoffkundliche Untersuchungen zu Kompositen. *Deutsche Zahnärztliche Zeitschrift* 2005; 60: 321-334.
- 6) De Gee AF, Feilzer AJ, Davidson CL. True linear polymerization shrinkage of unfilled resins and composites determined with a linometer. *Dent Mater* 1993; 9: 11-14.
- 7) Viöhl J. Depth of polymerisation of photopolymerizing filling plastics. [article in German] *Dtsch Zahnärztl Z* 1982; 37: 194-196.
- 8) Borba M, Della Bona A, Cecchetti D. Flexural strength and hardness of direct and indirect composites. *Braz Oral Res* 2009; 23: 5-10.
- 9) Peutzfeldt A. Resin composites in dentistry: the monomer systems. *Eur J Oral Sci* 1997; 105: 97-116.
- 10) Söderholm KJ, Zigan M, Ragan M, Fischlschweiger W, Bergman M. Hydrolytic degradation of dental composites. *J Dent Res* 1984; 63: 1248-1254.
- 11) Øysæd H, Ruyter IE. Composites for use in posterior teeth: mechanical properties tested under dry and wet conditions. *J Biomed Mat Res* 1986; 20: 261-271.
- 12) Söderholm KJ, Roberts M. Influence of water exposure on the tensile strength of composites. *J Dent Res* 1990; 69: 1812-1816.
- 13) Örtengren U, Wellendorf H, Karlsson S, Ruyter IE. Water sorption and solubility of dental composites and identification of monomers released in an aqueous environment. *J Oral Rehabil* 2001; 28: 1106-1115.
- 14) McCabe JF, Rusby S. Water absorption, dimensional change and radial pressure in resin matrix dental restorative materials. *Biomaterials* 2004; 25: 4001-4007.
- 15) Lee YK. Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites. *Dent Mater* 2008; 24: 1243-1247.
- 16) El-Meliegy. Preparation and characterisation of low fusion leucite dental porcelain. *Br Ceram Trans* 2003; 102: 261-264.
- 17) Ilie N, Hickel R. Correlation between ceramics translucency and polymerization efficiency through ceramics. *Dent Mater* 2008; 24: 908-914.
- 18) Van Noort R. Introduction to dental materials - 4th edition: Elsevier Inc. - Mosby Ltd, pp 2013: 231-246.
- 19) Awad D, Stawarczyk B, Liebermann A, Ilie N. Translucency of esthetic dental restorative CAD/CAM materials and composite resins with respect to thickness and surface roughness. *J Prosthet Dent* 2015; 113: 534-540.
- 20) Stawarczyk B, Egli R, Roos M, Özcan M, Hämmerle CH. The impact of in vitro aging on the mechanical and optical

- properties of indirect veneering composite resins. *J Prosthet Dent* 2011; 106: 386-398.
- 21) Wimmer T, Huffmann AM, Eichberger M, Schmidlin PR, Stawarczyk B. Two-body wear rate of PEEK, CAD/CAM resin composite and PMMA: effect of specimen geometries, antagonist materials and test set-up configuration. *Dent Mater* 2016; 32: e127-136.
 - 22) Stawarczyk B, Özcan M, Trottmann A, Schmutz F, Roos M, Hämmerle C. Two-body wear rate of CAD/CAM resin blocks and their enamel antagonists. *J Prosthet Dent* 2013; 109: 325-332.
 - 23) Condon J, Ferracane J. In vitro wear of composite with varied cure, filler level, and filler treatment. *J Dent Res* 1997; 76: 1405-1411.
 - 24) Oliveira GU, Mondelli RF, Charantola Rodrigues M, Franco EB, Ishikiriyama SK, Wang L. Impact of filler size and distribution on roughness and wear of composite resin after simulated toothbrushing. *J Appl Oral Sci* 2012; 20: 510-516.
 - 25) Manhart J, Kunzelmann KH, Chen HY, Hickel R. Mechanical properties of new composite restorative materials. *J Biomed Mater Res* 2000; 53: 353-361.
 - 26) St Germain H, Swartz ML, Phillips RW, Moore BK, Roberts TA. Properties of microfilled composite resins as influenced by filler content. *J Dent Res* 1985; 64: 155-160.
 - 27) Lawson NC, Burgess JO. Wear of nanofilled dental composites at varying filler concentrations. *J Biomed Mater Res B Appl Biomater* 2015; 103: 424-429.
 - 28) Heintze SD, Faouzi M, Rousson V, Ozcan M. Correlation of wear in vivo and six laboratory wear methods. *Dent Mater* 2012; 28: 961-973.
 - 29) Lawson NC, Bansal R, Burgess JO. Wear, strength, modulus and hardness of CAD/CAM restorative materials. *Dent Mater* 2016; 32: e275-e283.
 - 30) Knobloch LA, Kerby RE, Seghi R, van Putten M. Two-body wear resistance and degree of conversion of laboratory-processed composite materials. *Int J Prosthodont* 1999; 12: 432-438.
 - 31) Dietschi D, Argente A. A comprehensive and conservative approach for the restoration of abrasion and erosion. Part I: concepts and clinical rationale for early intervention using adhesive techniques. *Eur J Esthet Dent* 2011; 6: 20-33.
 - 32) Bollen CML, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. *Dent Mater* 1997; 13: 258-269.
 - 33) Quirynen M, Marechal M, Busscher HJ, Weerkamp AH, Darius PL, van Steenberghe D. The influence of surface free energy and surface roughness on early plaque formation. An in vivo study in man. *J Clin Periodontol* 1990; 17: 138-144.
 - 34) Rzanny A, Göbel R, Küpper C. Moderne Verblendkomposite – ein werkstoffkundlicher Vergleich. *Dtsch Zahnärztl Z* 2007; 62: 733-746.
 - 35) Li Y, Swartz M, Phillips R, Moore B, Roberts T. Materials science effect of filler content and size on properties of composites. *J Dent Res* 1985; 64: 1396-1403.
 - 36) Pratten DH, Johnson GH. An evaluation of finishing instruments for an anterior and a posterior composite. *J Prosthet Dent* 1988; 60: 154-158.
 - 37) Strassler HE, Bauman G. Current concepts in polishing composite resins. *Pract Periodont Aesthet Dent* 1993; 5: 12-17.
 - 38) De Gouvea CV, Bedran LM, de Faria MA, Cunha-Ferreira N. Surface roughness and translucency of resin composites after immersion in coffee and soft drink. *Acta Odontol Latinoam* 2011; 24: 3-7.
 - 39) Shahdad SA, McCabe JF, Bull S, Rusby S, Wassell RW. Hardness measured with traditional Vickers and Martens hardness methods. *Dent Mater* 2007; 23: 1079-1085.