Polymerization shrinkage, shrinkage stress, and mechanical evaluation of novel prototype dental composite resin

Na ZHANG¹ and Chao XIE²

¹ Department of Endodontics, School of Stomatology, Wannan Medical College, 22 West Weng-chang Road, Wuhu, Anhui 241001, China

² Department of Oral Implantology, School of Stomatology, Fourth Military Medical University, 145 West Chang-le Road, Xi'an, Shannxi 710032, China

Corresponding author, Chao XIE; E-mail: XIECHAO20062012@outlook.com

A new photocurable composite resin for dental restorations was synthesized using a monovinyl acrylate diluent. Its polymerization shrinkage, shrinkage stress, degree of conversion, and mechanical properties were investigated and compared to those of a conventional composite resin synthesized using a triethyleneglycol dimethacrylate diluent as well as three commercial resins: Tetric N-Ceram, Neofil, and Gradia Direct. The polymerization shrinkage and shrinkage stress of the new composite resin were statistically lower than those of the conventional resin ($p < 0.05$), but not those of the commercial resins ($p > 0.05$). The degree of conversion of the new resin was statistically better than all other tested resins ($p < 0.05$) except the Neofil resin ($p > 0.05$). The mechanical properties of the resins were not statistically different ($p > 0.05$). Overall, the new composite resin exhibited less polymerization shrinkage, lower shrinkage stress, a higher degree of conversion, and similar mechanical properties to the other resins, demonstrating its potential for clinical application.

Keywords: Resin monomer, Polymerization shrinkage, Polymerization shrinkage stress, Degree of conversion, Mechanical properties

INTRODUCTION

Composite resin restoration has become an important field in clinical dental restoration. Composite resins have extensive applicability in clinical dentistry¹⁾ owing to their ease of operation²⁾, beneficial physiochemical properties, wide range of color and lustre options, and strong biocompatibility. However, resin monomers undergo polymerization shrinkage (PS) in the range of 1.67–5.68%³⁾ when exposed to light, transforming them into reticular structures. In composite resins, PS causes shrinkage stress, resulting in cuspal cracking, enamel fracture, and postoperative pain⁴⁾. PS may also result in marginal discoloration, marginal gaps, and micro-leakages⁵⁾. Marginal gaps between a tooth and a restoration, are a major cause of dental caries⁶⁾. Thus, reducing the volumetric shrinkage of composite resins remains an important research topic.

Significant research has been conducted on reducing PS in composite resins, with particular emphasis on developing low-shrinkage composite resins^{7–10)}. One phenomenon that has been extensively investigated is ‘ring-opening polymerization’, which occurs when a spiroorthocarbonate is exposed to a certain catalyst, causing volumetric expansion of the resulting polymer^{11,12)}. However, the resulting materials exhibit poor mechanical properties, and the ring-opening reaction produces undesirable residues^{13,14)}. Ge *et al.* found that using high-molecular-weight dimethacrylate monomers, such as 2,2-bis[4-[2-methacryloxy-3-(4'-tert-butylphenoxy)prop-1-oxy]phenyl]propane and 2,2-

bis[4-[2-methacryloxy-3-(3',5'-di-tert-butylphenoxy)prop-1-oxy]phenyl]propane, can reduce the PS of the resulting composite resin¹⁵⁾. In addition, researchers have attempted to reduce the PS of composite resins using bisphenol A-glycidyl methacrylate (Bis-GMA) derivatives, but the use of these monomers did not reduce the PS to the desired level. Low-viscosity Bis-GMA replacements have been studied, and although the PS was reduced to a certain degree, problems relating to inferior mechanical properties and water absorption were not resolved^{16–18)}.

To address the above issues, we propose that resin monomers that are screened from a series of monovinyl acrylate resin monomers with secondary functional groups could be used to form suitable photocurable composite resins. These resin monomers can undergo polymerization with common resin monomers for dental applications; moreover, they exhibit a high reactivity, conversion ratio, and storage stability, and can effectively reduce the problems of PS and shrinkage stress associated with composite resins used in dental applications. In a pilot study, monovinyl acrylate resin monomers with secondary functional groups were synthesized. These resin monomers exhibited higher monomer conversion ratios than traditional resin monomers, as well as substantially lower degrees of oxygen inhibition during polymerization, as revealed by the thickness of the anaerobic layer on the resulting resin surfaces following light exposure.

In this experiment, a new monovinyl acrylate resin monomer, 2-(phenyl amino formaldehyde-based oxygen ethyl methacrylate) (BOCNA, Fig. 1(b)), was used to replace the conventional triethyleneglycol

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dimethacrylate (TEGDMA, Fig. 1(a)) diluent to synthesize a new photocurable composite resin. The physiochemical properties of the new composite resin were subsequently tested and compared with the conventional TEGDMA-based resin and three commercial composite resins. The null hypothesis was that the proposed photopolymerisable composite resin formulated with BOCNA monomer would exhibit similar properties to the conventional composite resin formulated with TEGDMA monomer.

MATERIALS AND METHODS

Materials selection and formulation of experimental composites

Three commercial photocurable composite resins (Tetric

Fig. 1 Chemical structures of (a) TEGDMA and (b) BOCNA.

N-Ceram, TN; Neofil, NE; and Gradia Direct, GD) and two experimental photocurable composite resins with similar filler levels and different diluent monomers were tested (see Table 1). The experimental composites comprised a Bis-GMA:TEGDMA (Esstech, Linwood, PA, USA) or Bis-GMA:BOCNA matrix, barium borosilicate glass filler (Esstech), and a photoinitiator comprising 0.5% camphoroquinone (CQ) ($C_{10}H_4O_2$, 97%, Sigma, San Francisco, CA, USA) and 0.5% dimethylaminoethyl methacrylate (DMAEMA) (98%, Sigma). The BOCNA monomer was synthesized in the laboratory at Northwest Polytechnical University¹⁹.

Preparation of composite resins

The composite resin specimens for the proposed composite group (BB) and Control Group 1 (BT) were prepared as follows: the principal resin monomer Bis-GMA was mixed with the diluent (BOCNA or TEGDMA, respectively) at a ratio of 7:3 (w/w) and stirred in a magnetic stirrer for 30 min. The photoinitiator (0.5% CQ and 0.5% DMAEMA) was then added into the mixture, and the resulting mixture was stirred for 2 h. Finally, the inorganic filler (75 wt%) was added to the mixture, followed by vacuum stirring for 2 h. The final mixture was stored in an environment without light exposure. Tetric N-Ceram (TN), Neofil (NE), and Gradia Direct (GD) were used for Control Groups 2 to 4, respectively (see Table 1).

Flexural strength and elastic modulus measurements

Eight specimens measuring 25×2×2 mm were prepared using each resin, and subsequently used for flexural strength and elastic modulus measurements according to ISO standard 4049²⁰. The specimens were prepared and tested as follows: The photocurable resin was poured

Table 1 Composite materials used and their compositions^a

Product	Code	Filler (wt%)	Filler	Base resin	Manufacturer
Proposed group	BB	75	Barium borosilicate glass (0.7–2.0 μ m)	Bis-GMA ^b , BOCNA ^c	—
Control group 1	BT	75	Barium borosilicate glass (0.7 to 2.0 μ m)	Bis-GMA ^b , TEGDMA ^d	—
Tetric N-Ceram	TN	80–81	Barium glass filler, Ytterbium trifluoride, Mixed oxide (0.04–3.0 nm)	Bis-GMA ^b , Bis-EMA ^e	Ivoclar Vivadent (Shaan, Liechtenstein)
Neofil	NE	75	Silica zirconium (0.02–0.7 nm)	Bis-GMA ^b modified by polycarbonate	Kerr (Orange, CA, USA)
Gradia Direct	GD	77	Silica, prepolymerised filler, fluoroaluminosilicate glass (0.85 μ m)	Hydroxyl ethyl methacrylate, toluene trimethylcycloethyl carbonate	GC Dental Products (Tokyo, Japan)

^a Composition of base resin and filler content obtained from manufacturer's information, ^b Bis-GMA: bisphenol A-glycidyl methacrylate, ^c BOCNA: 2-(phenyl amino formaldehyde-based oxygen ethyl methacrylate), ^d TEGDMA: triethyleneglycol dimethacrylate, ^e Bis-EMA: ethoxylated bisphenol A-dimethacrylate

into a mold, and the specimen surface was covered with a thin polyethylene film. The specimen was then exposed to light from a light-emitting diode curing lamp (3M ESPE, St. Paul, MN, USA; wavelength: 430–480 nm; light intensity: 600–800 mW/cm²) for 60 s for every exposed area, then removed from the mold. The specimens were polished as follows: in the presence of injected water, the specimen was manually polished by successively applying 400-, 600-, 800-, 1000-, 1500-, 2000-, and 3000-grit sandpaper. Immediately after the polishing process, the specimen was subjected to ultrasonic cleaning. These operations were all performed by the same person. The specimen was then immersed in a temperature-controlled water bath at 37°C for 24 h, and its width w (mm) and height h (mm) were measured and recorded. The deflection d (mm) was measured upon applying load F (N) in the elastic regime. The samples were tested on a universal testing machine at a loading speed of 0.5 mm/min, and the load F (N) was recorded. The flexural strength σ_{flex} (MPa) and elastic modulus E (GPa) were computed using the following equations (span $L=20$ mm):

$$\sigma_{\text{flex}} = 3FL/2wh^2. \quad (1)$$

$$E = FL^3/4wh^3d. \quad (2)$$

Compressive strength measurement

Eight specimens measuring 4×6 mm were prepared from each resin using the same molding process as for the flexural strength measurements, and subsequently used for compressive strength measurements according to ISO standard 4049. The specimens were polished using the procedure described above. The radii r (mm) of the specimens were measured and recorded after immersion in a temperature-controlled water bath. The samples were tested on a universal testing machine at a loading speed of 0.5 mm/min, and the failure load F (N) was recorded. The compressive strength σ_{com} (MPa) was then computed using the following equation:

$$\sigma_{\text{com}} = F/\pi r^2. \quad (3)$$

Diametric tensile strength measurement

Eight specimens measuring 3×6 mm were prepared from each resin using the same molding process as for the flexural strength measurements, and subsequently used for diametric tensile strength measurements according to ISO standard 4049. The specimens were polished using the procedure described above. The diameters d (mm) and heights h (mm) of the specimens were measured and recorded after immersion in a temperature-controlled water bath. The specimens were tested on a universal testing machine at a loading speed of 0.5 mm/min, and the failure load F (N) was recorded. The diametric tensile strength σ_{DTS} (MPa) was then computed using the following equation:

$$\sigma_{\text{DTS}} = 2F/\pi dh. \quad (4)$$

Microhardness measurement

Eight specimens measuring 3×6 mm were prepared from each resin using the same molding process as for the flexural strength measurements. After molding, the molded specimens were ground and polished, then immersed in a water bath at 37°C for 24 h. Their Vickers hardness (H_v) values were then tested using a microhardness tester under a load of 100 g, which was maintained for 15 s.

Degree of conversion (DC)

The DC refers to the proportion of methacrylate double bonds in the organic resin matrix that are converted to single bonds. To measure the DC in this study, the number of double bonds in each resin before and after light curing was determined using Fourier-transform infrared (FTIR) spectroscopy (Shimadzu 8100M, Kyoto, Japan). First, potassium bromide (KBr) was pressed into a thin disk using a press and scanned as a background. The KBr disk was then coated with a trace amount of an uncured resin specimen. The infrared (IR) spectrum of the uncured resin specimen was subsequently recorded using the FTIR spectrometer. Afterwards, the uncured resin-coated KBr disk was removed from the spectrometer and subjected to light curing for 20 s. The KBr disk was then placed back into the FTIR spectrometer to record IR spectra at various time points (20, 40, 60, 120, 300, and 600 s). The resolution and scanning range of the IR spectra were 4 cm⁻¹ and 4,000–400 cm⁻¹, respectively. Five repeated tests were conducted on each specimen. The DC was measured using the double bonds on the aromatic ring (peak position: 1,607 cm⁻¹) as an internal standard, as these bonds did not participate in the polymerization reaction, and using the change in the peak area of the aliphatic double bonds (peak position: 1,637 cm⁻¹), which participated in the reaction as a measurement index. The DC (%) of the double bonds was calculated using the following equation:

$$DC = [1 - \frac{(1637\text{cm}^{-1}/1607\text{cm}^{-1}) \times \text{peak area cured}}{(1637\text{cm}^{-1}/1607\text{cm}^{-1}) \times \text{peak area uncured}}] \times 100. \quad (5)$$

PS measurement

The PS was measured as follows: the uncured resin was placed in a cylindrical organic glass container (diameter, 6 mm; height, 2 mm) and then placed in the chamber of a micro-computed tomography (micro-CT) scanner (SIEMENS Inveon, Munich, Germany). The specimen was scanned using the following parametric settings: current, 500 μ A; voltage, 80 kVp; layer thickness, 15 μ m; and light exposure time, 800 ms. Subsequently, the scanned specimen was exposed to light for 60 s by placing a light-curing lamp 1 mm vertically above the specimen. The specimen was allowed to fully cure and then rest for 1 h, after which it was placed back in the micro-CT scanning chamber. The obtained three-dimensional (3D) digital images were imported into Inveon software for 3D reconstruction. The measurement process was repeated on eight specimens of each resin (Table 2). The PS (%) was computed using the following equation:

$$PS = (V_0 - V_1) / V_0 \times 100\%, \quad (6)$$

where V_0 is the volume before curing, and V_1 is the volume after curing.

PS stress measurement

The PS stress σ_{PS} (MPa) was tested using a universal testing machine with a custom-made mold, as illustrated in Fig. 2⁵⁾. A support was manufactured using organic glass, and the top flat surface was coarsened by sand blasting. The support was then fixed onto the universal testing machine. A cylindrical stainless-steel mold (diameter, 6 mm; height, 20 mm) was manufactured and placed atop the glass support. One end of the mold was connected to a sensor, with the other end perpendicular to the glass support surface. The specimen was placed between the glass support and stainless-steel mold. The specimen height was controlled at 2 mm by lowering the mold and removing surplus resin. The specimen was then exposed to light for 300 s. The measurement process was repeated on eight specimens of each resin (Table 2).

Statistical analysis

Statistical analysis of the obtained data was performed using the SPSS software (SPSS version 23, IBM, Armonk, NY, USA). The statistical differences between the proposed, conventional, and commercial resins were analyzed using one-way ANOVA and Tukey's *post hoc* comparison test, with $p < 0.05$ indicating statistical

significance.

RESULTS

The σ_{flex} , E , σ_{com} , σ_{DTS} , and H_v values for the five composite resins are listed in Table 3. The E of TN was higher than those of BB, TN, NE, and GD. The results demonstrate that BB, BT, NE, and GD all exhibited comparable E values ($p > 0.05$). In addition, BB and BT exhibited comparable σ_{flex} , σ_{com} , σ_{DTS} , and H_v ($p > 0.05$) values.

Table 2 summarizes the DC values for the five composite resin groups. As demonstrated in Table 2, the

Fig. 2 Setup for PS stress measurement.

Table 2 Degree of conversion (DC), polymerization shrinkage (PS), and polymerization shrinkage stress (σ_{PS}) of the composite resins listed in Table 1

Materials	DC	PS	σ_{PS} (diameter: 6 mm)
BB	81.21 (1.09) ^a	1.88 (0.17) ^a	2.67 (0.26) ^a
BT	74.84 (0.88) ^b	3.29 (0.26) ^b	3.88 (0.17) ^b
TN	78.99 (0.74) ^b	1.93 (0.16) ^a	2.59 (0.34) ^a
NE	79.81 (1.02) ^a	2.01 (0.24) ^a	2.65 (0.36) ^a
GD	76.98 (0.79) ^b	2.09 (0.57) ^a	3.02 (0.15) ^a

^{a,b} These groups were statistically different ($p < 0.05$).

Table 3 Flexural strength (σ_{flex}), elastic modulus (E), compressive strength (σ_{com}), diametric tensile strength (σ_{DTS}), and Vickers hardness (H_v) of the composite resins listed in Table 1

Material	Σ_{flex} (MPa)	E (GPa)	σ_{com} (MPa)	σ_{DTS} (MPa)	H_v (MPa)
BB	107.27 (6.37) ^a	7.28 (0.08) ^a	321.58 (3.88) ^a	29.85 (1.21) ^a	65.95 (2.97) ^a
BT	112.98 (5.92) ^a	7.31 (0.06) ^a	324.39 (6.46) ^a	32.69 (3.12) ^a	66.28 (1.25) ^a
TN	114.46 (4.04) ^a	7.61 (0.04) ^b	329.10 (4.33) ^a	31.49 (2.35) ^a	68.14 (1.50) ^a
NE	110.63 (4.57) ^a	7.26 (0.10) ^a	326.65 (8.66) ^a	32.27 (1.57) ^a	65.75 (2.34) ^a
GD	112.08 (5.37) ^a	7.33 (0.06) ^a	327.85 (5.72) ^a	30.19 (1.53) ^a	67.74 (2.16) ^a

^a These groups were statistically similar ($p > 0.05$). ^{a,b} These groups were statistically different ($p < 0.05$).

Fig. 3 PS stress σ_{PS} vs. time at room temperature.

DC of BB was statistically different from those of BT, TN, and GD ($p < 0.05$), but not statistically different from that of NE ($p > 0.05$).

The PS results are presented in Table 2. It can be observed that BB exhibited the lowest PS ($p < 0.05$) out of all the composite resins, whereas BT had the highest PS ($p < 0.05$) among all the composite resins. The PS of BB was statistically similar to those of TN, NE, and GD ($p > 0.05$).

Table 2 displays the σ_{PS} values, while Fig. 3 illustrates σ_{PS} vs. time t . The σ_{PS} of BB was the same as those of TN, NE, and GD ($p > 0.05$), but lower than that of BT. TN, NE, and GD exhibited comparable σ_{PS} values (Table 2). σ_{PS} developed rapidly after light curing began, and then continued to increase at a reduced rate up to the fixed measuring time for all groups.

DISCUSSION

We evaluated the prospect of using a new resin (BB; formed with BOCNA diluent) in clinical applications by comparing it a conventional composite resin (BT; formed with TEGDMA diluent) and to three common commercial resins (TN, NE, and GD). Based on our findings, the null hypothesis that the BB and BT composite resins would perform equally well was rejected. While BB and BT had comparable mechanical properties, BB exhibited reduced PS and a lower σ_{PS} . Compared to the three commercial resins, BB exhibited a lower PS and superior mechanical properties.

The mechanical properties of composite resins are affected by the properties of the filler²¹⁾ and the resin matrix structure²²⁾. Once in place, dental restorations are liable to fracture under the stress caused by repetitive mastication, primarily owing to the development of microcracks in areas of the restorative material that develop under stress concentrations. The material is continually subjected to load in the mouth cavity, causing microcracks to merge into larger cracks, and finally leading to failure of the material. The force acting on a dental restoration or filler in the mouth cavity is not purely tensile or compressive²³⁾; it is a combination of forces acting on multiple points. σ_{flex} , which is the

maximum stress withstood by a material before it fractures owing to bending stress, is a measure of the capability of the material to bear complex stresses²⁴⁾. In the context of this study, this is related to the performance of the resin matrix and filler. The elastic modulus E is used to quantitatively characterize the capacity of a material to resist deformation when subjected to an external tensile or compressive force. Ideally, the E of a restorative material should be as similar to that of the dental tissues as possible. A restorative material with an excessively high E will result in significant hardness of the tooth neck, making it unable to bend to accommodate oral functions. By contrast, restorative materials with relatively high E values are required for occlusal and proximal tooth surfaces to resist flexural cuspal deflection²⁵⁾. Therefore, σ_{flex} and E were measured using three-point bending tests.

The compressive strength σ_{com} and diametric tensile strength σ_{DTS} are important measures of the mechanical properties of a material, and can fully reflect the mastication biting force. A restoration with a higher σ_{com} value exhibits a superior capability to resist continuous mastication load²⁶⁾. Thus, σ_{com} is an effective indicator of the mechanical behavior of restorative materials. The hardness H_v of a material is a measure of its degree of softness or hardness, and indicates its ductility and polishability. It is used to characterize the capability of the material to resist localized compressive deformation and fracture²⁷⁾. A material with poor surface hardness tends to exhibit poor mechanical properties, particularly wear resistance, and therefore a short service life. The experimental results contained in this study demonstrated that the σ_{flex} , E , σ_{com} , σ_{DTS} , and H_v values of group BB were 107.27 MPa, 7.28 GPa, 321.58 MPa, 29.85 MPa, and 65.95 MPa, respectively, thereby satisfying all the requirements of ISO standard 4049 and clinical applications²²⁾. Moreover, these properties were not statistically different from those of NE and GD ($p > 0.05$).

The DC of double bonds is a primary index that reflects the degree of curing of a resin. It significantly affects the post-curing physical and mechanical properties, because the number of residual unreacted double bonds is closely related to the mechanical, physical, and chemical properties of the cured resin²⁸⁾. The experimental results in this study demonstrated high DCs for both BB and BT. TEGDMA is a type of methacrylate; during the course of photopolymerization, the methyl group can stabilize the free radical induced by the double bond, thus decreasing the activity of chain propagation, and ultimately decreasing the reaction speed and conversion rate. However, BOCNA is a type of acrylate, which has no stabilising effect; thus, it presents a better reaction speed and conversion rate. The DC of BB was not statistically different to that of NE, although it was statistically higher than those of TN and GD ($p < 0.05$).

Composite resins have been used extensively for anterior and posterior restorations^{29,30)}. Despite the numerous advances that have been made in terms of

techniques and materials^{31,32}, various problems remain, with the greatest being PS³³. PS is intrinsically related to the structure of the resin material used³⁴. Various methods have been used to measure PS in recent years, such as dilatometry, density measurements, video image processing, and displacement sensor measurements. However, these methods all exhibit limitations, including complex operation and inaccurate results. With the use of micro-CT, 3D digital images of micro-objects can be obtained non-destructively³⁵. The major working principle of tomography is that of 3D reconstruction; a composite resin with radio-opaque components is scanned, and its volume is reconstructed using a software package. Sun and Lin-Gibson³⁶ found that the resin volumes can be effectively measured before and after polymerization using micro-CT, allowing accurate determination of the magnitude of PS. This method exhibits obvious advantages over the density measurement method. For example, several specimens can be measured simultaneously, with no strict requirements for the specimen size and shape.

The PS ratios of the resins were obtained by scanning the specimens before and after polymerization using a micro-CT scanner and computing their volumes using a software package. The BB and BT resins were prepared using a silanized inorganic filler (0.7–2.0 μm). With the filler uniformly distributed in the resin matrix, the resin volume can be measured accurately using micro-CT, owing to the radio-opaque property of the filler. The PS of the proposed composite group was smaller than those of the control groups (Table 2). The experimental results demonstrated that the PS values of BB (1.83%) and BT (3.29%) were statistically different ($p < 0.05$). The shrinkage stresses σ_{PS} of BB and BT were 2.67 and 3.88%, respectively, and also statistically different.

The process of resin polymerization results in an increase in the density and a decrease in the volume of the resin³⁷. However, PS is affected by many factors, including the monomer structure, initiator activity, and filler content³⁸. σ_{PS} is a dynamic phenomenon, and is influenced by the type of resin matrix used³⁹. In this study, the BB and BT resins were prepared with the same filler, initiator, and principal monomer, but different diluents (BOCNA and TEGDMA, respectively). BOCNA has only one functional group with a C=C double bond, while the conventional diluent TEGDMA has an additional functional group. With one less C=C double bond, BOCNA has a smaller intermolecular distance than TEGDMA (0.15 nm *vs.* 0.3–0.5 nm), and the resulting polymer has a lower cross-linking density⁴⁰, therefore resulting in a decrease in volumetric shrinkage⁴¹. Although the impact of the monomer content on the resin properties remains unclear, we can infer that BOCNA contributes to a lower reticular cross-linking structure content in the resulting polymer, thereby leading to a lower σ_{PS} .

In this study, σ_{PS} was measured using a universal testing machine. It is important to note the shortcomings of existing methods for σ_{PS} measurement. The method employed in this study exhibited low compliance;

consequently, the stress values tended to be higher than those recorded using compliant systems⁴². Further research is therefore required to evaluate these findings using a clinically relevant and compliant system. The specimen remained connected to the sensor during the entire 300 s of σ_{PS} measurement for all the resins. All tested resins yielded similar compressive stress *versus* time curves, which is consistent with the typical stress variation curves reported in the literature⁴³. The stress variation trend is related to the gelation effect caused by the rapid increase in polymer viscosity. As polymerization proceeds, the free flow of monomers in the reaction system is constrained, and the decreased monomer content towards the end of the process results in drastically decreasing stress⁴⁴. This stress variation represents the trend of the polymer system, which develops a reticular cross-linking structure⁴⁵.

The proposed resin synthesized using the new diluent exhibited strong mechanical properties, low PS, a relatively high DC, and low σ_{PS} . However, certain problems remain that should be experimentally investigated; for example, the water absorption and biological behaviors of the resulting resin.

CONCLUSIONS

The TEGDMA diluent used to synthesize a conventional photocurable composite resins for use in clinical dental restorations was replaced by a new BOCNA diluent. The properties of the proposed photocurable composite resin were compared to those of the conventional resin as well as three commercial resins (Tetric N-Ceram, Neofil, and Gradia Direct). The resin synthesized with BOCNA exhibited less shrinkage, lower shrinkage stress, and equally strong mechanical properties compared to the conventional resin. This is because the BOCNA monomer has only one functional group with a C=C double bond, while the TEGDMA monomer has an additional functional group. The new BOCNA-based composite resin is promising for restorations that have low shrinkage to inhibit secondary caries. To improve the overall performance of the resin, its solubility, water absorption, and cytotoxicity, and as well as the impact of the filler content on performance will be investigated in the future.

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