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

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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\text{IT}), and (4) translucency (T). The highest impact on HM and E\text{IT} was exerted by VRC brand (HM: \eta_p=0.960/ E\text{IT}: \eta_p=0.968; p<0.001), followed by VRC paste material (HM: \eta_p=0.502/ E\text{IT}: \eta_p=0.580; p<0.001), and aging duration (HM: \eta_p=0.157/ E\text{IT}: \eta_p=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)\textsuperscript{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 \mu m— 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 wear\textsuperscript{3-7}. 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 system\textsuperscript{8}. 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\textsuperscript{9,10}. 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 composites\textsuperscript{10-14}. This might also negatively affect the material’s properties.

Concerning optical properties, the more inorganic fillers in the composite, the opaquer the material\textsuperscript{15}. 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\textsuperscript{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 opaque\textsuperscript{15}. 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\textsuperscript{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\text{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.
MATERIALS AND METHODS

The veneering resin composites (Table 1) were manually pressed into a silicone form (picodent twinduo extrahart, picodent, Wipperfürth, 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/E) and P4000 (TB, R, 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-Westernham, Germany). To determine material loss, the surfaces of the specimens and antagonists were digitized before aging (baseline) and after 480,000 chewing cycles (LASERSCANNER LAS20, 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 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 to two millimeters between each measurement to avoid double-scanning any measured length.

The HM and E<sub>T</sub> 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 (α=136°) 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:
| Product name                  | Paste type | Color shade | Lot.No.  | Type of veneering resin composite | Manufacturer                      | Composition                                                                 | Curing unit/time* | Irradiance curing unit (Watt/W) | Wavelength curing unit (nm) |
|------------------------------|------------|-------------|----------|-----------------------------------|-----------------------------------|------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------|
| Ceramage Incisial enamel     | enamel     | 59          | 101671   | Microhybrid                       | Shofu, Kyoto, Japan               | 5–15% UDMA; 73 wt% ZrSiO$_4$ filler                                        | Solidlite V      | 600                             | 400–500                     |
| Ceramage Body dentin         | dentin     | A3B         | 111688   | Microhybrid                       | Schütz Dental, Rosbach, Germany   | UDMA, Bis-GMA, BDMA; 74 wt% glass filler, pyrogenic silica                  | HiLite           | 3 (LED)                         | peak: 405                   |
| dialog Vario Occlusal enamel | enamel     | A59         | 2017002801 | Microhybrid                       | GC Europe, Leuven, Belgium        | 1–5% Bis-GMA, 5–10% TEGDMA, 1–5% UDMA; ceramic filler                     | Labolight Duo    | —                               | 380–510                     |
| dialog Vario dentin          | dentin     | A3          | 2017002799 | Microhybrid                       | GC Europe, Leuven, Belgium        | 1–5% Bis-GMA, 5–10% TEGDMA, 1–5% UDMA; ceramic filler                     | Labolight Duo    | —                               | 380–510                     |
| 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    | —                               | 380–510                     |
| Gradia Plus Heavy Body Dentine | dentin     | HB-DA3      | 1703141   | Nanohybrid                        | GC Europe, Leuven, Belgium        | 1–5% Bis-GMA, 5–10% TEGDMA, 1–5% UDMA; ceramic filler                     | Labolight Duo    | —                               | 380–510                     |
| in:joy incisal enamel        | enamel     | medium      | 10055979  | Microhybrid                       | Dentsply Sirona, Konstanz, Germany | ≤5% Decandiol-DMA, ≤5% TEGDMA; 55 wt% prepolymer filler, pyrogenic silica, glass | Eclipse Junior   | 150                             | 400–500                     |
| in:joy dentine dentin        | dentin     | A3          | 10055359  | Microhybrid                       | Dentsply Sirona, Konstanz, Germany | ≤5% Decandiol-DMA, ≤5% TEGDMA; 55 wt% prepolymer filler, pyrogenic silica, glass | Eclipse Junior   | 150                             | 400–500                     |
| Signum composite enamel      | enamel     | EL          | 010516A   | Microhybrid                       | Kulzer, Hanau, Germany            | Decandiol-DMA, TEGDMA; 74 wt% SiO$_2$ filler, polymerisate splitter        | HiLite           | 3 (LED)                         | peak: 405                   |
| Signum composite dentine     | dentin     | DA3         | 010530A   | Microhybrid                       | Kulzer, Hanau, Germany            | Decandiol-DMA, TEGDMA; 74 wt% SiO$_2$ filler, polymerisate splitter        | HiLite           | 3 (LED)                         | peak: 405                   |
| SR Nexco Paste Incisal enamel | enamel     | I3          | W04319    | Nanohybrid                        | Ivoclar Vivadent, Schaan, Lieschtenstein | 3–10% Decandiol-DMA, 1–2.5% UDMA, 1–2.5% TCDMA; 82–83 wt% prepolymer filler, SiO$_2$, Micro-Opal-filler | HiLite           | 3 (LED)                         | peak: 405                   |
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 (µm³) | TB of enamel antagonist surface (µm³) | TB of veneering resin composite surface+enamel antagonist surface (µm³) | Surface roughness (µm) | Translucency (%) |
|------------------------------------------|---------------------------------------------|--------------------------------------|---------------------------------------------------------------------|------------------------|------------------|
| Ceramage                                 | 0.261±0.084 <sup>ab</sup>                    | 0.212±0.062 <sup>ab</sup>            | 0.559±0.133 <sup>ab</sup>                                           | 0.043±0.007 <sup>ab</sup> | 49.0±0.4 <sup>a</sup> |
| dialog Vario                             | 0.331±0.058 <sup>b</sup>                    | 0.286±0.063 <sup>c</sup>            | 0.616±0.109 <sup>c</sup>                                           | 0.050±0.009 <sup>b</sup> | 44.5±0.3 <sup>a</sup> |
| Gradia Plus Heavy Body                   | 0.328±0.084 <sup>b</sup>                    | 0.231±0.063 <sup>c</sup>            | 0.473±0.137 <sup>c</sup>                                           | 0.051±0.009 <sup>b</sup> | 45.2±0.5 <sup>a</sup> |
| in:joy                                   | 0.238±0.072 <sup>b</sup>                    | 0.124±0.024 <sup>d</sup>            | 0.362±0.086 <sup>c</sup>                                           | 0.031±0.006 <sup>b</sup> | 48.5±0.6 <sup>a</sup> |
| Signum composite                         | 0.219±0.068 <sup>a</sup>                    | 0.122±0.031 <sup>d</sup>            | 0.341±0.089 <sup>c</sup>                                           | 0.030±0.005 <sup>a</sup> | 54.6±0.8 <sup>c</sup> |
| SR Nexco Paste                           | 0.291±0.092 <sup>ab</sup>                    | 0.127±0.035 <sup>ab</sup>            | 0.418±0.116 <sup>a</sup>                                           | 0.029±0.005 <sup>a</sup> | 48.5±0.6 <sup>a</sup> |

* non-normally distributed data
<sup>abc</sup> 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: $\eta^2_p=0.960$; $E_{IT}$: $\eta^2_p=0.968$; $p<0.001$), followed by the resin composite paste material (HM: $\eta^2_p=0.502$; $E_{IT}$: $\eta^2_p=0.580$; $p<0.001$) and aging duration (HM: $\eta^2_p=0.157$; $E_{IT}$: $\eta^2_p=0.112$; $p<0.001$). The effect of the binary combination was significant only for the combinations veneering resin composite coupled with resin composite paste (HM: $\eta^2_p=0.589$; $E_{IT}$: $\eta^2_p=0.663$; $p<0.001$), and veneering resin composite coupled with aging duration (HM: $\eta^2_p=0.272$; $E_{IT}$: $\eta^2_p=0.214$; $p<0.001$). In general, comparable outcomes were observed for HM and $E_{IT}$ (Tables 3 and 4).

No impact of veneering resin composite paste (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
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 paste | Veneering resin composite | 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^d   |
| dentin                         | 489±18.9^e                | 468±20.0^d | 473±22.5^d | 451±48.0^f  | 450±44.2^g  | 456±16.0^d  |
| dialog Vario enamel            | 572±13.5^d                | 547±22.6^c | 540±17.9^c | 498±35.8^d  | 500±18.1^c  | 510±14.4^c  |
| dentin                         | 441±19.4^d                | 427±17.1^c | 424±10.5^c | 401±25.2^a  | 392±14.8^b  | 392±18.4^e  |
| Gradi 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^d                | 386±24.8^b | 396±28.4^b  | 394±10.3^d  | 371±36.1^b  | 380±13.6^c  |
| in:joy enamel                  | 278±21.8^c                | 275±12.3^c | 283±8.9^c   | 274±9.5^c   | 268±11.4^c  | 264±9.5^c   |
| dentin                         | 280±10.3^c                | 275±12.3^c | 278±9.0^c   | 273±10.4^c  | 263±17.4^c  | 261±13.6^c  |
| Signum composite               | 305±11.4^b                | 296±11.0^c | 294±13.8^b  | 287±6.1^c   | 277±16.4^b  | 288±5.6^b   |
| dentin                         | 308±10.3^c                | 295±11.0^c | 299±6.6^c   | 294±5.6^c   | 290±7.5^c   | 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^c | 13.1±0.4^c | 12.6±1.1^e  | 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    |
| Gradi Plus Heavy Body     | 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   |
| enamel                    | 8.8±0.3^b  | 10.0±0.4^b  | 9.8±0.4^c   | 9.8±0.2^c   | 9.3±0.5^c   | 9.3±0.3^c    |
| dentin                    | 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^c    |
| in:joy                    | 6.0±0.2^a  | 275±12.3^c  | 5.9±0.2^a   | 5.8±0.2^a   | 5.7±0.2^a   | 5.6±0.2^a    |
| Signum composite          | 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    |
| enamel                    | 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    |
| dentin                    | 8.3±0.4^b  | 8.2±0.2^e   | 8.4±0.2^c   | 8.3±0.2^b   | 8.3±0.2^a   | 8.2±0.3^b    |

* group not normally distributed
abc letters 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_N, 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 composites and/or CAD/CAM composites were determined. 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. A different influence of thermal load changes on the material is also conceivable. 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. 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 resistance. 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 prepolymer, caused the slightest loss of substance in the opposing enamel antagonist. This tendency also coincides with another investigation. In addition, a correlation with hardness abrasion behavior was established in another investigation. 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 SiO_2 fillers, which ensures penetration of the matrix and thus a strong filler–matrix bond, 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 balance.

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 µm described in the scientific literature. The results obtained can be partially compared with the results of other studies. 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. 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 SR. 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 materials. This test method was therefore chosen in the present study.

Concerning Martens hardness parameters (HM and E_N), it is interesting that 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 Gradia. 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 method.
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 confirmed\(^{15}\). In the present study, for example, SR Nexco with a high filler content (82–83 wt%) presented the same T as injoy 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 decreases with increasing values of the other properties tested. The negative correlation of T and SR can be confirmed in the literature\(^{37}\), 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.

CONFICT OF INTEREST

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