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Flexural Property of a Composite Biomaterial in Three Applications

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Abstract: Resin composite is widely used in the dental field in clinics as a biomaterial. For example, it has been used as a composite material, a type of biomaterial, to repair caries and restore masticatory function, and as a luting agent to adhere the restoration to the tooth substrate. In order to demonstrate its function, we have measured the mechanical strength. From such basic research, we explain the potential of a dental material through the measurement of flexural strength and modulus of elasticity. In this research, we introduce commercial products that are actually used as composite materials suitable for tooth substrate and provide readers with their properties based on flexural strength and modulus of elasticity. In clinical performance, it might be advisable to delay polishing when a composite material is used for a luting material, a filling material and a core build-up material, as the flexural strength and the flexural modulus of elasticity were improved after 1 day of storage, and flexural strength and characteristics are considered as important mechanical properties of oral biomaterials.

Keywords: biomaterial; resin composite; luting agents; core build-up materials; application in dentistry

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1. Introduction

Composite resin is widely used as a biomaterial in the dental field. For example, it has been used as a biomaterial for repairing cavities and restoring masticatory functions, and as a cement for adhering restorations to tooth substrates. For the purpose of predicting its function, dental biomaterials are measured by measuring their own flexural strengths and flexural moduli using luting materials, filling materials, and core build-up materials. As mentioned above, a composite is used with various restoration materials in dental clinics, but all have the same composition, i.e., composites consist of three phases: resin matrix, dispersed inorganic filler particles, and silane coupling agent on the filler particles to produce a good bond between the matrix and the filler in the clinical dentistry.

The mechanical properties of restorative luting materials [1,2], filling materials [3–10], and core build-up material [11] have been evaluated using in vitro flexural testing. In our previous studies [4,9,11], dental restorations which were polished after one-day storage following light activation showed improved shear bond strength and flexural properties, that is, as a result of the improvement of the tooth substrate adhesiveness and the resistance to the external force of polishing by this improvement of the adhesiveness, thus improved marginal integrity. For luting agents, their shear bond strengths to dentin and flexural modulus increased after one-day storage, coupled with markedly decreased incidence of interfacial gaps [7].

Therefore, in this paper, we consider the performance of composite materials widely used in the clinical practice of dentistry via the characteristics of flexural properties.

2. Luting Materials

Irie M, Maruo Y, Nishigawa G, Suzuki K, Watts DC. Physical properties of dual-cured luting-agents correlated to early no interfacial-gap incidence with composite inlay restorations. Dent Mater. 2010 Jun; 26(6):608–15. doi: 10.1016/j.dental.2010.02.012. Epub 23 March 2010. PMID: 20334906.

2.1. Introduction

In clinical practice, the popularity of tooth-colored posterior restorations has increased due to demand for an esthetic restorative and also a growing concern about the biocompatibility of amalgam. Resin composite showed better performance than luting-agent for an indirect esthetic restoration. Luting-agents for composite inlay restorations were produced in dual-polymerized formulations, which were indicated for restorations with material opacity sufficient to inhibit light energy from transmission to the cement. Although light irradiance reaching the cement might often initiate the surface polymerization process, a self-cure and some duration were needed to ensure a maximal cure [3,4]. These systems embody dual-cured processes consisted of photo-cured and chemical-cured reaction.

This investigation was, therefore, carried out with multiple types of dual-cured luting-agents to evaluate early stage behavior (both immediate and after 1-day storage).

2.2. Materials

The sources, compositional details and classification of the seven luting-agents used in this study, together with their pretreatment agents, were summarized in Table 1. All procedures were performed in accordance with the manufacturers' instructions. Capsules of RelyX Unicem Aplicap were triturated using a high-speed mixer (Silamat, Vivadent, Schaan, Liechtenstein) for 15 s. For light activation, a curing unit (New Light VL-II, GC, Tokyo, Japan; optic diameter: 8 mm) was used. The light irradiance was checked immediately before each application to the materials, using a radiometer (Demetron/Kerr, Danbury, CT, USA). During the experiment the light irradiance was maintained at 450 mW/cm^2.

Table 1. Luting-agents investigated. Information provided by the manufacturers.

Materials	Manufacturer	Material Composition
Self-Adhesive Resin Cement		
RelyX Unicem Aplicap	3M ESPE, Seefeld Germany	Filler Content 72 wt % (Aluminosilicate, Silanized Filler) Methacrylates, Initiators, Acidic Methacrylates
Adhesive Resin Cement		
Calibra	Dentsply/Caulk Milford, DE, USA	Filler Content 67–68 wt % (Silica Fume) Bis-GMA, TEGDMA, Titanium Dioxide, Catalyst
NEXUS 2	Kerr, Orange CA, USA	Filler Content 70 wt % (Fumed Silica and Barium Aluminosilicate) Bis-GMA, TEGDMA, EBPADMA, HEMA, UDMA, Catalyst
Panavia F	Kuraray medical, Kurashiki, Japan	Filler Content 78 wt % Paste A: MDP, Comonomer, Filler, NaF, BPO Paste B: Comonomer, Filler, NaF, amine, initiator
LINK MAX	GC, Tokyo Japan	Filler Content 68 wt % (Fluoroalumonisilicate Glass, SiO) UDMA, HEMA, Dimethacrylate, Catalyst
Bistite II	Tokuyama Dental Tokyo, Japan	Filler Content 77 wt % (Silica-Zirconia) MAC-10, EBPADMA, Monomer, Initiator
Chemiace II	Sun Medical Moriyama, Japan	P: Complexed Filler, SiO2, ZrO_2, Amine L: 4-META, HEMA, Dimethacrylate, BPO, Powder/Liquid: 1.15

Bis-GMA: bisphenol A glycidylmethacrylate, BPO: benzoyl peroxide, EBPADMA: ethoxylated bisphenol A, dimethacrylate, HEMA: 2- hydroxyethyl methacrylate, MAC-10: 11-methacryloxy-1,1-undecanedicarboxylic acid, 4-META: 4-methacryloxyethyl trimellitate anhydride, MMA: methyl methacrylate, TEGDMA: tri-ethylene-glycol-dimethacrylate, UDMA, urethan dimethacrylate.

2.3. Methods and Results

Teflon molds (25 × 2 × 2 mm) were used to prepare flexural specimens (n = 10/group). Bistite II, Chemiace II, Compolute and XenoCem were cured in three overlapping sections, each cured for 30 s. Flexural strength and flexural moduli of elasticity were measured, both immediately after setting and after 1-day storage in distilled water at 37 °C, using the three-point bending method with a 20 mm-span and a load speed of 0.5 mm/min (5565,

Instron, Canton, MA, USA) as outlined in ISO 9917-2 (1996) and were calculated (Software Series IX, Instron, Canton, MA, USA).

Tables 2 and 3 summarize the flexural strength and flexural modulus at the two time-points, respectively. In the immediate condition, Bistite II showed the greatest flexural modulus of all materials and Chemiace II showed the lowest value. After 1 day, the moduli of all luting-agents significantly increased. Panavia F and Bistite II showed the greatest moduli of all materials.

Table 2. Flexural strength of luting-agents (MPa, mean (S.D.)).

Luting Agent	Immediately	After 1-Day Storage	*p*-Value *
RelyX Unicem Aplicap	64.9 (6.7)	88.8 (4.4)	<0.001
Calibra	73.7 (7.4)	120.1 (11.7)	<0.001
NEXUS 2	83.4 (8.1)	123.0 (9.2)	<0.001
Panavia F	34.8 (5.6)	99.8 (10.6)	<0.001
LINK MAX	107.8 (10.6)	159.4 (19.5)	<0.001
Bistite II	73.2 (9.4)	108.1 (14.7)	<0.001
Chemiace II	37.1 (3.9)	57.8 (3.7)j	<0.001

n = 10; * t-test.

Table 3. Flexural modulus of luting-agents (GPa, mean (S.D.)).

Luting Agent	Immediately	After 1-Day Storage	*p*-Value *
RelyX Unicem	4.57 (0.55)	7.86 (0.81)	<0.001
Calibra	1.88 (0.20)	6.47 (0.30)	<0.001
NEXUS 2	3.10 (0.41)	6.69 (0.35)	<0.001
Panavia F	2.75 (0.25)	9.65 (1.01)	<0.001
LINK MAX	3.33 (0.82)	7.51 (0.49)	<0.001
Bistite II	5.23 (0.41)	9.61 (1.11)	<0.001
Chemiace II	0.47 (0.14)e	3.39 (0.26)j	<0.001

n = 10; * t-test.

2.4. Discussions

Thus, the higher value of flexural strength and flexural modulus after 1 day, compared with the immediate condition, resulted partly from the stiffer luting-agents with higher moduli [4,9,11]. The improvement in strength and elastic modulus after one day was a result of the improvement in the polymerization rate of cement over time [11].

A statistical analysis was performed on the relationship between flexural strength and filler content (wt % and vol%) of about seven luting materials. However, no significant relationship was found ($p > 0.05$, $n = 7$). Recent fillers have been devised in various ways, such as nano-fillers and organic composite fillers, and we do not think a significant relationship like this has been found before. As composite materials have the same purpose, they are made to exhibit similar mechanical strength as a manufacturer.

The flexural strength of LINK MAX one-day storage later showed the maximum value. As the clear reason was unknown from the composition (including the filler content) announced by the manufacturer, it may be possible to guess the molecular weight, compounding ratio, degree of cross-linking, polymerization rate, etc. of the content monomer. Chemiace II showed the lowest flexural strength of after one-day storage. By analogy with powder/liquid = 1.15 (filler content = 53 wt %), it was possible that the filler content is less than other luting agents. Further, as the flexural modulus was also low, the polymerization rate may have been low. Similarly, the molecular weight, compounding ratio, and degree of cross-linking of the monomers may be guessed.

2.5. Relevancy

Luting materials were used for cementation of restorations. Recent luting materials were used for bonding of all-ceramic or modern ceramic restoration, and special dental

applications. Important properties include working time, film thickness, mechanical strength, modulus of elasticity, and biocompatibility. In particular, it is thought that flexural characteristics will be important and significant from now on for all-ceramic or modern ceramic restoration. We hope that these results will guide selection in clinical situations.

3. Filling Materials

Irie M, Maruo Y, Nishigawa G. Performance of class I composite restorations when polished immediately or after one-day water storage. PLoS One. 2017;12(8):e0183381. Published 17 August 2017. doi:10.1371/journal.pone.0183381

3.1. Introduction

Polymerization shrinkage occurs during the early stage of polymerization of light-activated dental composites. This phenomenon adversely affects interfacial adaptation and bonding to tooth structure because the shrinkage forces generated can disrupt the bond to cavity walls and result in gap formation. As for the adhesive systems used to bond the restorative filling materials to tooth structure, their issues of flow ability, polymerization shrinkage and the resulting destructive shrinkage stress further contribute to gap formation in resin composite restorations. Compromised marginal integrity at the resin-tooth interface will lead to bacterial penetration, and subsequently pulpal damage and postoperative sensitivities. One way to predict the clinical success of dental composite restorations in vitro was to evaluate marginal adaptation. In butt-joint cavities restored with an adhesive system and a resin composite filling, the magnitude of interfacial gaps formed was dictated by these factors: (1) adhesive forces between the restorative material and cavity walls; (2) degrees of volumetric contraction of filling and luting materials; and (3) flow properties of filling and luting materials. Self-etch primer adhesive systems and all-in-one adhesives vary in their acidity because of differences in the composition and concentration of polymerizable acids and/or acidic resin monomers [4,7–15].

This investigation was carried out with filling materials to evaluate early stage behavior (both immediate and after 1-day storage).

3.2. Materials and Methods

Nine light-activated resin composite filling materials for premolar restorations were selected for this study. Details of these resin composite filling materials were listed in Table 4.

Table 4. Light-activated restorative materials investigated.

Product	Composition	Manufacturer	Lot No.
QuiXX	Silica nanofiller (86 wt %, 66 vol%) Bis-EMA, UDMA, TEGDMA, TMPTMA, Photo Initiators, Stabilizers	Dentsply/Caulk Milford, DE, USA	0503000635
Filtek P60	Zirconia/Silica (83 wt %, 61 vol%) Bis-GMA, UDMA, Bis-EMA, Photo Initiators Stabilizers	3M ESPE, St. Paul, MN, USA	3TC
Herculite XRV	Barium Silica Glass (79 wt %, 59 vol%) Bis-GMA, TEGDMA, EBPADMA	Kerr, Orange, CA, USA	112330
Tetric N-Ceram	Bariumglass Filler, Ytterbiumtrifluoride, Mixed Oxide (63.5 wt %, 55–57 vol%), Prepolymer (17%) UDMA, Bis-EMA, Bis-GMA, Photo Initiators	Ivoclar Vivadent AG, Schaan, Liechtenstein	KO4764
Gradia Direct P	Silica Powder, Prepolymerized Filler Fluoro-Aluminosilicate-Glass (79 wt %, 65 vol%) UDMA, Dimethacrylate, Pigment, Photo Initiators	GC, Tokyo, Japan	0403301
BEAUTIFIL II	S-PRG Filler, Multi-Functional Glass Filler Ultra-Fine Filler (83.3 wt %, 68.6 vol%) Bis-GMA, TEGDMA, UDA, Photo Initiators	Shofu, Kyoto, Japan	110615

Table 4. *Cont.*

Product	Composition	Manufacturer	Lot No.
EPIC-AP	Barium glass filler, TMPT reactive filler (82 wt %, 64 vol%) Dimethacrylates, Photoinitiator, Stabilizer	Sun Medical Moriyama, Japan	MX2F
Estelite Sigma	Silica/zirconia filler (82 wt %, 71 vol%) Bis-GMA, TEGDMA, Bis-MPEPP, Photo Initiators	Tokuyama Dental Tokyo, Japan	011K2
Clearfil AP-X	Silanated Glass Ceramics, Surface Treated Alumina Microfiller (85.5 wt %, 71.0 vol%) Bis-DGMA, TEGDMA, Hydrophobic Aromatic Dimetnacrulate, dl-Camphorquinone	Kuraray Medical Kurashiki, Japan	1121AA

Bis-EMA: bisphenol A ethoxyl methacrylate, UDMA: urethane dimethacrylate, TEGDMA: tri-ethylene-glycol dimethacrylate, TMPTMA: trimethylolpropane trimetharylate, Bis-GMA: bisphenol A glycidyl methacrylate, Bis-DGMA: bisphenol A diglycidyl mentacrylate, TMPT: trimethylolpropane trimetharylate, EBPADMA: ethoxylated bis-phenol-A-dimethacrylate, UDA: urethane diacrylate, S-PRG: surface reaction type pre-reacted glass-ionomer filler, Bis-MPEPP: 2,2-bis(4-methacryloyloxypolyethoxyphenyl)propane.

These resin composite restorative materials and adhesives systems were selected because they were the major restorative products used by dentists and thus provided a comprehensive, clinically relevant range of values for the parameters to be investigated in this study.

The method was the same as Section 2.3.

3.3. Results

Tables 5 and 6 presented the flexural strength and modulus data, respectively, obtained at two time points.

Table 5. Flexural strength of restorative materials (MPa, mean (S.D.)).

Restoration	Immediately	After One-Day Storage	Change (%) [#]	*p*-Value [a]
QuiXX	84.4 (3.3)	143.8 (12.1)	+70	<0.05
P-60	102.0 (5.6)	165.1 (9.8)	+62	<0.05
Herculite XRV	75.5 (9.3)	135.9 (10.5)	+80	<0.05
Tetric EvoCeram	84.1 (5.0)	122.7 (3.5)	+46	<0.05
Gradia Direct P	52.2 (3.5)	91.5 (7.0)	+75	<0.05
BEAUTIFIL II	77.0 (4.9)	113.9 (11.3)	+48	<0.05
EPIC AP	62.2 (5.0)	108.6 (10.4)	+75	<0.05
Estelite Sigma	61.9 (5.4)	93.5 (7.1)	+51	<0.05
Clearfil AP-X	128.4 (7.6)	167.9 (14.1)	+31	<0.05

$n = 10$; [#] percentage to the immediate condition; [a] *t*-test.

Table 6. Flexural modulus of restorative materials (GPa, mean (S.D.)).

Restoration	Immediately	After One-Day Storage	Change (%) [#]	*p*-Value [a]
QuiXX	9.29 (2.63)	18.21 (1.71)	+ 96	<0.05
P-60	8.62 (1.24)	15.76 (1.19)	+ 83	<0.05
Herculite XRV	4.77 (0.13)	11.88 (0.70)	+149	<0.05
Tetric EvoCeram	6.04 (0.87)	9.21 (0.88)	+ 52	<0.05
Gradia Direct P	2.78 (0.22)	5.26 (0.31)	+ 89	<0.05
BEAUTIFIL II	7.05 (0.86)	11.78 (0.99)	+ 67	<0.05
EPIC AP	5.26 (0.50)	10.77 (0.73)	+105	<0.05
Estelite Sigma	3.59 (0.19)	6.88 (0.46)	+92	<0.05
Clearfil AP-X	10.99 (0.98)	17.76 (1.35)	+62	<0.05

$n = 10$; [#] percentage to the immediate condition; [a] *t*-test.

Significant differences ($p < 0.05$) in flexural strength were observed between the immediate time point and after 1-day storage for all resin composite filling materials,

ranging from +31% to +80%. Immediately after setting, Clearfil AP-X showed the highest value while Gradia Direct P showed the lowest. After 1-day storage, P-60 and Clearfil AP-X showed the highest values, while Gradia Direct P and Estelite Sigma showed the lowest.

For flexural modulus data, significant differences ($p < 0.05$) were observed between the immediate time point and after 1-day storage for all restorative materials, ranging from +62% to +149%. Immediately after setting, Clearfil AP-X showed the highest value while Gradia Direct P and Estelite Sigma showed the lowest. After 1-day storage, QuiXX and Clearfil AP-X showed the highest values, while Gradia Direct P showed the lowest.

3.4. Discussions

Thus the higher value of flexural strength and flexural modulus after 1-day, compared with the immediate condition, resulted partly from the stiffer luting-agents with higher moduli [4,9,11]. The improvement in strength and elastic modulus after one day was a result of the improvement in the polymerization rate of cement over time [11].

In this study, commercially available resin composites were used for investigation. Despite significant differences in bonding performance, all composites displayed similar tendencies in their bond strengths to enamel and dentin and in their flexural properties when measured immediately after polishing and after 1-day storage. This could be attributed to their similar filler-matrix ratios [16–18].

Greater interfacial integrity exhibited by resin composite restorations in this study could stem from a combination of factors: smaller polymerization shrinkage, lower polymerization shrinkage stress, and good bond strength. In clinical settings, it might be advisable to delay polishing when resin composites were used for class I restorations, as improved mechanical properties were displayed after one-day storage. The clinical implication was that dentists and patients might agree to a next-day return visit for polishing to improve the survival rate of their restorations.

A statistical analysis was performed on the relationship between flexural strength and filler content (wt % and vol%) about nine filling materials. But no significant relationship was found ($p > 0.05$, $n = 9$). Recent fillers have been devised in various ways, such as nano-fillers and organic composite fillers, and we do not think a significant relationship like this has been found before.

The flexural strength of Gradia Direct P and Estelite Sigma after one day was lower than others. It was thought that the reason was that the flexural modulus might be low and the polymerization rate might be low by analogy with this tendency [19]. As the clear reason was unknown from the composition (including the filler content) informed by the manufacturer, it might be possible to guess the molecular weight, compounding ratio, degree of cross-linking, polymerization rate, etc. of the content monomer. Gradia Direct P showed the lowest flexural strength of after one-day storage. Further, as the flexural modulus was also low, the polymerization rate might be low. Similarly, the molecular weight, compounding ratio, and degree of cross-linking of the monomers might be guessed.

As filling materials might withstand occlusal loading and stress, they showed superior flexural strength and flexural modulus compared to luting materials. The manufacturer also designed with this intention.

3.5. Relevancy

There is a considerable requirement for filling materials that have the appearance of natural tooth tissue and that could be placed directly into a cavity preparation in a paste condition. Filling materials have recently been recommended for classes I to V restorative materials. Important properties included polymerization shrinkage, thermal conductivity, water sorption, mechanical strengths, modulus of elasticity, hardness and wear, and biocompatibility. In particular, it was thought that flexural characteristics would be important and significant from now on for the appearance of natural tooth tissue, and we hope that these results will guide selection in clinical situations.

4. Core Build-Up Materials

Irie M, Maruo Y, Nishigawa G, Yoshihara K, Matsumoto T. Flexural Strength of Resin Core Build-Up Materials: Correlation to Root Dentin Shear Bond Strength and Pull-Out Force. Polymers (Basel). 2020;12(12):2947. Published 9 December 2020. doi:10.3390/polym12122947.

4.1. Introduction

An endodontically treated tooth presents a higher risk of biomechanical failure than a vital tooth. An appropriate restoration for endodontically treated teeth was guided by both strength and esthetics. Posts were generally used to restore missing tooth structure and pulpless teeth, and new tooth-colored posts had improved the esthetics of teeth restored with posts and cores. To ensure the durability of endodontically treated teeth, it was extremely important that posts were optimally bonded to reduce debonding and fracture risks.

A core build-up system usually comprises a post, which restores the tooth to the extent necessary to support a crown or an abutment tooth. Therefore, a core build-up material, such as a resin composite, was a restoration placed in a badly broken-down tooth to restore the bulk of the tooth's coronal portion. Various types of bonding systems had been used with different luting cements and core build-up materials. Improvements in resin composites and advances in tooth substrate bonding systems had enabled the employment of more conservative techniques, which seek to maximally preserve the vitality of badly broken-down permanent premolar or molar teeth in their restoration. To provide post retention and improve the overall resistance of the root against fracture, resin composite core build-up materials were now widely used with an adhesive system [20–22].

This investigation was, therefore, carried out with multiple types of core build-up dual-cured materials to evaluate early stage behavior (both immediate and after 1-day storage).

4.2. Material and Methods

The manufacturers and compositional details of eight core build-up materials and three luting materials are shown in Table 7. All procedures were performed in accordance with the manufacturers' instructions. For light activation, a light curing unit (New Light VL-II, GC, Tokyo, Japan; optic diameter: 8 mm) was used. Before each application to the materials, light irradiance was checked using a radiometer (Demetron Kerr, Danbury, CT, USA). During the experiment, light irradiance was maintained at 450 mW/cm^2. The method is the same as Section 2.3.

As there were many build-up materials this time, we focused on flexural strength.

Table 7. Core materials investigated.

Product	Composition	Manufacturer	Batch No.
FluoroCore 2+	Barium Fluoro Alumino Borosilicate Glass (Silanated), Silane Treated Silica, Aluminum Oxide, Bis-GMA, Urethane Dimetacrylate, Polymerizable Dimetacrylate, Benzoyl Peroxide, Filler Content: 69.1 wt %, 46 vol%. The Particle Size Ranges from 0.04 to 25 µm.	Dentsply/Caulk, Milford, DE, USA	160415
RelyX Ultimate	Surface Treated Glass Powder Filler, Phosphate Ester monomer, TEGDMA, 1,12-Dodecane Dimethaycrylate, silica Filler, Initiator, Calcium Hydroxide, Titanium Dioxide, Filler Content: About 70 wt %	3M, Seefeld, Germany	642680
RelyX Unicem 2 Automix	Surface Treated Class Powder Filler, Phosphate Ester monomer, TEGDMA, 1,12-Dodecane Dimethaycrylate, Silica Filler, Initiator, Calcium Hydroxide, Sodium p-Toluensulfinatet, Methacrylated Amine, Titanium Dioxide, Filler Content: About 70 wt %	3M, Seefeld, Germany	646984

Table 7. *Cont.*

Product	Composition	Manufacturer	Batch No.
Filtek Bulkfill Flowable Restorative	Silane Treated Ceramic, UDMA, Bis EMA, Bis-GMA, TEGDMA, Other Dimethacrylate, Ytterbium Fluoride, Filler Content: 64.5 wt %, 42.5 vol%	3M, St. Paul, USA	N815551
NX3	Barium Aluminoborosilicate Glass, Ytterbium Trifluoride, Fumed Silica, TEGDMA, UDMA, EBPADMA, Initiator, Stabilizer, Filler Content: 67.5 wt %, 43.3 vol%	Kerr, Orange, CA, USA	6021181
MultiCore Flow	Ytterbium Trifluoride, Bis-GMA, UDMA, TEGDMA, Dibenzoyl Peroxide, Filler Content: 70 wt %, 46 vol%, The Particle Size Ranges from 0.04 to 25 µm.	Ivoclar Vivadent AG, Schaan, Liechtenstein	W02582
UniFil Core EM	UDMA, Dimethacrylate, Fluoroaluminosilicate Glass, Iron Oxide, Dibenzoyl Peroxide, Butylated Hydroxytoluene, Filler Content: 75 wt %	GC, Tokyo, Japan	1604251
Beauti Core Flow Paste	Glass Powder Filler (S-PRG Filler), Bis-GMA, TEGDMA, Silica, Initiator, Others, Filler Content: 60–70 wt %	Shofu, Kyoro, Japan	61610
i-TFC system Post Resin	Dimethacrylates, Silica, Barium Glass Filler, Photoinitiators, Stabilizer, Others Filler Content: 67 wt %	Sun Medical, Moriyama, Shiga, Japan	MX13
ESTECORE	Bis-GMA, TEGDMA, Bis-MPEPP, Silica-Zirconia Filler, Camphorquinone, Peroxide, Radial Amplifier, Others, Filler Content: 75 wt %	Tokuyama Dental, Tokyo, Japan	112006
Clearfil DC Core Automix ONE	Bis-GMA, TEGDMA, Hydrophilic Aliphatic Dimethacrylate, Hydrophobic Aromatic Dimethacrylate, Silanated barium Glass Filler, Silanated Colloidal Silica, Colloidal Silica, dl-Camphor Quinone, Aluminum Oxide Filler, Initiators, Accelerators, Pigments. Filler Content: 74 wt %, 52 vol%	Kuraray Noritake Dental, Tainai, Niigata, Japan	B30218

Bis-GMA: Bisphenol A glycidyl methacrylate, TEGDMA: Tri-ethylene-glycol dimethacrylate, Bis-EMA: Bisphenol A ethoxyl methacrylate, UDMA: Urethane dimethacrylate, EBPADMA: Ethoxylated bis-phenol-A-dimethacrylate, S-PRG: Surface reaction type pre-reacted glass-ionomer filler, Bis-MPEPP: 2, 2-Bis(4-methacryloyloxypolyethoxyphenyl) propane.

4.3. Results

Table 8 presents the flexural strength, obtained at two time points. The flexural strength data and their statistical analysis results are given. Except for RelyX Unicem 2 Automix, the flexural strength of all core build-up materials changed significantly with time ($p < 0.05$). The one-day time period yielded the highest mean data, except for Clearfil DC Core Automix ONE. For the two time periods, ESTECORE showed the higher values between all the core build-up materials.

Table 8. Flexural strength of various Core build-up materials and luting materials (MPa, mean (S.D.)).

	Immediate	After One-Day Storage	*p*-Value [a]
FluoriCore 2	83.3 (8.8)	132.0 (8.4)	<0.05
RelyX Ultimate	71.4 (4.6)	119.4 (3.6)	<0.05
RelyX Unicem 2 Automix	71.9 (5.7)	108.0 (6.8)	<0.05
Filtek BulkFill Flowable Restorative	50.3 (1.8)	144.9 (5.3)	<0.05
NX3	39.1 (5.2)	123.7 (9.8)	<0.05
MultiCore Flow	99.4 (7.4)	142.1 (9.1)	<0.05
UniFil Core EM	90.8 (7.3)	153.6 (11.4)	<0.05
BeautiCore Flow Paste	112.4 (9.3)	140.7 (7.9)	<0.05
i-TFC system Post Resin	84.3 (4.1)	139.4 (6.4)	<0.05
ESTECORE	122.3 (9.1)	172.8 (10.2)	<0.05
Clearfil DC Core Automix ONE	97.3 (19.4)	140.6 (9.6)	<0.05

$n = 10$; [a] *t*-test.

For flexural moduli data (Table 9), significant differences ($p < 0.05$) were observed between the immediate time point and after 1-day storage for all restorative materials. Immediately after setting, ESTECORE showed the highest value while NEXUS 3 showed the lowest. After 1-day storage, ESTECORE showed the highest values, while NEXUS 3 showed the lowest. Immediate and after one- ay storage, the tendency was very similar.

Table 9. Flexural modulus of various core build-up materials and luting materials (GPa, mean (S.D.)).

	Immediate	After One-Day Storage	*p*-Value [a]
FluoriCore 2	4.61 (0.34)	9.20 (0.85)	<0.05
RelyX Ultimate	3.78 (0.31)	9.22 (0.73)	<0.05
RelyX Unicem 2 Automix	4.16 (0.51)	8.22 (0.58)	<0.05
Filtek BulkFill Flowable Restorative	3.25 (0.21)	7.82 (0.51)	<0.05
NX3	0.84 (0.26)	5.97 (0.49)	<0.05
MultiCore Flow	4.27 (0.73)	8.44 (0.47)	<0.05
UniFil Core EM	4.72 (0.39)	11.12 (0.92)	<0.05
BeautiCore Flow Paste	5.79 (0.47)	9.62 (0.66)	<0.05
i-TFC system Post Resin	3.33 (0.35)	6.86 (0.42)	<0.05
ESTECORE	8.05 (0.95)	13.80 (1.35)	<0.05
Clearfil DC Core Automix ONE	4.74 (0.56)	8.43 (0.55)	<0.05

$n = 10$; [a] *t*-test.

4.4. Discussions

The higher value of flexural strength and flexural modulus after 1 day, compared with the immediate condition, resulted partly from the stiffer luting-agents with higher moduli [4,9,11]. The improvement in strength and elastic modulus after one day was a result of the improvement in the polymerization rate of cement over time [11].

Flexural strength testing was sensitive to surface defects such as cracks, voids, scratches, and which can influence the fracture characteristics of a brittle material. The degree of high flexural strength was believed to reflect high resistance to surface defects and erosion. Therefore, it was thought that flexural strength was a significant important mechanical property of resin composite materials (luting materials, filling materials and core build-up materials). In the bid to better these materials, ensuing research and development efforts should focus on the change of flexural strength with elapsed time [4,6–8,23].

The flexural strength and the flexural modulus of ESTECORE after one day was higher than others. The polymerization rate might be high by analogy with this tendency. The flexural strength of RelyX Unicem 2 Automix after one day was lower than others. It was thought that the reason is that the flexural modulus might be low, and with this tendency the polymerization rate might be low by analogy [19]. As the clear reason was unknown from the composition (including the filler content) informed by the manufacturer, it might be possible to guess the molecular weight, compounding ratio, degree of cross-linking, polymerization rate, etc. of the monomer. Similarly, the molecular weight, compounding ratio, and degree of cross-linking of the monomers might be affected.

The core build-up materials showed excellent values similar to filling materials that were required to withstand occlusion and maintain the crown. The manufacturer also designed with this intention.

In clinical settings, it might be advisable to delay polishing when composite biomaterials are used for luting materials, filling materials and core build-up materials, as improved mechanical properties were displayed after 1-day storage. The clinical implication was that dentists and patients might agree to a next-day returned visit for polishing to improve the survival rate of their restorations.

4.5. Relevancy

At times, so much tooth structure can be lost from caries that the crown of the tooth might be built up to receive a crown. Until now, composite materials have been the most

common core material. Composite core materials were typically two-paste, self-cured composites, although light-cured and dual-cured products were available. Composite core materials had the following advantages as compared with amalgam: they could be bonded to dentin, could be easy to contour, had mechanical properties, had good color under ceramic, and biocompatibility. In particular, it was thought that flexural characteristics would be important and significant from now on for the appearance of modern ceramic restoration. We hope that these results will guide selection in clinical situations.

5. Novelty

This paper briefly states that the flexural strength and flexural modulus of composite materials widely used as restoration materials in the oral cavity can be measured by the same method, and the mechanical properties can be grasped uniformly.

6. Conclusions

It was concluded that the composites used as luting materials, filling materials and core build-up materials were all shown to improve flexural strength and flexural modulus over the course of one day. The improvement in strength and elastic modulus after one day was a result of the improvement in the polymerization rate of cement over time.

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