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Article

Resin Cements as Core Build-Up Materials: Impact of Universal Adhesives on Fiber Post Cementation

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Abstract

Eleven resin cements, used as core build-up materials in this study, were evaluated *via* the following measurements: (a) push-out force between root dentin and fiber post; (b) pull-out force between core build-up material and fiber post; (c) shear bond strength of resin cement to root dentin; (d) flexural strength of resin cement; and (e) flexural modulus of elasticity of resin cement. All tests were performed at two time periods: after 1-day storage in water (Base) and after 20,000 thermocycles (TC 20k). For the push-out test, single-rooted human premolars were used to create simulated cavities. The specimens were sectioned horizontally perpendicular to their long axes into 2-mm slices. These slices were then subjected to push-out test to determine the bond strength between human root dentin, resin cement layer, and the fiber post. There were no significant differences in bond strength between Base and TC 20k. Therefore, surface pretreatments of multiple substrates with universal adhesives for fiber post cementation could ensure not only strong, but also durable, adhesion over time.

Keywords: shear bond strength; universal adhesive; fiber post; resin luting materials; root dentin; durability

1. Introduction

Where natural-looking teeth and a confident smile are non-negotiable outcomes, most aesthetic-centric tooth restorations are currently inclined towards fiber posts and resin cores. Compared with traditional cast metal posts, fiber posts have a modulus of elasticity similar to that of dentin. This is clinically advantageous because it reduces the occurrence of root canal fractures [1–6]. In endodontically treated teeth without an adequate ferrule, lost ferrule portions can be restored with resin cores. However, the resin core build-up procedure can be cumbersome because different substrates require different surface treatment agents: a silane coupling agent for the cured composite resin (the restored portion of the ferrule) and an acid monomer-containing treatment agent for the natural root dentin structure [7–10].

Recently developed resin cements have overcome the major hurdle of requiring different surface treatment agents for different substrates when used as a core build-up material. These updated resin cements can be applied to all types of substrates and were shown to exhibit strong adhesion to root canal dentin. In addition, they no longer require one surface treatment agent for root canal dentin and another different one for the cured composite resin (restored portion of the ferrule). Other improvements which favor their pragmatic use as a core build-up material include possessing excellent mechanical strength to withstand occlusal bite forces during mastication [11–14].

Fiber posts are typically reinforced with E-glass or S-glass fibers. Known for their high tensile strength, excellent flexibility and biocompatibility, these fibers are embedded within a polymeric resin matrix, typically epoxy or methacrylate polymer, to create a composite material with an elastic modulus ranging from 16 to 40 GPa [4]. In addition to their aesthetic appeal, fiber posts offer several advantages such as high impact resistance, high shock absorption capacity, increased fatigue resistance, and reduced root fracture risk [15]. In endodontically treated teeth, fiber posts are traditionally bonded to the root canal surface using resin cement and a silane primer, thereby forming an integrated dentin-post adhesive system.

Recently, a new version of adhesive system categorized as a “universal” adhesive has been shown in market. A universal adhesive system is a single-step procedure that can be applied to teeth substrates in clinical conditions. This single-step adhesive system can then be applied to bond to restorative materials in many cases: such as zirconia, metal, and various ceramic materials without pretreating by a priming agent [16–21].

In our previous studies, we focused on the impact of the flexural properties of resin cements as core build-up materials on bonding performance. We investigated the relationships between the flexural strength or flexural modulus of elasticity of core build-up materials and their shear bond strength to root dentin, as well as with the retentive force of dental restorative materials (e.g., dental post and lithium disilicate ceramic) [21,22]. In a more recent study, our focus progressed to the impact of universal adhesives on long-term bonding durability. In the absence of hydrofluoric acid (HF) pretreatment, Tokuyama Universal Bond II — a universal adhesive — showed significantly higher shear bond strength to lithium disilicate (LDS) ceramic than other bonding agents after 20,000 thermocycles [23]. For LDS, long-term bonding durability could be maintained by pre-treating with Tokuyama Universal Bond II instead of the hazardous HF.

In this study, a simplified procedure using “universal adhesives” was applied to fiber posts, root dentin substrates, and updated core build-up materials that have emerged in the market. At two time periods, after 1-day storage (Base) and after 20,000 thermocycles (TC 20k), this study measured the following fiber post cementation-related values: (a) push-out force between root dentin and fiber post; (b) pull-out force between core build-up material and fiber post; (c) shear bond strength of resin cement to root dentin; (d) flexural strength of resin cement; and (e) flexural modulus of elasticity of resin cement.

Three hypotheses were tested in this study: (1) One or more values of (b), (c), (d), and (e) would correlate with value (a); (2) “Universal adhesives” could provide durable bonding among root dentin, fiber posts, and core build-up materials, and this bonding would not be influenced by the time period (Base *versus* TC 20k); (3) Tokuyama Universal Bond II would be confirmed as an effective “universal adhesive” for diverse core build-up materials, luting cements, and fiber posts.

2. Materials and Methods

Tables 1 to 3 list the manufacturers and compositions of all materials used in this study.

Table 1. Core build-up materials used in this study.

Product	Composition	Manufacturer	Batch No.
RelyX Universal Resin Cement	Surface treated glass powder filler, Phosphate ester monomer, TEGDMA,	Solventum, Seefeld, Germany	11531204

	DiurethaneDimethacrylate, Silica filler, Initiator, Titanium Dioxide		
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.%. Bis-GMA, TEGDMA, Bis-MPEPP, Silica-Zirconia Filler, Camphorquinone, Peroxide, Radial amplifier, Others, Filler content: 75 wt.%	Kuraray Noritake Dental, Tainai, Niigata, Japan	8L06384
ESTECORE	Bis-GMA, TEGDMA, Bis-MPEPP, Silica-Zirconia Filler, Camphorquinone, Peroxide, Radial amplifier, Others, Filler content: 75 wt.%	Tokuyama Dental, Tokyo, Japan	U295
ESTECEM II Plus	Paste A: Bis-GMA, TEGDMA, Bis-MPEPP, Silica-Zirconia Filler Paste B: Bis-GMA, TEGDMA, Bis-MPEPP, Silica-Zirconia Filler, Camphorquinone, Peroxide, Filler content: 74 wt.%. UDMA, Dimethacrylate, Fluoroaluminosilicate glass, Iron oxide, Dibenzoyl peroxide, Butylated hydroxytoluene, Filler content: 75 wt.%	Tokuyama Dental, Tokyo, Japan	A09719
UniFil Core EM	UDMA, Dimethacrylate, Fluoroaluminosilicate glass, Iron oxide, Dibenzoyl peroxide, Butylated hydroxytoluene, Filler content: 75 wt.%. Ytterbium trifluoride, Bis-GMA, UDMA, TEGDMA, Dibenzoyl peroxide, Filler content: 70 wt. %, 46 vol. %, The particle size ranges from 0.04 to 25 µm.	GC, Hasunuma, Itabashi, Tokyo, Japan	2302201
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. Paste A: Zirconium silicate filler, Bis-GMA, Phosphonic acid monomer, Carboxylic acid monomer, Polymerization initiator, Others Paste B: Glass powder filler (S-PRG filler), UDMA, Polymerization initiator, Pigments, Others Filler content: approximately 60 wt.%. Barium Aluminoborosilicate glass, Ytterbium trifluoride, Fumed Silica, TEGDMA, UDMA, EBPADMA, Initiator, Stabilizer, Filler content: 67.5 wt.%, 43.3 vol.%. Urethane Dimethacrylate, Di- & Tri-functional Methacrylates, Barium Boron, Fluoroaluminosilicate Glass, Camphorquinone (CQ) Photoinitiator, Photoaccelerators, Silicon Dioxide, Benzoyl Peroxid	Ivoclar Vivadent AG, Schaan, Liechtenstein	ZO7ZCY
BeaitiLink SA	Paste A: Zirconium silicate filler, Bis-GMA, Phosphonic acid monomer, Carboxylic acid monomer, Polymerization initiator, Others Paste B: Glass powder filler (S-PRG filler), UDMA, Polymerization initiator, Pigments, Others Filler content: approximately 60 wt.%. Barium Aluminoborosilicate glass, Ytterbium trifluoride, Fumed Silica, TEGDMA, UDMA, EBPADMA, Initiator, Stabilizer, Filler content: 67.5 wt.%, 43.3 vol.%. Urethane Dimethacrylate, Di- & Tri-functional Methacrylates, Barium Boron, Fluoroaluminosilicate Glass, Camphorquinone (CQ) Photoinitiator, Photoaccelerators, Silicon Dioxide, Benzoyl Peroxid	Shofu, Kyoto, Japan	122303
NX3	Barium Aluminoborosilicate glass, Ytterbium trifluoride, Fumed Silica, TEGDMA, UDMA, EBPADMA, Initiator, Stabilizer, Filler content: 67.5 wt.%, 43.3 vol.%. Urethane Dimethacrylate, Di- & Tri-functional Methacrylates, Barium Boron, Fluoroaluminosilicate Glass, Camphorquinone (CQ) Photoinitiator, Photoaccelerators, Silicon Dioxide, Benzoyl Peroxid	Kerr, Orange CA, USA	A172592
Core-X flow	Urethane Dimethacrylate, Di- & Tri-functional Methacrylates, Barium Boron, Fluoroaluminosilicate Glass, Camphorquinone (CQ) Photoinitiator, Photoaccelerators, Silicon Dioxide, Benzoyl Peroxid	DENTSPLY Caulk, Milford	DE 19963
SI-300381	Paste A: Fluoroboroaluminosilicate glass, Bis-GMA, TEGDMA, Polymerization initiator, Pigments, Others Paste B: Fluoroboroaluminosilicate glass, Bis-GMA, TEGDMA, Polymerization initiator, Others	Shofu, Kyoto, Japan	250517D
i-TFC system Post Resin	Dimethacrylates, Silica, Barium glass filler, Photoinitiators, Stabilizer, Others Filler content: 67 wt.%. TEGDMA: Triethyleneglycol dimethacrylate , Bis-GMA: Bisphenol A diglycidylmethacrylate, MDP: 10-Methacryloyloxydecyl dihydrogen phosphate, HEMA: 2-Hydroxymethacrylate PMMA: poly(methyl methacrylate), 4-META: 4-methacryloxyethyl trimellitate anhydride, MMA: methyl methacrylate, TBB: Tri-n-butylborane.	SUN MEDICAL, Moriyama, Japan	MX13

TEGDMA: Triethyleneglycol dimethacrylate , Bis-GMA: Bisphenol A diglycidylmethacrylate, MDP: 10-Methacryloyloxydecyl dihydrogen phosphate, HEMA: 2-Hydroxymethacrylate PMMA: poly(methyl methacrylate), 4-META: 4-methacryloxyethyl trimellitate anhydride, MMA: methyl methacrylate, TBB: Tri-n-butylborane.

All procedures were performed in accordance with the manufacturers’ instructions. For light activation, a light-curing unit (G-Light Prima II, GC, Tokyo, Japan) 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/cm². Human premolars and molars, extracted for orthodontic reasons, were used. After extraction, the tooth was immediately stored in cold distilled water at about 4°C for 1 or 2 months before using. The research protocol of this study was approved by the Ethics Committee of Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences and Okayama University Hospital (No. 1901-036). A single operator performed all the procedures according to the manufacturers’ instructions. For each test and time period, ten specimens were prepared for each resin cement.

2.1. Push-out Test

Simulated cavities were prepared using extracted single-rooted human premolars with K reamers (new Endo K Reamers, Shofu, Kyoto, Japan; 25 mm length, Sizes 10 and 15), K-files (new Endo K-Files, Shofu, Kyoto, Japan; 25 mm length, Sizes 25 and 30) and a Peeso reamer (new Endo Peeso Reamer, Shofu, Kyoto, Japan; 16 mm length, Size 6) according to the conventional methods. Root canals of the simulated cavities were cleaned with a 3–6% sodium hypochlorite solution (Antiformin, Nippon Shika Yakuhin, Shimonoseki, Japan) for 1 min, followed by a 3% EDTA solution (SMEARCLEAN, Nippon Shika Yakuhin, Shimonoseki, Japan) for 1 min.

Root dentin surfaces were pretreated with universal adhesives according to each manufacturer’s instructions (Table 2).

Table 2. Universal adhesives used in this study.

Adhesive	Batch No.	Composition	Manufacturer	Surface treatment
Scotchbond Universal Plus Adhesive	8846013	Brominated dimethacrylate, HEMA, Silane Treated Silica, Vitrabond Copolymer, MDP, Initiators, MPTES, Ethanol, Water	3M, Seefeld, Germany	Scotchbond Universal Plus Adhesive (20 s) – air (5 s)
CLEAFIL Universal Bond Quick 2	AH0023	3-Methacryloxypropyl trimethoxysilane, MDP, Ethanol	Kuraray Noritake Dental, Tainai, Niigata, Japan	CLEAFIL CERAMIC PRIMER PLUS (1-2 s) – air (5 s)
G-Cem One Multi Primer	2104221	Vinyl silane, Phosphate ester monomer, Thiophosphate ester monomer, Methacrylic ester, Ethanol	GC, Hasunuma, Itabashi, Tokyo, Japan	G-Cem One Multi Primer (10 s) – air (5 s)
Tokuyama Universal Bond II (A+B)	Bond A: 0011 Bond B: 0510	Liquid A: Phosphoric acid monomer (New 3D-SR monomer), MTU-6, HEMA, Bis-GMA, TEGDMA, Acetone, Others. Liquid B: γ-MPTES, Borate, Peroxide, Acetone, Ethanol, Water, Others	Tokuyama Dental, Tokyo, Japan	Tokuyama Universal Bond II Mix (Liquid A + Liquid B, 1-2 s) – air (5 s)

Monobond Plus	ZO1LG8	Phosphoric acid monomer, Silane methacrylate, Ethanol	Ivoclar Vivadent AG, Schaan, Liechtenstein	Monobond Plus (60 s) – air
BeautiBond Xtreme	042347	Acetone, Water, Bis-GMA, TEGDMA, Phosphoric ester monomer, Silane coupling agent, Initiator, Others	Shofu, Kyoto, Japan	BeautiBond Xtreme (20 s) – air
OptiBond eXTRa Universal	Primer: 8199022 Adhesive: 8181793	HEMA, dimethacrylate monomers, tri-functional methacrylate monomer, Ethanol, Photo-initiator, Bariumaluminosilicate filler, Silica, Sodium hexafluorosilicate	Kerr, Orange CA, USA	OptiBond eXTRa Adhesive (15 s) – air (5 s) – LED light (5 s)
Prime&Bond universal	DE 19963	Phosphoric acid modified acrylate resin, Multifunctional acrylate,, Bifunctional acrylate, Acidic acrylate, Isopropanol, Water, Initiator, Stabilizer	DENTSPLY Caulk, Milford	<u>Endodontic post cementation</u> 1. Apply mixture of Prime&Bond universal & Dentsply Self cure Activator post surface 2. Leave it undisturbed for 10 sec. and dry naturally <u>Post Cementation</u> Core-X flow into the post space and immediately insert the post into the post space. Light-cure from every aspect using a light-curing unit to fix the post: Halogen for 20 sec.
SI-303062	Primer A: 250317 Primer B: 250314	Primer A: Acetone, Distilled water, Bis-GMA, Carboxylic acid monomer, TEGDMA, Phosphonic acid monomer, others Primer B: Distilled water, Acetone, initiator	Shofu, Kyoto, Japan	<u>Preparation of the post</u> 1. Apply SHOFU Porcelain Primer to the post in one layer with a disposable brush. 2. Leave it undisturbed for 10 sec. and dry naturally <u>Pretreatment of post space</u> 1. Primer A and Primer B in equal amounts and apply the mixture onto the entire adhesive surface of the post space. 2. Leave undisturbed for 10 sec. Air dry with gentle air for 3 sec and then dry with stronger air to dry the surface sufficiently. 3. Light-cure with a light-curing unit: Halogen for 10 sec. <u>Post Cementation</u> 1. Fill SI-300381 Paste into the post space and immediately insert the post into the post space. Light-cure from every aspect using a light-curing unit to fix the post: Halogen for 20 sec.
i-TFC Luminous Bond II	Bond: FW1, Catalyst blush: ES1	Bond: Methacrylic acid esters (4-META, others), Acetone, water, others	SUN MEDICAL,	Mix (Bond + Catalyst prush, 5 sec) – air (10 sec) – LED light (20 sec)

Catalyst blush: Aromatic amines, aromatic sulfinates Moriyama, Japan

2-HEMA:Hydroxyethylmethacrylate, MDP: 10-methacryloyloxydecyl dihydrogen phos-phate, Bis-GMA: Bisphenol A diglycidylmethacrylate, 4-MET: 4-methacryloxyethyl trimellitic acid, MTU-6: 6-methacryloxyhexyl 2-thiouracil-5-carboxylate, γ -MPTES: 3-(triethoxysilyl) propyl methacrylate, VTD: 6-(4-vinylbenzyl-n-propyl) amino-1,3,5-triazine-2,4-dithione, MMA: methyl methacrylate, γ -MPTS: 3-methacryloxypropyl trimethoxy silane.

Similarly, the surface of each fiber post (Table 3) was treated with the respective system’s universal adhesive according to the manufacturers’ instructions in Table 2. For Ivoclar Vivadent’s Monobond Plus and Kerr Dental’s OptiBond eXTRa Universal adhesives which had no recommended post system, BeautiCore FiberPost (diameter: 1.6 mm; Shofu, Kyoto, Japan; Table 3) was used as the post system.

Table 3. Fiber posts used in this study.

Product (Diameter)	Composition	Manufacturer	Batch No.
RelyX FiberPost (1.6 mm)	Glass fibers, Composite resin matrix	Solventum, Seefeld, Germany	306831603
Tokuyama FR Post (1.6 mm)	Glass fibers, Colpolymer Bis-GMA resin	Tokuyama Dental, Tokyo, Japan	1604251
GC Fiber Post (1.6 mm)	Glass fibers, Metacrylate	GC, Tokyo, Japan	1609021
Clearfil AD Fiber Post (1.6 mm)	Glass fibers, Colpolymer Bis-GMA and Methacrylic acid monomer	Kuraray Noritake Dental, Tainai, Niigata, Japan	7U0001
BeautiCore FiberPost (1.6 mm)	Glass fiber, Copolymer of Bis-GMA and Methacrylic ester monomer	Shofu, Kyoro, Japan	41601
i-TFC Luminous Fiber II (1.6 mm)	Glass components: Borosilicate glass, barium oxide, and others Resin component: Dimethacrylate and diacrylate copolymer, others	SUN MEDICAL, Moriyama, Japan	EL1S

A resin cement paste of the respective systems listed in Table 1 was filled into the post space, and the pre-treated fiber post was placed in the root canal. The resin pastes were light-irradiated twice, 20 sec each time, from the occlusal surface of the post using a light-curing unit (G-Light Prima II, GC, Tokyo, Japan). Test specimens obtained were stored in 37°C water for 24 hr, and then the coronal portion of each specimen was removed using a low-speed precision cutter (IsoMet, Buehler, Lake Bluff, IL, USA). Each root canal specimen was sectioned horizontally perpendicular to the long axis of the specimen into 2-mm slices (Figure 1) at a crosshead speed of 0.5 mm/min using a universal testing machine (5565, Instron, Canton, MA, USA) to determine the bond strength between human dentin, the resin cement layer, and the fiber post — which constituted the integrated dentin-post adhesive system.

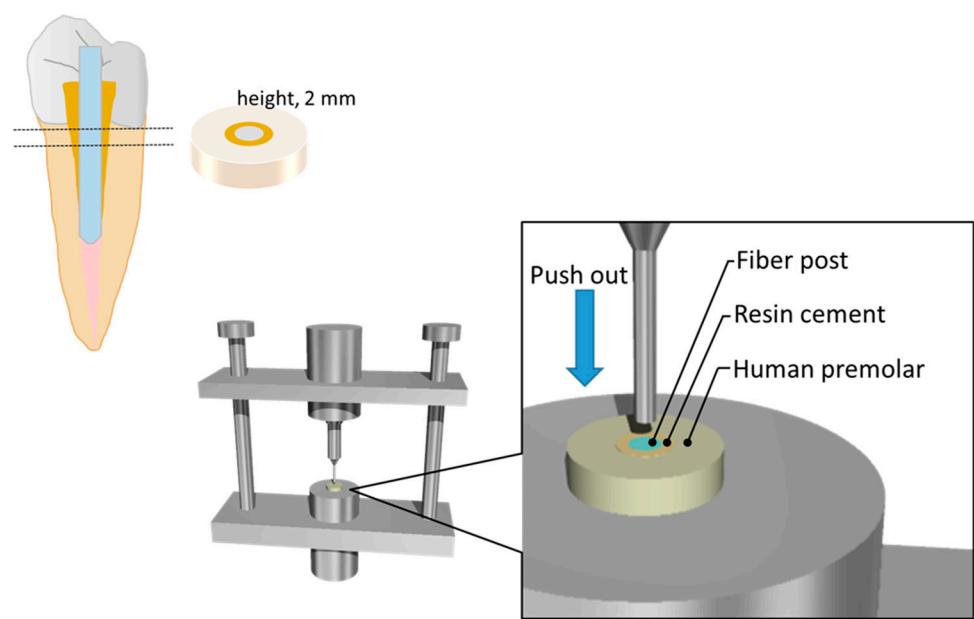


Figure 1. Schematic illustration of push-out test.

All failed specimens were checked with a light microscope (SMZ-10, Nikon, Tokyo, Japan) to determine the nature of their fractures [21–23].

2.2. Pull-out Test

Each post was pretreated with a universal adhesive according to the manufacturers’ instructions in Table 2. For Ivoclar Vivadent’s Monobond Plus and Kerr’s OptiBond eXTRa Universal adhesives which had no instructed post procedure system, BeautiCore FiberPost (Diameter: 1.6 mm; Shofu, Kyoto, Japan; Table 3) was utilized as the post procedure system.

Each resin core build-up material was filled in a Teflon mold (Upper diameter: 8 mm, bottom diameter: 3.6 mm, height: 5 mm) set on a glass plate pre-coated with Vaseline. Then, each post was inserted at the center of the Teflon mold using a retainer and cured in four overlapping sections, with each section cured for 20 X 4 sec. in Figure 1

Specimens thus obtained were mounted on a universal testing machine (5565, Instron, Canton, MA, USA), and pull-out force was applied at a crosshead speed of 0.5 mm/min ($n=10/\text{group}$) in Figure 1. As each post differed in its external form, the maximum failure load was expressed in Newton (N). After the pull-out force testings, all failed specimens were checked with a light microscope (50 X; Measurescope MM-II, Nikon, Tokyo, Japan) to determine the status of their fracture modes. Three categories of fractured mode were evaluated: (1) adhesive failure at the interface between post and resin core material; (2) cohesive failure within the resin core material; and (3) combination of adhesive and cohesive failures on the same surface or a mixed failure [21].

2.3. Shear Bond Strength of Resin Cement to Root Dentin

Specimens were gotten from human premolars and molars, embedded in slow-polymerizing epoxy resin (EpoFix Resin, Struers, Copenhagen, Denmark) with their buccal surfaces up, and wet-ground with silicon carbide abrasive papers up to 320 grit until a superficial dentin area of at least 4 mm diameter was exposed. A split Teflon mold having a cylindrical hole (Diameter: 3.6 mm, height: 2 mm) was fixed to the prepared dentin surface in a mounting apparatus. The Teflon mold was filled with resin cement paste after applying its corresponding treatment agent to the dentin surface according to the manufacturers’ instructions in Table 2. Light irradiation was performed to harden the cement paste (20 sec each from two directions). After 24-hr storage in 37°C distilled water, the specimens were subjected to a shear force using a universal testing machine (Autograph DCS-2000, Shimadzu, Kyoto, Japan) at a crosshead speed of 0.5 mm/min. The force was transmitted *via* a flat

(blunt) 1-mm-thick shearing blade at a perpendicular direction to the load. Stress at failure was calculated and recorded as the shear bond strength value. All failed specimens were analyzed using a light microscope (SMZ-10, Nikon, Tokyo, Japan) to determine the nature of their fractures [21–23].

2.4. Flexural Strength and Flexural Modulus of Elasticity of Resin Cement

Test specimens of respective resin cements ($n=10/\text{group}$) were prepared using a Teflon mold ($25\times2\times2\text{ mm}$). Each resin paste was light-irradiated in three overlapping sections, with each section irradiated for 20 sec. Both sides of the specimen were light-irradiated in the same way. After 24-hr storage in 37°C distilled water, the specimens were subjected to flexural properties testing *via* a three-point loading upon the specimens with a 20-mm span and at a loading rate of 0.5 mm/min using a universal testing machine (5565, Instron, Canton, MA, USA) as outlined in ISO 9917-2:1998. Their flexural strength and flexural modulus of elasticity values were then calculated (Series IX software, Instron, Canton, MA, USA).

2.5. Scanning Electron Microscope (SEM) Observations

Following the pull-out tests, fractured surfaces of specimens were randomly selected for observation using a scanning electron microscope (SEM; JSM-IT800 SHL, Jeol, Tokyo, Japan), which operated at an accelerating voltage of 5 kV. To prevent charging occurring at the specimen surface, a thin film of osmium was deposited using an osmium coater (Neoc-STB, Meiwaafosis, Tokyo, Japan).

2.6. Statistical Analysis

Statistical analyses were analysed using the software package, Statistica 9.1 (StatSoft, OK, USA). Analyses of variance (two-way ANOVA) with Tukey’s HSD for post-hoc comparison were used to analyse the data obtained for push-out force, pull-out force, shear bond strength to root dentin, flexural strength, and flexural modulus of elasticity ($p<0.05$).

Any possible correlations between push-out force and pull-out force, between push-out force and shear bond strength to root dentin, between push-out force and flexural strength, and between push-out force and flexural modulus of elasticity were evaluated (Spearman; $p<0.05$). Analyses were conducted using SPSS version 19 (Chicago, IL, USA). In addition, based on the results of the correlation analysis previously conducted between the two results, multiple linear regression analyses were performed using the three independent factors of push-out force, pull-out force, and flexural modulus of elasticity. Level of significance was performed at $p<0.05$.

3. Results

3.1. Push-out Test

Push-out force data and their statistical analysis results are given in Table 4.

Table 4. Push-out force data of core build-up systems (N, Mean (S.D.), Adh.).

Core build-up systems: Resin cement / Pretreating agent / Fiber-post	Time		<i>t</i> -Test *
	Base (1-day)	TC 20k	
RelyX Universal Resin Cement / Scotchbond Universal Plus Adhesive / RelyX Fiber Post	19.8 (4.2, 0) ab [#]	19.6 (3.1, 0) e	NS
Clearfil DC Core Automix ONE / Clearfil Universalbond Quick 2 + Clearfil Porcelain Bond Activator / Clearfil AD Fiber Post	24.5 (5.3, 0) abc	23.0 (4.3, 0) efgh	NS
UniFil Core EM / G-Premio BOND + G-Premio BOND DCA / GC Fiber Post	23.4 (4.6, 1) abc	20.4 (2.4, 0) ef	NS

ESTECER II / Tokuyama Universal Bond II (A+B) / Tokuyama FR Post	26.7 (3.6, 0) c	23.1 (3.9, 0) efgh	NS
ESTECORE Hand Type / Tokuyama Universal Bond II (A+B) / Tokuyama FR Post	26.4 (2.9, 0) c	25.6 (3.2, 0) efg	NS
MultiCore Flow / Monobond Plus / BeautiCore Fiber	23.7 (5.0, 0) abc	18.9 (2.7, 0) e	S
NX3 / OptiBond XTR + Porcelain Primer (Shofu) / BeautiCore Fiber	26.6 (4.9, 0) c	18.9 (3.2, 0) e	S
BeautiLink SA Automix + BeautiBond Xtreme, BeautiCore FiberPost	25.2 (3.6, 0) bc	24.1 (3.1, 0) efgh	NS
SI-303062 (A + B) / SI-300381 / Post pretreated by BeautiBond Xtreme / BeautiCore FiberPost	28.7 (2.7, 0) d	28.0 (2.6, 0) h	NS
core-X flow / Prime&Bond universal + Self cure Activator / FluoroPost	25.5 (4.9,0) bc	22.6 (4.7, 0) efgh	NS
i-TFC system Post Resin / i-TFC Luminous Bond II / i-TFC Luminous Fiber II	21.0 (4.2, 0) abc	22.7 (4.2, 0) efgh	NS

*: S: Significant difference ($p < 0.05$), NS: Not significant difference ($p > 0.05$), #: Superscript letters represent groups with no significant difference (a-d, e-h, Tukey HSD procedure), $p > 0.05$, TC 20k: after 20,000 thermocycles, n=10, Adh: Number of adhesive failure modes after failure ¹⁰).

The push-out force of many post-core systems did not change significantly with time ($p>0.05$, except MultiCore Flow and NX3 systems). The 1-day time period yielded the higher mean data. SI-300381 system showed the highest values at both time periods (after 1-day storage and after TC 20k), while MultiCore Flow system exhibited lower values at both time periods.

On failure mode, no adhesive fractures were observed. Overall, the proportion of adhesive failures for all systems was similar at both time periods.

3.2. Pull-Out Test for Pretreatment with Manufacturers’ Recommended Agents

Pull-out force data and their statistical analysis results are given in Table 5.

Table 5. Pull-out force data between core build-up materials and fiber posts (N, mean (S.D.), Adh.).

Materials / Fiber post (each manufacturer's recommended pretreatment agent)	Time		t-Test *
	Base (1-day)	TC 20k	
RelyX Universal Resin Cement / RelyX Fiber Post (Scotchbond Universal Plus Adhesive)	30.5 (2.7, 0) abcde	25.6 (3.1, 0) jk	S
Clearfil DC Core Automix ONE / Clearfil AD Fiber Post (Clearfil Universalbond Quick 2)	30.5 (3.5, 0) abcde	30.6 (4.7, 0) jklno	NS
UniFil Core EM / GC Fiber Post (G-Premio BOND + G-Premio BOND DCA)	33.1 (5.0, 0) cdef	34.1 (5.0, 0) mnopq	NS
ESTECER II / Tokuyama FR Post (Tokuyama Universal Bond II)	41.2 (3.4, 0) hi	41.8 (2.5, 0) s	NS
ESTECORE Hand Type / Tokuyama FR Post (Tokuyama Universal Bond II)	40.5 (3.7, 0) hi	44.3 (3.3, 0) s	NS
MultiCore Flow / BeautiCore Fiber (Monobond Plus)	36.5 (1.5, 0) ghi	23.6 (2.7, 0) j	S
NX3 / BeautiCore Fiber (OptiBond XTR + Porcelain Primer)	40.2 (4.5, 0) ghi	27.9 (4.6, 0) jklmn	S
BeautiLink SA Automix / BeautiCore FiberPost (BeautiBond Xtreme)	32.9 (2.3, 0) bcdef	29.4 (3.9, 0) jklm	NS
SI-303062 / BeautiCore FiberPost (BeautiBond Xtreme)	37.2 (3.5, 0) fghi	35.3 (3.3, 0) nopqr	NS

core-X flow / FluoroPost (Prime&Bond universal + Self cure Activator)	32.1 (4.1, 0) bcdef	26.9 (3.4, 0) jkl	NS
i-TFC system Post Resin / i-TFC Luminous Fiber II (i-TFC Luminous Bond II)	33.9 (4.0, 0) cdef	32.6 (5.0, 0) lmnop	NS

*: S: Significant difference ($p < 0.05$), NS: Not significant difference ($p > 0.05$), #: Superscript letters represent groups with no significant difference (a-i, j-s, Tukey HSD procedure), $p > 0.05$, TC 20k: after 20,000 thermocycles, n=10, Adh: Number of adhesive failure modes after failure ¹⁰).

The pull-out force of many post-core systems did not change significantly with time ($p>0.05$, except MultiCore Flow and NX3 systems). The 1-day time period yielded the higher mean data, except UniFil Core EM. BeautiLink SA Automix showed the highest values at the 1-day and TC 20k time periods.

On failure mode, no adhesive fractures were observed. Overall, the proportion of adhesive failures was the same at both time periods.

3.3. Pull-Out Test for Pretreatment with Tokuyama Universal Bond II

When Tokuyama Universal Bond II was used as the sole pretreatment agent, the pull-out force data and their statistical analysis results are given in Table 6.

Table 6. Pull-out force data for pretreatment with Tokuyama Universal Bond II (N, mean (S.D.), Adh.).

Materials / Fiber post (pretreated by Tokuyama Universal Bond II)	Time		t-Test *
	Base (1-day)	TC 20k	
RelyX Universal Resin Cement / RelyX Fiber Post	34.2 (4.5, 0) abcd	38.2 (4.7, 0) lmnopq	NS
Clearfil DC Core Automix ONE / Clearfil AD Fiber Post	34.7 (4.5, 0) abcde	35.5 (3.0, 0) jklmno	NS
UniFil Core EM / GC Fiber Post	38.0 (4.0, 0) bcdefgh	32.7 (2.8, 0) jkl	S
ESTEC EM II / Tokuyama FR Post	41.2 (3.4, 0) fghi	41.8 (2.5, 0) pqr	NS
ESTECORE Hand Type / Tokuyama FR Post	40.5 (3.7, 0) efghi	44.3 (3.3, 0) r	NS
MultiCore Flow / BeautiCore FiberPost	42.5 (1.2, 0) hi	36.9 (5.5, 0) klmnopq	S
NX3 / BeautiCore FiberPost	39.0 (2.6, 0) defghi	32.3 (1.7, 0) jkl	S
BeautiLink SA Automix / BeautiCore FiberPost	35.8 (4.1, 0) abcdefg	32.0 (3.1, 0) jk	NS
SI-303062 / BeautiCore FiberPost	38.0 (4.0, 1) bcdefgh	35.0 (3.7, 0) jklmno	NS
core-X flow / FluoroPost	35.7 (2.9, 0) abcdef	32.8 (4.4, 0) jkl	NS
i-TFC system Post Resin / i-TFC Luminous Fiber II	33.2 (3.8, 0) abcd	30.1 (5.8, 0) j	NS

*: S: Significant difference ($p < 0.05$), NS: Not significant difference ($p > 0.05$), #: Superscript letters represent groups with no significant difference (a-i, j-r, Tukey HSD procedure), $p > 0.05$, TC 20k: after 20,000 thermocycles, n=10, Adh: Number of adhesive failure modes after failure ¹⁰).

The pull-out force of many post-core systems did not change significantly with time ($p>0.05$, except UniFil Core EM, MultiCore Flow and NX3 systems). All systems showed values exceeding 30 MPa even after TC 20k.

On failure mode, no adhesive fractures were observed. Overall, the proportion of adhesive failures was the same at both time periods.

Based on the results in Table 6, Tokuyama Universal Bond II pretreatment produced higher pull-out force values for all post-core systems at both time periods. These results clearly confirmed that

the bonding effectiveness of Tokuyama Universal Bond II was extended to and applicable upon other manufacturers’ post-core systems.

3.4. Statistical Comparisons between Two Pretreatment Agents

When pretreated with Tokuyama Universal Bond II, all post-core systems used in this study showed values exceeding 30 MPa even after TC 20k. Significant difference was observed only when pretreatment with the manufacturer’s recommended agent yielded values below 30 MPa (Table 7).

Table 7. Comparison of the means (*t*-Test) of pull-out force data between two pretreatment agents (manufacturer-recommended adhesive *versus* Tokuyama Universal Bond II).

RelyX Universal Resin Cement		Clearfil DC Core Automix ONE		UniFil Core EM		ESTECCEM II	
Base	TC 20k	Base	TC 20k	Base	TC 20k	Base	TC 20k
NS	S	NS	NS	NS	NS	NS	NS
ESTECORE Hand Type		MultiCore Flow		NX3		BeautiLink SA Automix	
Base	TC 20k	Base	TC 20k	Base	TC 20k	Base	TC 20k
NS	NS	NS	S	NS	S	NS	NS
SI-303062		core-X flow		i-TFC system Post Resin			
Base	TC 20k	Base	TC 20k	Base	TC 20k		
NS	NS	NS	S	NS	NS		

TC 20k: after 20,000 thermocycles, S: Significant difference ($p < 0.05$), NS: Not significant difference ($p > 0.05$).

3.5. Shear Bond Strength to Root Dentin

Shear bond strength data and their statistical analysis results are given in Table 8.

Table 8. Shear bond strength data between root dentin and core build-up materials (MPa, mean (S.D.), Adh.).

Materials / Pretreating agent	Time		<i>t</i> -Test *
	Base (1-day)	TC 20k	
RelyX Universal Resin Cement / Scotchbond Universal Plus Adhesive	22.3 (3.9, 0) cd	19.2 (3.4, 0) fghi	NS
Clearfil DC Core Automix ONE / Clearfil Universalbond Quick 2	23.7 (3.7, 0) de	22.8 (2.9, 0) hij	NS
UniFil Core EM / G-Premio BOND + G-Premio BOND DCA	18.0 (4.1, 0) abc	19.0 (3.3, 0) fghi	NS
ESTECCEM II / Tokuyama Universal Bond II	22.0 (2.4, 0) bcd	20.3 (2.0, 0) fghi	NS
ESTECORE Hand Type / Tokuyama Universal Bond II	22.5 (3.5, 0) cd	21.6 (2.2, 0) fghi	NS
MultiCore Flow / Monobond Plus	21.2 (2.8, 0) abcd	21.5 (3.3, 0) fghi	NS
NX3 / OptiBond XTR	22.5 (3.0, 0) cd	16.8 (2.3, 0) fg	S
BeautiLink SA Automix / BeautiBond Xtreme	28.0 (4.3, 0) e	19.9 (2.4, 0) fghi	S
SI-303062 / BeautiBond Xtreme	21.0 (2.6, 0) abcd	18.6 (1.9, 0) fghi	NS
core-X flow / Prime&Bond universal + Self cure Activator	20.7 (4.2, 0) abcd	18.1 (2.4, 0) fgh	NS
i-TFC system Post Resin / i-TFC Luminous Bond II	17.8 (2.9, 0) abc	16.4 (3.3, 0) f	NS

*: S: Significant difference ($p < 0.05$), NS: Not significant difference ($p > 0.05$), #: Superscript letters represent groups with no significant difference (a-e, f-i, Tukey HSD procedure), $p > 0.05$, TC 20k: after 20,000 thermocycles, n=10, Adh: Number of adhesive failure modes after failure ¹⁰.

The shear bond strength of many core build-up materials did not change significantly with time ($p>0.05$, except NX3 and BeautiLink SA Automix). The 1-day time period yielded the higher mean data, except for MultiCore Flow. Clearfil DC Core Automix ONE showed the highest values at both time periods.

On failure mode, no adhesive fractures were observed. Overall, the proportion of adhesive failure modes was the same at both time periods.

3.6. Flexural Strength

Flexural strength data of core build-up materials and their statistical analysis results are given in Table 9.

Table 9. Flexural strength data of core build-up materials (MPa, mean (S.D.)).

Materials	Time		t-Test *
	Base (1-day)	TC 20k	
RelyX Universal Resin Cement	117.5 (7.0) c	108.8 (8.8) kl	NS
Clearfil DC Core Automix ONE	140.6 (9.6) efgh	140.9 (8.6) pqr	NS
UniFil Core EM	153.6 (11.4) i	151.2 (12.1) rs	NS
ESTECER II	162.1 (11.7) i	146.4 (10.1) qr	S
ESTECORE Hand Type	172.2 (10.2) i	153.9 (13.3) rs	S
MultiCore Flow	142.1 (9.1) fgh	126.3 (8.2) mno	S
NX3	123.7 (9.8) cd	97.9 (8.7) k	S
BeautiLink SA Automix	128.9 (5.3) cdef	101.7 (9.3) k	S
SI-303062	133.3 (6.4) defg	132.2 (5.8) mnopq	NS
core-X flow	136.0 (9.7) defg	128.0 (10.6) mnop	NS
i-TFC system Post Resin	139.4 (6.4) efgh	143.6 (9.0) pqr	S

*: S: Significant difference ($p < 0.05$), NS: Not significant difference ($p > 0.05$), #: Superscript letters represent groups with no significant difference (a-i, j-s, Tukey HSD procedure), $p > 0.05$, TC 20k: after 20,000 thermocycles, n=10, Adh: Number of adhesive failure modes after failure 10).

The 1-day time period yielded the higher mean data. Approximately half of the results showed a statistically significant decrease after TC 20k ($p<0.05$). At both time periods, ESTECORE Hand Type showed the highest values amongst the core build-up materials.

3.7. Flexural Modulus of Elasticity

Flexural modulus of elasticity data of core build-up materials and their statistical analysis results are given in Table 10.

Table 10. Flexural modulus data of core build-up materials (GPa, mean (S.D.)).

Materials	Time		t-Test *
	Base (1-day)	TC 20k	
RelyX Universal Resin Cement	4.27 (0.41) a	4.24 (0.28) i	NS
Clearfil DC Core Automix ONE	8.43 (0.55) cde	10.57 (1.10) nop	S
UniFil Core EM	11.12 (0.92) fg	11.26 (0.52) pq	NS
ESTECER II	12.42 (1.79) g	10.72 (0.67) op	S
ESTECORE Hand Type	13.80 (1.35) h	12.52 (0.59) r	NS
MultiCore Flow	8.44 (0.47) cde	7.77 (0.81) kl	NS
NX3	5.97 (0.49) b	5.90 (0.46) j	NS
BeautiLink SA Automix	8.49 (0.95) cde	7.91 (0.86) kl	NS
SI-303062	8.97 (0.77) de	9.27 (0.96) mn	NS
core-X flow	8.86 (0.82) de	9.75 (0.77) mno	NS
i-TFC system Post Resin	7.35 (0.52) c	7.92 (0.35) kl	NS

*: S: Significant difference ($p < 0.05$), NS: Not significant difference ($p > 0.05$), #: Superscript letters represent groups with no significant difference (a-h, i-r, Tukey HSD procedure), $p > 0.05$, TC 20k: after 20,000 thermocycles, $n=10$, Adh: Number of adhesive failure modes after failure 10).

Nearly all the core materials did not show a statistically significant decrease after TC 20k ($p>0.05$). Similar to flexural strength data, ESTECORE Hand Type showed the highest values at both time periods.

3.8. SEM Observations

Representative SEM images of fractured surfaces after pull-out testing are shown in Figure 2.

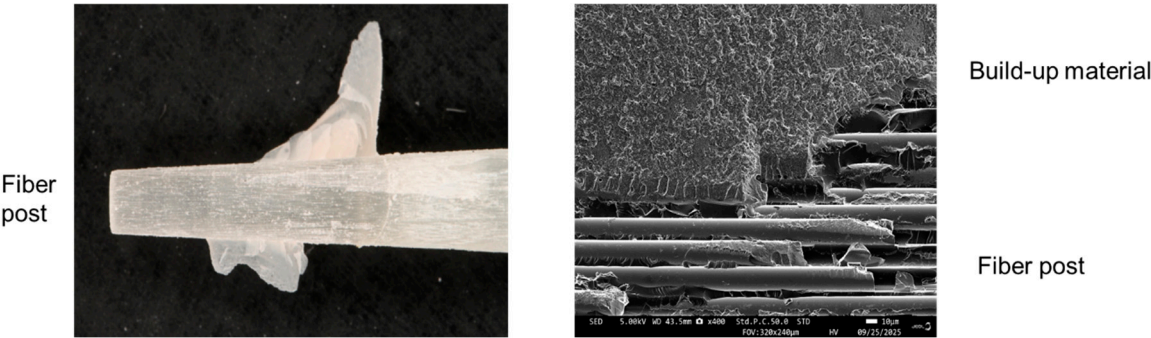


Figure 2. Left: Close-up image of core build-up material adhering to the fiber post. Right: SEM image of core build-up material adhering firmly to the fiber post and penetrating the fibers.

The lower-magnification SEM images showed cohesive failure pattern at the interface between the post (Tokuyama FR Post) and core material (ESTECORE II Plus). In other words, the post surface was chemically bonded to the core build-up material through universal adhesive pretreatment.

3.9. Correlations

For all core build-up materials at both time periods ($n=22$), relationships are shown in Table 11. Pull-out force ($r=0.656$, $p=0.0009$; Figure 3) and flexural modulus of elasticity ($r=0.475$, $p=0.025$) had a correlation respectively with push-out force (Table 11).

Table 11. Correlations with push-out force in Table 4 ($n=22$).

vs. Table4	<i>r</i>	<i>p</i>
Table 5	0.656	0.0009
Table 8	0.343	0.112
Table 9	0.409	0.058
Table 10	0.475	0.025

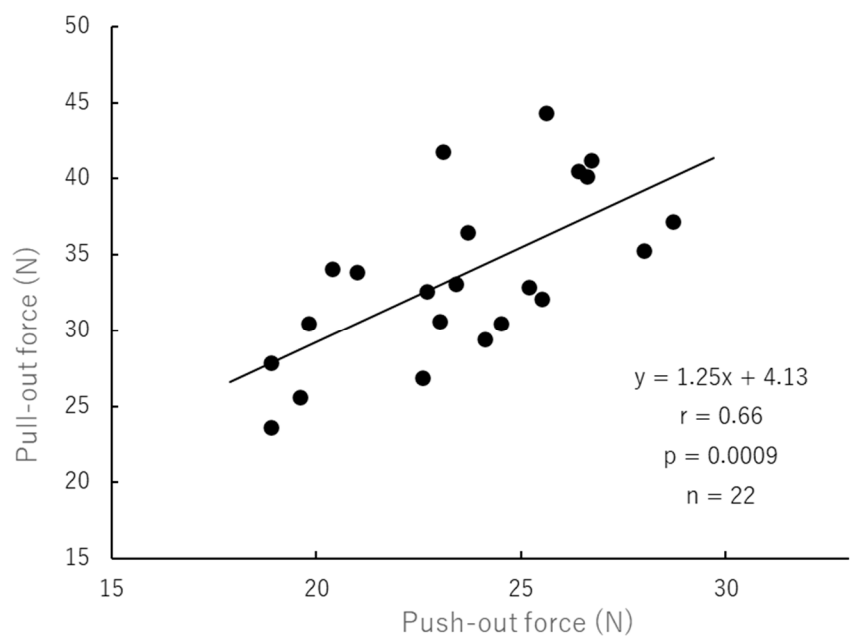


Figure 3. Relationship between push-out force and pull-out force.

Multiple linear regression analyses were conducted, yielding these relationships: Push-out Force = 0.353 Pull-out Force - 0.05 Flexural Strength + 12.285, $p=0.005$ (Figure 4), and Push-out Force = 0.300 Pull-out Force + 0.165 Flexural Modulus + 11.995, $p=0.0009$ (Figure 5).

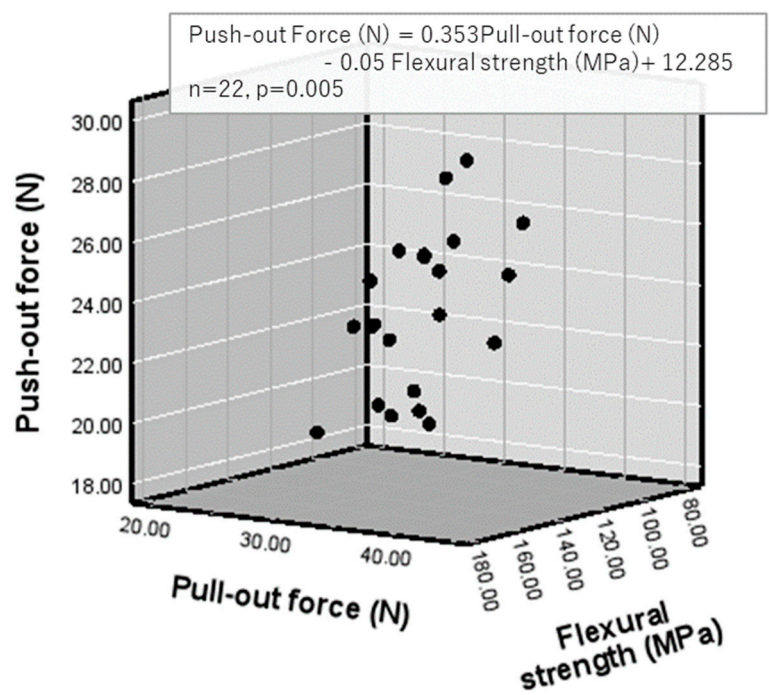


Figure 4. Relationships among push-out force, pull-out force and flexural strength.

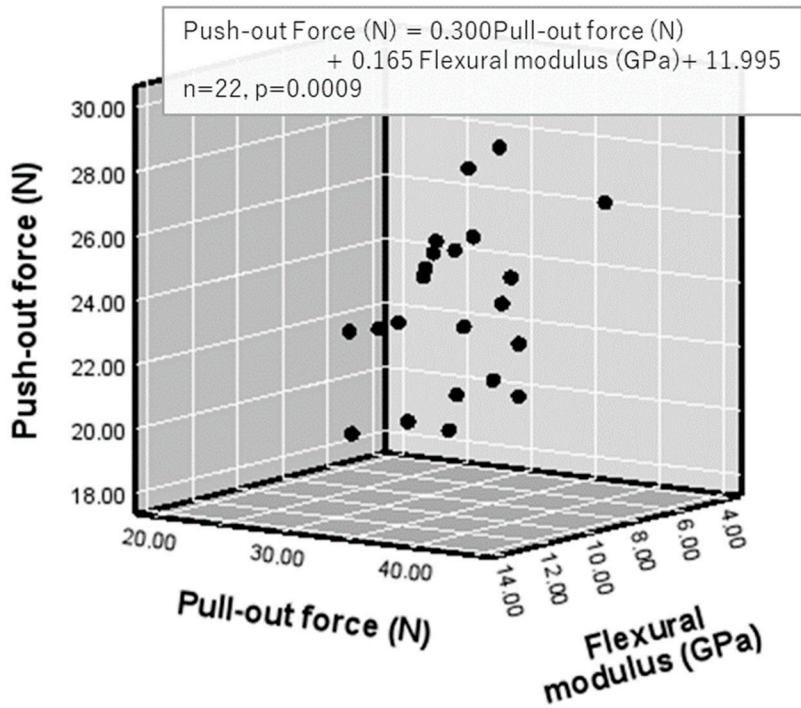


Figure 5. Relationships among push-out force, pull-out force and flexural modulus.

4. Discussion

The post and core system comprises the root canal dentin surface, core build-up material and the post surface, thereby producing two adhesive interfaces. Given the strong trend towards the use of fiber posts and resin cores for tooth restorations, a diverse range of products from myriad manufacturers have emerged to cater to this unabating demand. Therefore, the long-term durability of fiber post cementation should not just focus on the versatility and ease of use of universal adhesives for multiple substrates within the two adhesive interfaces, it should further explore the possibility of a singular, general-purpose universal adhesive that could be applied on other manufacturers’ post and core systems to yield the same effective bonding.

In this study, the impact of universal adhesives on fiber post cementation with resin cores was investigated by measuring the push-out force, pull-out force, shear bond strength, flexural strength and flexural modulus of elasticity. In addition, Tokuyama Universal Bond II was applied as a universal adhesive on other manufacturers’ post and core systems and investigated thereof for its bonding effectiveness.

4.1. Correlation Between Push-out Force and Pull-out Force (Table 11 and Figure 3)

When a body, an object or a material is pushed or pulled, a push force or pull force is a force generated upon an object arising from the object’s or body’s interaction with another object. If an object is in motion, an external push or pull may change the state or the direction of motion of that object [3]. Therefore, not only does a push or pull force produce motion in an object, it also has direction — which means that force is a vector quantity. If the directions of the force and moving object are opposite, then the magnitude of the net force acting on the object is decreased.

Change in the state of motion in an object or body is usually explained by the speed and direction of the acting force. In this study, a strong correlation was found between the push-out and pull-out values ($r = 0.656$, $p = 0.0009$, $y = 1.25x + 4.13$; $n=22$). This high correlation is understandable, given that the same pretreatment agents, fiber posts, and core build-up materials were used for both push-out and pull-out tests.

4.2. Correlation Between Push-out Force and Flexural Modulus of Elasticity or Flexural Strength (Table 11 and Figure 4)

Flexural strength of the core build-up materials had no strong correlation with the push-out force ($r=0.409$, $p=0.058$; close to a significant correlation). However, flexural modulus of elasticity had a significant correlation ($r=0.475$, $p=0.025$) with push-out force.

Displacement of the post due to push-out is thought to be more influenced by the elastic modulus — which determines how well the interface can withstand deformation — than by the core material's own mechanical strength (flexural strength). This would account for the elastic modulus to be more significantly correlated with the push-out force.

Elastic modulus describes the relative stiffness of a material within its elastic range of deformation. Natural hard tissues have a range of intrinsic stiffness or modulus values. Addition of restorative materials of different moduli can affect the overall stiffness of the restored tooth, and interfacial stresses are generated as a result. Therefore, the clinical outcome of a restored tooth is closely related to the matching of elastic modulus values. If the modulus mismatch is too great, interfacial stress may arise from thermal, mechanical, or shrinkage strain in the material. For this reason, core build-up material should have high elastic modulus similar to that of tooth structure (dentin) to withstand the forces of mastication and polymerization shrinkage stresses. To predict the clinical outcome of post and core restorations, it is hence vital to determine the elastic modulus values of core build-up materials [3].

4.3. Correlation Between Push-out Force and Shear Bond Strength (Table 11)

Push-out force did not correlate with shear bond strength ($p>0.10$). After push-out testing, only a small amount of core material adhered to the post. Since the majority of the root canal wall-core build-up material interface showed clear delamination failure, the effect of tooth structure adhesion appeared minimal, suggesting no correlation. This result could be due to pretreatment by universal adhesives. It was possible that the adhesive systems marketed by various manufacturers as “universal adhesives” failed to achieve the strong bond required for root canal dentin, such as that needed for bonding to core build-up materials or fiber posts.

4.4. Correlations among Push-out Force, Pull-out Force, and Flexural Strength or Flexural Modulus of Elasticity (Figures 4 and 5)

Both push-out force and pull-out force showed significant correlations with the flexural strength (Push-out Force (N) = 0.353 Pull-out Force (N) - 0.05 Flexural Strength (MPa) + 12.285 , $n=22$, $p=0.005$) and flexural modulus of elasticity (Push-out Force (N) = 0.300 Pull-out Force (N) + 0.165 Flexural Modulus (GPa) + 11.995 , $n=22$, $p=0.0009$) of the core build-up materials. These correlations indicated that the flexural strength and flexural modulus of core build-up materials significantly influenced the retentive force between root canal wall and fiber posts (Figure 2). These correlations also supported the first hypothesis, notwithstanding that push-out force and shear bond strength to root dentin were not correlated.

In addition, these significant correlations suggested that by measuring the flexural strength and flexural modulus of core build-up materials, especially the flexural modulus, the push-out force between root canal dentin and fiber post could be predicted. This finding indicated that clinical outcome prediction is possible without the use of valuable human premolars. This finding also partially supported the second hypothesis. When core build-up materials of optimal flexural modulus values are used, strong bonding could be delivered by universal adhesives for the entire post and core system.

Apart from the properties of core build-up materials, a weak or strong retention is inextricably dependent on the surrounding characteristics. In the oral cavity, water (as the major component of saliva) causes a major role in filler-matrix bond failures in resin-based materials. It causes filler elements to leach out. It induces filler failures and filler-matrix drop-out, thereby compromising the

matrix material because debonded fillers may act as stress concentrators and significantly multiply the number of potential crack growing. In addition, water has a plasticizing effect on the matrix.

Apart from water, many failures in practice occur because of thermal stress, especially at the root dentin-core interface and core-pretreated post interface. Due to the double factors both water immersion and thermal stress, microleakage occurs and weakens interfacial friction, eventually resulting in resin core build-up material failure [4].

4.5. Versatility of Universal Adhesives

Unlike the root dentin substrate which had a uniform composition (taken into consideration the differences that exist between individuals), each post presented a different composition as seen in Table 3 of this study. There were differences in terms of post material (quartz fiber *versus* glass fiber), matrix composition, and hence polymerization contraction stress — which is dependent on the chemical composition of the resin matrix and which affects interfacial bonding. Apart from the fiber post, bonding performance is also affected by the universal adhesive and filler content of the core build-up material [22].

In this study, the bonding performance results in Tables 4 and 5 were not only clinically acceptable, but remained stable and consistent from Base time period to TC 20k time period. Therefore, the second hypothesis was fully accepted because the universal adhesives could provide durable bonding among root dentin, fiber post and core build-up material, whereby this bonding was not influenced by the time period.

It is noteworthy that the results on the universal adhesives in this study highlighted their contribution to the treatment of traumatized teeth. Not only are they easy to use and convenient, the universal adhesives could provide good bonding results among different substrates and interfaces, which augur well for the success and longevity of dental restorations.

4.6. Applicability of Tokuyama Universal Bond II as General-Purpose Universal Adhesive

When Tokuyama Universal Bond II was used as a pretreatment agent on other manufacturers' post and core systems, comparable — and oftentimes better — bond strength results were obtained for the post-core systems investigated in this study (Tables 5 and 6). These results suggested that a two-bottle bonding agent was reliable and consistent in attaining durable bond strength between fiber posts and core build-up materials.

In two-bottle pretreatment agents, hydrolysis of the silane coupling agent in the product before mixing the two components is difficult to occur. Hydrolysis of the silane coupling agent proceeds only when the two components are mixed during use, resulting in the formation of silanol groups. As a result, the number of silanol groups that can condense and react with a fiber post is higher than that of one-component pretreatment agents. The strong chemical bonding to the fiber posts in this study thus helped to prevent decrease in retentive force during durability tests [23,24]. This suggestion was confirmed from the SEM image which showed the core build-up material adhering firmly to the fiber post and penetrating the fibers (Figure 2).

Amongst the post-core systems investigated in this study, highest pull-out force values were recorded for ESTECM II Plus /Tokuyama FR Post at both time periods. Moreover, these values were significantly higher than the other post and core systems. Two reasons were thought to contribute to their superior bonding performance. The first reason was that the flexural strength and flexural modulus of the core material were significantly higher than the rest. The second was that post surface pretreatment with Tokuyama Universal Bond II had a greater effect on the retentive force of the post, as explained in the preceding paragraph [22,23].

And then, the adhesive performance of Tokuyama Universal Bond II is attributed to the effects of the new functional monomer, New 3D-SR monomer, which contributes to its storage stability at room temperature and its resistance to hydrolysis and degradation of γ -MPTES [3-(triethoxysilyl)propyl meth-acrylate].

Beyond the present manufacturer-recommended use, results of this study was shown that its future application could be expanded to be a general-purpose pretreatment agent for bonding ability between fiber posts and core build-up materials. Based on the above, the third hypothesis of this study was accepted.

4.7. Limitations

This study presents results obtained under limited in vitro conditions. In fact, the materials used in this study are actually employed in the oral cavity. Further measurements simulating thermal changes and occlusal forces within the oral environment are necessary.

5. Conclusions

Universal adhesives were not only convenient and easy to use across multiple types of substrates, they were effective in achieving strong adhesion among root canal dentin, resin core build-up materials and fiber posts. The bonding was also stable and durable as there were no significant differences in bonding performance between Base and TC 20k.

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Conflicts of Interest: The authors declare no conflicts of interest.

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