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ORIGINAL ARTICLE

Degree of conversion of nano-hybrid resin-based composites with novel and conventional matrix formulation

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Abstract
Objectives This study aimed to determine the degree of conversion (DC) of two nano-hybrid resin-based composites (RBCs) with novel monomer composition based on dimer acid derivates (hydrogenated dimer acid) and tricyclodecane–urethane structure compared to three nano-hybrid materials containing conventional matrices. DC was evaluated at 0.1, 2, and 6 mm depth at varying irradiation times (10, 20, and 40 s) and layering techniques (bulk and incremental).
Materials and methods DC was measured in real time by a Fourier transform infrared spectroscopy (FTIR) spectrometer with attenuated total reflectance accessory. The FTIR spectra were recorded on the bottom of the samples in real time for 5 min from photoinitiation. Results were compared using one- and multiple-way ANOVA, Tukey's HSD post hoc test (α=0.05), and partial eta-squared statistic.
Results After 5 min of measurement, DC showed no significant difference by varying cure time for specimens of 0.1 mm thickness. At 2 mm depth, the DC significantly increased after a cure time of 20 s compared to 10 s, remaining equal after 40 s of irradiation. At 6 mm depth, bulk curing showed significantly lower DC compared to incremental curing for all polymerization times. Specimen geometry revealed a strong effect on DC (η^2=0.90) followed by curing time (η^2=0.39).
Conclusions The RBCs containing the dimer acid and tricyclodecane–urethane structure showed a relatively low decrease of DC with increasing incremental thickness compared to the conventionally formulated materials. The former reached the highest DC among the tested materials.
Clinical relevance For the tested RBCs, increments of 2 mm and irradiation time of at least 20 s may be recommended for clinical practice. The two materials containing novel monomer composition might be applied for enlarged increments because of the low decrease of DC they demonstrated for 6-mm increments.

Keywords Degree of conversion · Nano-hybrid resin-based composites · Dimer acid derivates · Tricyclodecane–urethane

Introduction

Since the very first dental resin-based composites (RBCs) were developed, many efforts have been undertaken to improve their clinical performance [1, 2]. Research on the resin matrix is mainly based on the development and enhancement of new monomers [1, 3–5] while studies on the filler content focus on improvements of particle composition, size, and loading [1]. In this field, one of the most important advances of the last few years was the incorporation of nanotechnology to dental RBCs [2]. Modern nanohybrid RBCs have shown distinguished properties in regards of both aesthetics as well as mechanical performance [6] and hence have taken position as universal dental filling materials in diverse application ranges [7].

An ideal RBC is considered to exhibit a high degree of conversion (DC) and a minimal polymerization shrinkage [8]. But DC and polymerization shrinkage vary generally antagonistically as an increased chemical interlacing of monomer components, that means a comparatively higher DC, goes along with higher volume shrinkage and vice versa [9–11]. High-volume shrinkage of dental RBCs,

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caused by the chemical network building process [12], clinically induces stress to cavity walls [13]. This may cause gaps or cracks, postoperative sensitivity [14], and secondary caries [15] and impinges upon longevity of dental composite fillings. For this reason, extensive investigations have been undertaken to reduce polymerization shrinkage being based on various approaches, such as the use of high molecular weight monomers [11, 16] or copolymerization with expandable monomers [17]. However, the lower mobility of high molecular weight monomers reduces the final degree of conversion which may in turn introduce problems like release of unreacted monomer components [18] or comparably high water sorption [19]. Following further research, a new class of high molecular weight dimethacrylate monomers derived from a core structure based on hydrogenated dimer acid (h-DA) has been developed for application in the range of dental RBCs. The main characteristic of h-DA is its composition of both linear as well as cyclic aliphatic structures (Fig. 1) [20]. A reduced initial double bond concentration compared to Bis-GMA (bisphenol-A-di(meth) acrylate) could be demonstrated in these new materials, which accordingly reduced the extent of shrinkage, and also lead to significantly higher final double bond conversion in comparison to common dimethacrylate monomers [20]. Moreover, low water sorption could be shown for these new materials and a relatively low molecular hydrophilicity is held responsible for this finding [20], but may also be attributed to their high DC values [21]. Potential drawbacks are seen in lower values in modulus of elasticity and hardness [20, 22, 23]. Another novelty in the range of resin composite matrix components is a monomer referred to as tricyclodecane–urethane dimethacrylate. This low viscosity monomer is, according to the manufacturer's information, dispensing with the use of diluents which play a major role in the development of polymerization shrinkage of conventional composites. Regarding its chemical structure, this molecule exhibits three connected rings in its central part (Fig. 2) [24], which considerably add to the molecular volume. This feature is presumed to diminish overall shrinkage and stress [22, 24, 25].

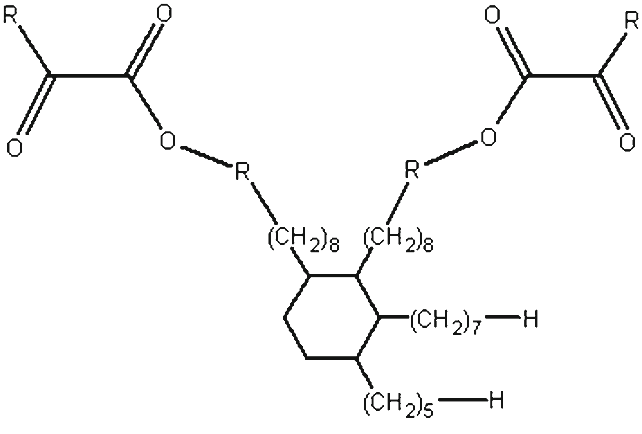

Fig. 1 Chemical structure of h-DA monomer [20]

The aim of this study was to evaluate the degree of conversion of nano-hybrid RBCs with novel monomer components in comparison to materials containing conventional matrices by means of variable specimen geometry and irradiation time. The following null hypotheses were tested: (a) Depth and irradiation time have no significant influence on DC; (b) DC is not influenced by the filling technique; and (c) DC of the evaluated RBCs with novel monomer composition shows no significant difference to conventional materials.

Materials and methods

Five dimethacrylate-based nano-hybrid RBCs were investigated in this study (Table 1). Three conventionally formulated and clinically well-established materials as well as two nano-hybrid RBC materials with novel matrix composition containing either a dimer acid or a tricyclodecane–urethane structure in its monomer components were chosen.

The degree of conversion was measured in real time by varying the sample geometry and the irradiation time by an Fourier transform infrared spectroscopy (FTIR) spectrometer with an attenuated total reflectance (ATR) accessory (Nexus, Thermo Nicolet, Madison, USA). The FTIR spectra were recorded on the bottom of the samples for 5 min from photoinitiation, with two scans per second at a resolution of 8 cm^{-1}. The diameter of the measured surface on the ATR crystal was 800 µm; the wave number range of the spectrum was 4,000–650 cm^{-1}. Specimens ($n=6$) were applied directly on the ATR crystal in a thin film of 0.1 mm or in a mold of 2 and 6 mm height with a diameter of 4 mm. The 2-mm mold was filled in a bulk, whereas the 6-mm mold was filled both in a bulk as well as by applying a horizontal incremental layering technique with three consecutive 2-mm increments being separately cured. The light-curing unit (Freelight 2, 3M ESPE, Germany, 1,241 mW/cm^2) was applied directly on the upper mold surface. A polymerization time of 10, 20, and 40 s was used for all sample geometries.

To determine the percentage of the remaining unreacted double bonds, the DC was assessed as the variation of the absorbance intensities peak height ratio of the methacrylate carbon double bond (peak at 1,634 cm^{-1}) related to an internal standard (IS) prior and during polymerization. For all of the tested materials, the aromatic carbon double bond (peak at 1,608 cm^{-1}) was taken as IS, except for Venus Diamond where a methyl group ($-CH_3$) (peak at 775 cm^{-1}) served as IS, due to the absence of the benzene ring.

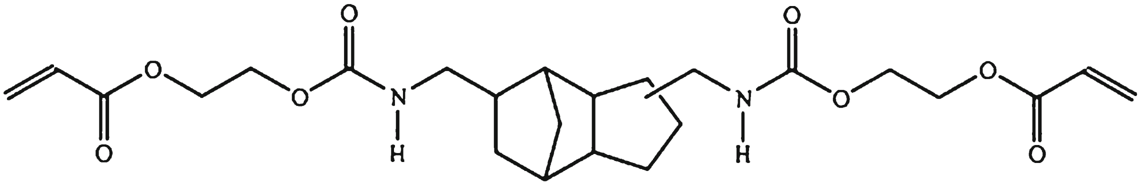

Fig. 2 Chemical structure of tricyclodecane–urethane dimethacrylate monomer (TCD-di-HEA) [24]

$$\text{DC height}\,\% = \left[1 - \frac{(1{,}634\,\text{cm}^{-1}/\text{IS})\text{Peak after curing}}{(1{,}634\,\text{cm}^{-1}/\text{IS})\text{Peak before curing}}\right] \times 100$$

Statistical analysis

Results were compared using one- and multiple-way ANOVA, Tukey's HSD post hoc test ($\alpha=0.05$), and partial eta-squared statistic (SPSS 18.0, Chicago, IL, USA). The results of the measured DC values were compared within each geometry. Additionally, the DC for the tested geometries was comparatively evaluated within a defined material and curing time. In the multivariate analysis, the influence of the parameters "geometry" and "curing time" on DC were analyzed. The partial eta-squared statistic reports the practical significance of each term, based upon the ratio of the variation accounted for by the effect. Larger values of partial eta-squared statistic indicate a greater amount of variation accounted for by the model effect, to a maximum of 1.

Results

The results are listed in Table 2 and visualized in Fig. 3. Post hoc multiple pairwise comparisons with Tukey's HSD test ($p<0.05$) showed no significant increase of DC with prolonged curing time for all specimens with 0.1 mm thickness. In a depth of 2 mm, DC was, except for N'Durance, significantly higher for a curing time of 20 s compared to 10 s and showed no increase after 40 s of irradiation. The highest values

Table 1 Summary of the five dental resin composites with conventional and novel matrix composition which were investigated in this study

Brand name	Manufacturer	Composition	Shade, dosage	Batch no. (LOT)
Miris 2	Coltène/Whaledent AG, Altstätten, Switzerland	Matrix: Bis-GMA, TEGDMA, UDMA Filler: silanized barium glass, amorphous silica (hydrophobed); (range of particle size, 0.02–2.5 µm; average particle size, 0.6 µm) [80 wt%, 65 vol.%]	S2[b]	191818
N'Durance	**Septodont, Louisville, CO, USA**	**Matrix: Bis-EMA, UDMA, dicarbamate dimethacrylate dimer acid** **Filler: Ytterbium fluoride (silanated), barium glass (silanated), silica;** **(range of particle size, 0.01–0.5 µm) [80 wt%, 65 vol.%]**	**A3[a]**	**080609A**
Premise	Kerr, Orange, CA, USA	Matrix: Bis-EMA,TEGDMA Filler: barium glass, silica filler, pre-polymerized filler; (range of particle size, 0.02–50 µm) [84 wt%, 69 vol.%]	A3[b]	3123777, 3120178
Simile	Pentron Clinical, Orange, CA, USA	Matrix: PCBis-GMA, Bis-GMA, UDMA, HDDMA Filler: Barium boro-silicate glass, silica filler,zirconium silicate; (range of particle size: 0.02 - 0,7 µm) [75 wt.%, 68 vol.%]	A3[a]	180254
Venus Diamond	**Heraeus Kulzer GmbH, Hanau, Germany**	**Matrix: TCD-DI-HEA, UDMA** **Filler: barium aluminum fluoride glass, highly discrete nano-particles; (range of particle size, 0.005–20 µm) [82 wt%, 64 vol.%]**	**A3[a]**	**10029**

The two novel-formulated RBC materials are presented in bold

Bis-GMA bisphenol-A-di(meth)acrylate, *Bis-EMA* ethoxylated bisphenol-A-di(meth)acrylate, *UDMA* urethanedimethacrylate, *TEGDMA* triethyleneglycoldimethacrylate, *PCBis-Gma* polycarbonated bisphenol-A-di(meth)acrylate, *HDDMA* hexanedioldimethacrylate, *TCD-di-HEA* bisacryloyloxymethyltricyclodecan

[a] Syringe, ca 4.5 g—dosage

[b] Unidose, ca 0.25 g—dosage

Table 2 Degree of conversion evaluated on specimens of variable geometries after different irradiation times

Material	Time (s)	DC 0.1 mm (%)	DC 2 mm (%)	DC 6 mm bulk (%)	DC 6 mm increment (%)
Miris 2	10	$52.00^{C, D,}$ *** (2.38)	$49.06^{b,}$ ** (1.74)	$3.98^{A, B,}$ (3.61)	$47.85^{\beta, \gamma,}$ ** (1.87)
	20	$53.62^{D, E,}$*** (1.56)	$54.39^{c, d,}$ *** (3.20)	$26.32^{E,}$ (3.87)	$46.52^{\beta, \gamma, \delta,}$ ** (11.93)
	40	$54.26^{D, E,}$ ** (1.47)	$56.14^{d, e,}$ ** (1.46)	$41.42^{G,}$ *(5.04)	$55.03^{\varepsilon,}$ ** (1.51)
N'Durance	10	$58.93^{F,}$ *** (1.72)	$56.77^{d, e,}$ **,*** (2.47)	$17.45^{D,}$ (7.91)	$54.18^{\varepsilon, \zeta,}$ ** (2.65)
	20	$59.27^{F,}$ **,*** (1.41)	$59.67^{e, f,}$ *** (1.46)	$36.41^{F,}$ (5.90)	$56.50^{\zeta, \eta,}$ ** (3.47)
	40	$60.91^{F,}$ ** (2.20)	$58.69^{e, f,}$ ** (3.64)	$50.39^{H,}$ (3.41)	$60.00^{\eta,}$ ** (2.40)
Premise	10	$60.48^{F,}$ **** (3.69)	$54.37^{c, d,}$ *** (4.17)	$3.32^{A, B,}$ (3.32)	$42.58^{\alpha, \beta, \gamma,}$ ** (7.26)
	20	$61.45^{F,}$ **** (2.04)	$58.46^{e, f,}$ *** (2.07)	$1.18^{A,}$ (1.69)	$55.86^{\zeta, \eta,}$ ** (4.77)
	40	$61.58^{F,}$ ** (2.93)	$61.03^{f,}$ ** (2.22)	$13.87^{C, D,}$ (7.46)	$57.79^{\zeta, \eta,}$ ** (2.86)
Simile	10	$54.72^{D, E,}$ *** (2.12)	$44.17^{a,}$ ** (4.59)	$3.11^{A, B,}$ (3.09)	$41.95^{\alpha, \beta,}$ ** (2.30)
	20	$54.90^{D, E,}$ **** (2.15)	$51.18^{b, c,}$ *** (2.82)	$9.08^{B, C,}$ (5.21)	$46.25^{\beta, \gamma, \delta,}$** (2.38)
	40	$55.56^{E,}$ *** (2.08)	$50.98^{b, c,}$ ** (1.78)	$25.81^{E,}$ (4.75)	$50.15^{\delta, \varepsilon,}$ ** (4.65)
Venus Diamond	10	$46.80^{A,}$ *** (4.31)	$44.20^{a,}$ *** (6.82)	$11.26^{C, D,}$ (6.67)	$38.07^{\alpha,}$ ** (4.07)
	20	$47.41^{A, B,}$ *** (4.12)	$49.37^{b,}$ *** (4.34)	$26.66^{E,}$ (7.15)	$42.73^{\alpha, \beta, \gamma,}$ ** (4.41)
	40	$49.94^{B, C,}$ *** (3.81)	$50.57^{b, c,}$ *** (3.61)	$31.26^{E, F,}$ (7.65)	$45.52^{\beta, \gamma, \delta,}$ ** (3.42)

Statistical analysis was made respectively within one geometry (shown by the superscript letters in the table, e.g., A and B or α and β), as well as within all geometries for each material and irradiation time (shown by the number of asterisks in the table fields, e.g., *, **). Standard deviations are indicated in parentheses

were reached by N'Durance and Premise which performed similar in a depth of 2 mm. For specimens of 6 mm that were cured in a bulk, a prolonged cure time resulted in a significantly increased DC but delivered inconsistent data among the tested materials.

For the incremental layering technique, only few differences in DC as a function of irradiation time could be observed. At 6 mm depth, an irradiation of 40 s significantly increased DC for Miris 2 when compared to 10 and 20 s of irradiation. For Premise, DC already increased significantly after 20 s remaining constant when longer irradiation was applied. N'Durance, Simile, and Venus Diamond showed only significant differences between 10 and 40 s of irradiation.

Within the range of the evaluated materials, the significantly lowest DC for each curing time was achieved for bulk curing in a depth of 6 mm, the highest in 0.1 mm depth. The values of the tested geometries of 2 and 6 mm using incremental technique were determined in the midrange. Either DC showed no significant difference within these groups, or DC for 2 mm showed significantly higher results. The least diminishment of DC with increasing depth was shown by N'Durance, followed by Venus Diamond. After 20 s of irradiation, these two materials reached in a depth of 6 mm (bulk curing) still beyond 50 % of corresponding DC values that were measured in a depth of 0.1 mm, while Premise (Fig. 3) and Simile delivered very low results in this context and Miris 2 performed moderately. For a curing time of 40 s, N'Durance, Miris 2, and Venus Diamond showed the least decrease of DC with increasing depth—N'Durance in a depth of 6 mm even reached more than 80 % of its corresponding surface value. Venus Diamond as the only material showed no significant increase of DC in 6 mm depth after 40 s of irradiation when compared to its corresponding values documented with 20 s of irradiation.

The influence of the parameters geometry and curing time on DC was analyzed in an ANOVA multivariate test. The significance values of these parameters were less than 0.05, indicating that both of them contribute to the model. Specimen geometry (η^2=0.90) had a very strong effect on DC followed by curing time (η^2=0.39).

Discussion

RBC materials are in the environment of the oral cavity exposed to a rather complex milieu that comprises different kinds of physical stress (hygroscopic, thermal, and occlusal stress) but also the influence of a variety of endogenous (proteins, enzymes, polysaccharides, and bacteria) as well as exogenous (different sorts of compounds from the diary intake diet) biochemical substances [26]. These factors may be responsible for degrading matrix components and material fatigue after a certain time of exposure [27]. High values of double bond conversion are corresponding to a low amount of leachable residual monomer [28] and a high degree of resistance to biodegradation. In our tests, DC was measured till 5 min after photoinitiation without regarding the possible effects of postpolymerization. It is assumed that the DC of RBC fillings still increases by means of postpolymerization [29]. This statement is sustained by previous in vitro studies showing a significant increase in the degree of conversion [30], Vickers hardness, fracture toughness, as well as a reduced tendency to water sorption and amount of uncombined, possibly leachable components after water bath storage, heating, or microwave treatment of RBCs [30, 31]. However, leaching of unreacted matrix components starts already with the first contact of the dental material to oral fluids. In our study, the materials N'Durance and Premise reached the highest DC values. It may thus be suggested that the release of unreacted resin components could be comparatively low for these materials. Venus Diamond in contrast, as one of the novel-formulated materials, reached lower DC values but, as shown in former studies, was concomitant with a very good mechanical stability also after aging [23, 32] allowing the deductive reasoning of a good chemical stability, probably as a result of the big molecular size of the tricyclodecane (TCD)–urethane and the absence of diluting agents. Ultimately, the molecular architecture of a polymer or, rather, the manner of cross-linking of the components of a polymer-based material is not directly reflected by DC, thus asking for further research on polymerization mechanisms at molecular level in order to make more precise statements about the chemical and mechanical properties and the biocompatibility of dental RBC materials.

The release of leachable monomer components may induce a series of biological responses on cells influencing their metabolism and function [33]. This may implicate allergic or toxic reactions possibly leading to clinical symptoms such as irritation, hypersensitivity, or inflammation of oral tissues [34, 35]. Cell culture techniques have provided evidence that the epoxy-compound 2,3-epoxymethacrylic acid (2,3-EMA) has emerged from methacrylic acid as an intermediate in the metabolism of matrix monomer components such as triethylene glycol dimethacrylate (TEGDMA) which is often used as a diluting agent in dental RBCs [33, 36] like for example in Premise, a material which was evaluated in this study. TEGDMA in its unreacted monomer form is relatively hydrophilic and shows greater water solubility potential than most other commonly used monomer components, so that it is more easily eluted from an RBC material in comparison to other monomers like Bis-GMA for example [37]. TEGDMA in particular may have toxic effects on oral tissue cells like gingival or pulp cells [38] and may cause genotoxicity and changes in cytokine expression [39]. Moreover, TEGDMA as its chemical precursor is assumed to be disseminated systemically via salivary–intestinal or pulp–tissue circulation pathways to be metabolized in other inner organs [36]. These negative prospects promoted ongoing research on new monomers which do not need any diluting components. As an example, the dimer acid derivates contained in the RBC material N'Durance have higher molecular weights (847 g/mol) than common dimethacrylate monomers (e.g., Bis-GMA, 512 g/mol; UDMA (urethanedimethacrylate), 470 g/mol) and lower initial double bond concentrations [20]. It is suggested that the relatively low viscosity of this dimer acid derivate-based monomer matrix results from the high flexibility of the molecule's core structure coupled with a low hydrogen bond density [20]. As an advantageous consequence of these particular characteristics, dilution with low viscosity, comparatively easily leachable monomers like TEGDMA are not necessary for these novel-formulated materials. Nevertheless, in the context of potential toxicity of dental RBCs by means of leachable components, the degree of conversion has always to be taken into account, which is primarily asking for materials with a preferably high DC.

The novel-formulated materials in this study—N'Durance and Venus Diamond—showed the least diminishment of DC with increasing depth. In this context, besides the monomer matrix, also the filler content might have an influence on DC at various depths since a diminishment of the filler particle size was shown to induce increased DC values in former tests

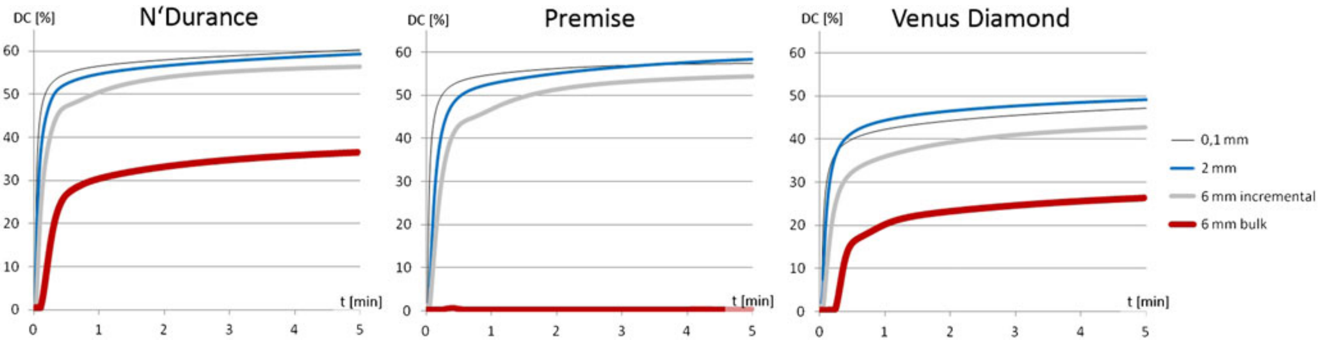

Fig. 3 Three of the tested materials, N'Durance, Premise, and Venus Diamond, in visual comparison. The graphs show the variation of DC for the tested geometries (0.1, 2, and 6 mm incremental and 6 mm bulk) after an irradiation time of 20 s. Mean values (n=6) of measurements recorded in real time for 5 min after photoinitiation are presented

[40]. Moreover, a lower filler content and a higher fraction of nano-particles might be regarded responsible for better light conduction of a certain RBC material compared to another, as a former study showed that small nano-particles do not contribute to light scattering because their dimension only amounts a fraction of the polymerization light's wavelength [41]. Admittedly, this behavior is dependent on nano-particles remaining distinct within the material. Since it was shown, however, that nano-particles may tend to arrange in agglomerates [42] which, as a consequence of increased size, may thoroughly contribute to light scattering, it is difficult to discuss the real effects of nano-particles in terms of their size and their influence on light conduction in this context. Regarding one of the other materials in this study, Premise, according to its manufacturer, contains filler particles up to 50 µm and the highest filler volume (69 %) and weight (84 %) fraction among the tested materials. This fact might be given as a reason that Premise showed a strong diminishment of DC with increasing depth. On the other hand, however, this material reached very good results for lower depths. The reason for this observation might be found in the monomer composition which contains a fraction of the flexible diluting monomer TEGDMA which was able to reach very high DC values in former evaluation [43, 44]. Going beyond looking solely at filler contents, consideration of the refractive indices of the matrix and the filler phases in terms of light conduction may be worthwhile, too. It has been shown that the opalescence of dental materials is influenced by differences in the refractive indices between the filler particles and the resin matrix [45, 46] which leads to light scattering within the material [47], while translucency thus correlates with similar refractive indices of the components of a certain RBC [48]. Therefore, possible similar refractive indices of the contents of N'Durance might also contribute to the very high results for DC reached by this material in our study.

One aim of this study was to evaluate the differences in the degree of conversion after bulk and incremental layering technique. Generally, it is recommended to fill dental cavities by placing multiple resin layers in order to reduce the occurrence of shrinkage stress and strain within the composite [49, 50] and to ensure adequate polymerization [32]. Concerning the clinical application of dental RBCs, the results of this study indicate that incremental filling leads to significantly higher DC values compared to bulk filling in a depth of 6 mm. It is also suggested that for fillings with horizontal increments, like they were used in our tests, lower polymerization shrinkage stress can be estimated in comparison to bulk technique if DC is constant [49]. In this context, it should be pointed out that numerous procedures for incremental filling have been proposed that may help to further diminish shrinkage stress [49]. It can also be concluded from the results of this trial that bulk curing is considerably more dependent on adequate irradiation times in contrast to incremental layering in which, according to this, processing inaccuracies might also play an important but less determinant role in daily practice. As demonstrated in the ANOVA multivariate test, the specimen geometry showed a strong influence on DC (η^2=0.90) followed by curing time (η^2=0.39). Accordingly, the null hypotheses (a) and (b) can be rejected. Most of the resin materials in this evaluation showed a strong decrease of DC at 6 mm depth while incremental curing delivered values that were similar or partially slightly lower than those of a 2-mm bulk curing. The light-tip–resin surface distance which was preset by the shape of the different molds, representing the clinical situation of an oral cavity, might be given as a reason for this observation. As light intensity is diminished while light passes through air [51], the lowest 2 mm using incremental technique, which was irradiated with a distance of 4 mm between light-tip and resin surface, was thus reached by a lower amount of light energy in comparison to 2 mm bulk curing in which the light-tip was positioned directly on the resin surface. Although the two subsequent layers in incremental technique were cured separately, the repeated doses of light energy did not have a further effect on the lowest 2 mm due to the distance and the subsequent overlying increments of light-absorbing composite material. A relatively low decrease of DC for specimens of 6 mm (bulk) compared to specimens of 0.1 and 2 mm strength was shown by N'Durance and Venus Diamond, which was in accordance to our former study, in which these two products reached the highest depth of cure within the same material range [32]. These RBCs might, according to this, most likely be approved for larger incremental thickness. The strongest decrease of DC in a depth of 6 mm was shown by Premise and Simile, although the former reached high values in 0.1 and 2 mm depth. As already discussed, these observations may be explained by the differences in the filler phase, as a high filler content may negatively affect light transmission [52] which plays a more prominent role in thicker increments.

Concerning DC values, it can be outlined that the measured data from this study reflect the average area of current literature for traditional RBC materials [29, 53]. For the tested materials containing novel monomer components (N'Durance and Venus Diamond) compared to those with conventional matrices, differences could be demonstrated with particular respect to higher DC rates (N'Durance) and lower decrease of DC for increasing incremental thickness (N'Durance and Venus Diamond). Hence, the null hypothesis referred to as (c) can be rejected. In former tests with these new materials, N'Durance has shown higher polymerization shrinkage and stress in direct comparison to Venus Diamond, as well as a low modulus of elasticity and flexural strength [22, 23]. These findings may probably be related to the conventional components (Bis-EMA and also UDMA) in the monomer matrix of N'Durance. For Venus Diamond, the DC values in this trial were significantly lower compared to N'Durance, but it reached good performance with respect to polymerization shrinkage and stress as well as very high flexural strength and moderate modulus of elasticity in these aforecited evaluations [22, 23]. These observations point out once again that the manner of cross-linking in the polymer network and subsequent mechanical properties of dental RBCs are not entirely reflected by DC values alone. For a definite comparison and clinical recommendation, further tests in a detailed manner of these new materials concerning the chemical network and also regarding aspects of biocompatibility would be preferable.

Conclusion

The evaluation of RBCs containing novel monomer components showed distinctive differences concerning the degree of conversion in comparison to the tested materials with conventional monomer composition. DC after light curing of specimens with different depth geometries increased with extended curing time and decreased with depth by trend. The two layering methods that were evaluated for the specimens of 6 mm height strongly diverged to an extent that incremental filling technique delivered results for DC that were significantly higher than their corresponding values obtained from bulk curing. The proposed null hypotheses could be rejected.

As recommendable facts for clinical practice, it can be suggested that oral cavities should be filled in increments of lamination strengths of about 2 mm and that these increments should be irradiated for at least 20 s in order to definitely reach a high degree of conversion throughout the whole depth of the cavity. The RBCs N'Durance and Venus Diamond may most likely be approved for increased increments because of the relatively low decrease of DC these materials demonstrated at 6 mm bulk curing.

Conflict of interest The authors declare that they have no conflict of interest.

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