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Immediate *versus* water-storage performance of Class V flowable composite restoratives

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Short Title: Marginal-gap formation of light-activated restoratives

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Abstract

Objectives: The aims of this investigation were to clarify the effects of 24 h water-storage and finishing-time on mechanical properties and marginal adaptation to a Class V cavity of eight modern flowable resin-composites.

Methods: Eight flowable composites, plus two controls (one microfilled and one hybrid composite), were investigated with specimen sub-groups (n = 10) for each property measured. The principal series of experiments was conducted in model Class V cavities with interfacial polishing *either* immediately (3 min) after setting *or* after 24 h water-storage. After the finishing procedure, each tooth was sectioned in a buccolingual direction through the center of the restoration, and the presence or absence of marginal-gaps was measured (and then *summed* for each cavity) at 14 points (each 0.5 mm apart) along the cavity restoration interface (n=10 per group; total points measured = 140). The shear bond-strengths to enamel and to dentin, and flexural strengths and moduli data were also measured at 3 min *or* after 24 h water-storage.

Results: For all flowable composites, polished immediately after setting, *summed* gap-formations of 14-30 gaps were observed; (controls: 64 and 42). For specimens polished after 24 h, a significantly ($p<0.05$) reduced number of 8-17 *summed* gaps occurred for only three flowable composites; whereas for five flowable composites there were *non*-significantly-different ($p>0.05$) numbers (11-17) of *summed* gaps, (controls: 28 and 22). After 24 h storage, shear-bond-strengths to enamel and to dentin, flexural strengths and moduli increased highly significantly ($p< 0.001$) for all materials, except Silux Plus.

Significance: A post-cure interval of 24 h resulted in enhanced mechanical and adhesive properties of flowable dental composites. In a minority of cases there was also a reduced incidence of marginal-gap

formation. However the latter effect may be partly attributed to 24 h delayed-polishing, even though such a delay is not usual clinical practice.

Keywords: Flowable composite, Gap-formation, Class V restoration, Flexural, Bond-strength

INTRODUCTION

Marginal adaptation and bonding of restorative filling materials to the tooth cavity may not be secure in the initial stage. Restoration failure may occur immediately after setting or during the initial stage of restoration [1] and early gaps may lead to bacterial penetration and pulpal damage [2, 3]. Therefore protocols for measuring marginal-gap formation were developed to evaluate the marginal adaptation of resin-composite restorations. The incidence of gap-formation with composites in a butt-joint cavity may be determined by: 1) the adhesion-forces between the restorative material and cavity walls, 2) the volumetric-shrinkage magnitude of the restorative materials and 3) their viscosity or ability to flow. Polymerization shrinkage and flow were found to be significant determinants of gap-formation around resin-composite [1, 4, 5]. In the initial stage of setting, when a restorative material still adheres to the cavity walls, the shrinkage may be released as a flow of material from the free surface. Comparing restorative materials with the same volumetric shrinkage, but with different fluidity, the flow from the free surface will decrease with decreasing fluidity of the restorative material and consequently give an increased contraction at the margin.

A new class of low-viscosity resin-composites, commonly called “flowable composites”, has become established for restorative dentistry. Flowability is regarded as a desirable handling property which allows the material to be injected through small-gauge dispensers, thus simplifying the placement procedure and amplifying the range of possible clinical applications. These have been critically reviewed in relation to usefulness beyond flow, after a preliminary screening of *in vitro* physical properties [6, 7]. These authors expressed some concern regarding their inferior mechanical properties when compared to traditional hybrid composites, and discouraged their use in high-stress applications. However, composites with a lower filler-content and/or elastic modulus have shown better marginal sealing in Class V restorations compared to composites with a higher filler-content [8, 9], and it is generally accepted that using materials with a low modulus of elasticity reduces the cervical gap formation and marginal leakage. Microfilled composites with a relatively low elastic modulus, have also been speculated to reduce stresses at the adhesive interfaces generated by occlusal forces associated with cervical lesions [10]. Therefore, flowable composites might be expected to demonstrate reduced marginal-gap formation in Class V restorations.

Contemporary self-etching adhesives and the recently introduced all-in-one adhesives vary in their acidity by differences in the composition and concentration of polymerizable acids and/or acidic resin-monomers. They are generally less technique sensitive compared with systems that utilize separate acid-conditioning and rinsing steps [11-14]. Masticatory and parafunctional stresses vary markedly in different clinical situations. Thus, thresholds in mechanical properties needed for success may vary considerably from case to case, with stronger restorative materials being required where greater stresses are anticipated. Flexural tests are appropriate to assess the mechanical properties of restorative materials [5, 6, 15, 16]. In our previous studies [15 - 17], restorative materials and luting agents were proposed to improve their marginal seal or gap formation by enhancement of their flexural-strength during 24 h after light-activation. Moreover, delaying the finishing procedure for 24 h resulted in reduced gap-formation for Class V restorations of conventional and resin-modified glass-ionomers and a microfilled composite [18, 19].

The principal aims of the present study, therefore, were: 1) to evaluate both gap-formation integrity around but-joints in model restorations, analogous to Class V, with self-etching adhesives, compared to microfilled and hybrid types, using conventional bonding agents; and 2) determination of the early development of their flexural and adhesive properties. An important clinical variable was to be assessed in this connection: namely, the effect on these properties of an immediate *versus* a 24 h-delayed finishing procedure. Hence, a major hypothesis to be tested was that *premature finishing would significantly reduce gap-formation integrity, relative to delayed finishing*. Flexural properties and shear-bond strengths, to both enamel and dentin substrates, were also to be measured to further elucidate the effects of the 24 h delay and to discriminate between flowable and conventional resin-composite restorative types.

MATERIALS AND METHODS

Ten light-activated restorative materials, including eight flowable composites, one microfilled composite and one hybrid composite, as controls, are listed in Table 1. This range of materials was not only representative of major clinical types but provided a range of values for the parameters under investigation. Tooth preparation procedures, bonding, mixing and handling were carried out according to the manufacturers' recommendations (Table 2). A visible-light curing unit (New Light VL-II, GC, Tokyo, Japan; irradiated diameter: 8 mm) was used for light-activated materials with an irradiation time of 40 s. The irradiance was checked immediately before each application of the adhesive-resin and restorative material, using a radiometer (Demetron/Kerr, Danbury, CT, USA).

During the experiment the irradiance was maintained at 450 mW/cm^2. Human premolars, extracted for orthodontic reasons, were used throughout this study. After extraction and cleaning, teeth were immediately stored in cold distilled water at 4 ^{o}C for 1-2 months before testing, then mounted in a holder using a slow setting epoxy resin (Epofix Resin, Struers, Copenhagen, Denmark).

Class V Restoration

Cavity preparations were placed in the premolar teeth on the facial surface *(Figure 1).* A cylindrical cavity was prepared with a tungsten carbide bur (200,000-rpm) and a fissure bur (8,000-rpm) under wet conditions to a depth of 1.5 mm with a diameter of 3.5 mm. A cavity preparation was placed parallel to the cemento-enamel junction (CEJ) with the preparation extended 1.0 mm above the CEJ (Figure 1). Cavosurface walls were finished to a butt joint. This design differed from a Class V clinical cavity in that cavity corners were geometric-box angles to prepare a constant-volume model. One cavity was prepared in each of 200 teeth; (10 materials x 2 polishing or inspecting times x 10 repeats = 200). The cavity walls and surrounding enamel margin were pretreated according to the manufacturers' instruction as described in Table 2. Each cavity was filled with various restorative materials using a syringe tip (Centrix C-R Syringe System, Centrix, Connecticut, USA). Cavities were filled with mixed materials using a syringe tip (Centrix C-R Syringe System, Centrix, Connecticut, USA) and covered with a plastic strip and hardened by light-curing.

Inspection Procedure

Immediately after light-curing and setting, *or after 24 h storage* in distilled water at 37 ^{o}C, the outer surfaces of restorations were polished with abrasive points (Silicone Mide, Shofu, Kyoto, Japan) in wet condition to avoid desiccation and breakdown through rinsing with distilled water. Each tooth was sectioned in a buccolingual direction through the center of the restoration with a low-speed diamond saw (Isomet, Buehler Ltd., Lake Bluff, IL). The presence or absence of marginal-gaps was measured with a traveling microscope (x 1,000, Measurescope, MM-11, Nikon, Tokyo, Japan) at 14 points (each 0.5 mm apart) along the cavity restoration interface (n=10; total points measured = 140) and the gap-data was *summed* for each cavity, as previously described [17 - 19].

Shear bond strength to enamel and to dentin

Wet grinding of buccal surfaces was performed with up to 1000 grit silicon carbide abrasive paper until a flat enamel or superficial dentin area of at least 4 mm in diameter was exposed. The surface was pretreated as described above. A split Teflon mold with a cylindrical hole (diameter, 3.6 mm; height, 2 mm) was clamped to the prepared enamel or dentin surface. The Teflon mold was filled with various restorative materials using a Centrix syringe tip (Centrix C-R Syringe System, Centrix, Connecticut, USA). It was covered with a plastic strip and the material was hardened by light irradiation, as described above. For each material, 10 specimens were prepared. Prepared specimens were secured in a mounting jig. At a time of either *3 minutes from start of light irradiation*, or after 24 h water-storage, the shear force was transmitted by a flat (blunt) 1 mm broad shearing edge making a 90^o angle to the direction of the load (or the back of the load plate). The shear force was applied (Autograph DCS-2000, Shimadzu, Kyoto, Japan) at a cross-head speed of 0.5 mm/min. The stress at failure was calculated and recorded as the shear-bond strength. The failed specimens were examined under a light microscope (x 4; SMZ-10, Nikon, Tokyo, Japan) to determine the total number of adhesive failure surfaces [15, 16].

Flexural strength and flexural modulus of elasticity

Teflon molds (25 x 2 x 2 mm^3) were used to prepare flexural specimens (n = 10/group), which were cured in three overlapping-sections, each cured for 40 s. The flexural properties were measured, both immediately after setting and after 24 h storage, 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 the flexural modulus was calculated (Software Series IX, Instron, Canton, MA, USA).

All procedures, except for testing, were performed in an air-conditioned room at 23$\pm$0.5 ^{o}C and 50$\pm$2 % R.H. The results were analyzed statistically using the Mann-Whitney U test, Tukey Test (non-parametric, [16, 17, 20]), Tukey Test, *t*-Test. Significant differences at p<0.05 were determined.

RESULTS

Tables 3 and 4 present the data for the *summed* gap-formations observed in the Class V cavity groups for the two time points (immediate and after 24 h storage). The data *mean* was not used because many specimens had no gaps. Therefore, the *overall sum* of data was used [17-19].

Immediately after setting, five flowable composites, had *summed interfacial gaps* from 14 to 22 gaps, and of these, almost none had no gaps. After 24 h, 11-17 summed gaps were found and there was no significant difference (p>0.05) between the immediate and 24 h storage results.

Immediately after setting, three flowable composites (Esthet X Flow, Filtek Flow and Point 4

Flowable) had 28 to 30 *summed interfacial gaps*. After 24 h, a significantly ($p<0.05$) reduced number of 8-17 *summed* gaps occurred, but then the summed gaps for the eight flowable composites were all statistically equivalent.

For the control materials, significant differences ($p<0.05$) were observed between the immediate and 24 h storage results. Interfacial gaps of Silux Plus, immediately after setting and after 24 h were significantly different from those of the flowable composites. The most critical cavity locations, # 1 and # 14, showed the most gaps for all composites in both measured conditions. The cervical corner area, # 10 and # 11, also showed several gaps. Although the axial regions of flowable composites and Herculite showed almost no gaps in the two measured conditions, the axial regions of Silux Plus, showed many gaps, for the both conditions.

The shear-bond strengths to enamel are presented in Table 5. Significant differences were observed between the immediate and 24 h storage data for all materials. Immediately after setting and after 24 h, the greatest bond-strengths were obtained for Clearfil Flow FX and Herculite XRV (control). Immediately after setting, the lowest bond-strengths were obtained for Esthet X Flow, Point 4 Flowable, Metafil Flo and Silux Plus (control). After 24 h, the lowest bond-strengths were obtained for Filtek Flow, Point 4 Flowable, Metafil Flo and Silux Plus (control). Immediately after setting, only Point 4 Flowable, Metafil Flo and Palfique Estelite LV Medium Flow showed adhesive failures. Composites paired with their own adhesives had 30-50 percent adhesive failures. But after 24 h, only Point 4 Flowable and Palfique Estelite LV Medium Flow showed adhesive failures, (10-20 percent).

The shear bond strengths to dentin are presented in Table 6. Significant differences were observed between immediate and 24 h storage data for all restorative materials, except for Filtek Flow and Silux Plus. Immediately after setting, the greatest bond-strengths were obtained for Beautifil Flow F02 and Clearfil Flow FX. After 24 h, the greatest bond-strengths were obtained for Esthet X Flow, UniFil LoFlo Plus, Beautifil Flow F02, Palfique Estelite LV Medium Flow and Clearfil Flow FX. Immediately after setting, the lowest bond-strength was obtained for Silux Plus (control). After 24 h, the lowest bond-strengths were obtained for Filtek Flow, Point 4 Flowable, Metafil Flo, Silux Plus and Herculite XRV (controls). Immediately after setting, only Beautifil Flow F02 and Palfique Estelite LV Medium Flow, showed adhesive failures. The proportion of adhesive failures of composites paired with their own adhesive was 10-20 percent. After 24 h, only Palfique Estelite LV Medium Flow and Silux Plus, showed adhesive failures, (10-40 percent). The proportion of adhesive fractures was almost the same for both time-points.

Tables 7 and 8 summarize, respectively, the flexural strengths and moduli at the two time-points. For flexural strength, a significant difference was observed between the immediate and 24 h storage data for all restorative materials, except Silux Plus (control). Immediately after setting, Herculite XRV (control) showed the highest value of all materials and Palfique Estelite LV Medium Flow showed the lowest value. Similar trends were seen with flexural moduli. Filtek Flow and UniFil LoFlo Plus were similar to Palfique Estelite LV Medium Flow.

DISCUSSION

This study used a model cavity for the geometry of typical cervical cavities. This only approximates the Class V morphology and is not the typical morphology for a flowable composite, but has the advantage of a constant volume, reproducible geometry that is beneficial for an *in vitro scientific study* [5, 18, 19].

This study demonstrated that there was no statistically-significant difference in gap-incidence between polishing times for flowable-composites, except for three of the eight materials. The materials' interfacial-gaps slightly decreased when specimens were polished after 24 h water-storage. However, for conventional composites (controls), interfacial-gaps significantly reduced when specimens were polished after 24 h. Only the polymerization-shrinkage that occurs after the gel point can influence stress-formation and gaps in a cavity [5], although the onset of gelation is very rapid in light-cured materials [23]. In a cavity, shrinkage is counteracted by adherence and by plastic flow of the resin-composite. The higher the bond-strength and the higher the plastic flow, the longer the resin composite can withstand gap-formation and the smaller the resulting gap. Hence the later part of the polymerization-shrinkage has the greatest tendency to promote gap-formation. Hence the correlation between polymerization-shrinkage and gap-formation improves when only the later shrinkage is considered [8, 9].

All bonding-systems used in this study, except the wet-bonding system (Scotch bond Multi-Purpose), gave almost the same strength for both the *immediate* and the *24 h* conditions. Therefore, the fluidity of resin-composites was evidently more important for interfacial gap-formation in Class V restoration than the identity of the bonding-systems. The rationale behind the use of self-adhesive systems is the formation of continuity between tooth surfaces and adhesive material, accomplished by the simultaneous demineralization and penetration of this agent [11-13, 21]. This could be advantageous compared to the reported technique-sensitivity of wet-bonding system.

For only three flowable composites, Esthet X Flow, Filtek Flow and Point 4 Flowable, and the two control restorative materials, interfacial-gaps were significantly reduced when specimens were polished after 24 h. Contributing causes were the improvements over 24 h in bond-strength to both the enamel and dentin substrates (Tables 5 & 6) and the increases in flexural strength and moduli (Tables 7 & 8).

After 24 h all the flowable composites investigated showed 10-20 gaps, and the changes in mechanical strength over 24 h were generally similar to those seen with luting materials [16].

The cervical corners of the cavity restorations had more gaps than the coronal corner with flowable composites. This is unsurprising as cervical dentin is a less favorable bonding substrate than coronal dentin [18, 19, 22].

This study examined commercially available flowable-composites for interfacial gap-formation to Class V cavities. Despite important differences in performance, all the flowable composites had similar properties in bond-strength to tooth substrate and flexural-properties, and the similar filler/matrix ratio may explain these features.

The greater interfacial integrity of flowable composites compared to controls may result from harmony between better fluidity and good bond-strength with these composites. With flowable composites it is thus generally inadvisable to delay polishing. However enhanced mechanical properties were showed after 24 h.

A more extensive approach to the evaluation of sealing efficacy with commercially available flowable composites would require longer-term durability testing or load cycling.

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Caption to Figure

Figure 1 Class V restoration and measurement locations for gap-formation.

E: Enamel substrate, D: Dentin substrate

Table 1 Light-activated restorative materials investigated

Product	Composition	Manufacturer	Batch No.
EsthetX Flow	barium fluoro boroalumino silicate glass, silica nanofiller (61 wt%, 53 vol%) Bis-GMA, TEGDMA photo initiators, stabilisers	Dentsply/Caulk Milford, DE, USA	030115
Filtek Flow	silica, silica/zirconia (68 wt%, 47 vol%) Bis-GMA, TEGDMA, photo initiators stabilizers	3M ESPE, St. Paul, MN, USA	2EB
Point 4 Flowable	barium silica glass (70 wt%, 48 vol%) TEGDMA, EBPADMA, photo initiators	Kerr, Orange, CA USA	212303
Unifil LoFlow Plus	fluoro-aluminosilicate-glass, organic filler colloidal silica (63 wt%) UDMA, dimethacrylate, , photo initiators, stabilizer	GC, Tokyo, Japan	0403171
Beautiful Flow F02	modified S-PRG filler, multi-functional glass filler (55 wt%, 35 vol%) Bis-GMA, TEGDMA, photo initiators	Shofu, Kyoto, Japan	099900
Metafil Flo	Barium silica glass, colloidal silica, TMPT-filler (65 wt%, 44 vol%) UDMA	Sun Medical Moriyama, Japan	FW1
Estetite LV Medium Flow	silica/zirconia filler (68 wt%) Bis-MPEPP, Bis-GMA, TEGDMA, photo initiators	Tokuyama Dental Tokyo, Japan	V315Z3
Clearfil Flow FX	Barium glass filler , Silica filler (65 wt%, 40 vol%) UDMA, Bis-GMA, TEGDMA	Kuraray Medical Kurashiki, Japan	031222a3
Silux Plus	Collodal silica (52 wt%, 38 vol%) Bis-GMA, TEGDMA	3M ESPE St. Paul, MN, USA	1DW1
Herculite XRV	Barium silica glass (79 wt%, 59 vol%) Bis-GMA, TEGDMA, EBPADMA	Kerr, Orange CA, USA	112330

Bis-GMA: Bisphenol A glycidyl methacrylate,
TEGDMA: Tri-ethylene-glycol dimethacrylate,
EBPADMA: Ethoxylated bis-phenol-A-dimethacrylate,
UDMA: Urethane dimethacrylate,
S-PRG: Surface reacted type of glass-ionomer
Bis-MPEPP: 2,2-Bis(4-methacryloyloxypolyethoxyphenyl)propane,
TMPT-filler: Prepolymerized filler (trimethylolpropanetrimethacrylate [TMPT] filler)

Table 2 Self-etching adhesive and system adhesive components

Adhesive	Composition and surface treatment	Manufacturer	Batch No.
Xeno IV	polymerizable organophosphate monomer polymerizable organocarboxlic acid monomer polymerizable tri/dimethacrylate resin light cure initiator, stabilizer, acetone Experimental Self-Etching adhesive (20 s) – air – light (10 s)	Dentsply/Caulk Milford, DE, USA	0106285
Adper Prompt L-Pop	methacrylated phosphoric acid ester, water, phosphine oxide, stabilizer, fluoride complex Adper Prompt L-Pop (15 s) – air – light (10 s)	3M ESPE, Seefeld, Germany	FW66757
OptiBond SoLo Plus Self-Etch Adhesive	HFGA-GDM, GPDM, ethanol, water Phototoinitiator Self-Etch Primer (15 s) – air – OptiBond SoLo Plus (15 s) – air – OptiBond SoLo Plus (15 s) – air – light (20 s)	Kerr, Orange, CA USA	208113
G-Bond	UDMA, 4-MET, silica filler, phosphoric acid ester monomer, acetone, water, phototoinitiator G Bond (10 s)– strong air – light (10 s)	GC, Tokyo, Japan	040216
FL-Bond	Primer: 4-AET, 4-AETA, HEMA, UDMA, TEGDMA, water, initiator Bond: F-PRG filler, HEMA, UDMA, TEGDMA, initiator Primer (10 s) – air – Bonding Agent – light (10 s)	Shofu, Kyoto, Japan	0303
AQ Bond Plus	Liquid: 4-META, UDMA, Monomethacrylates, water-acetone Photo initiator, Stabilizer Cata-sponge: Sopdium p-toluenesulfinate AQ Bond Plus (20s) – gentle air (5s) – strong air (5s) – light (5s)	Sun Medical Moriyama, Japan	FW1
One-up Bond F Plus	Bonding A: methacryloyloxyalkyl phosphate, MAC-10, Bis-MPEPP, MMA, bifunctional dimethacrylate, co-catalyst Bonding B: HEMA, MMA, water, fluoro-aluminosilicate photoinitiatar (aryl borate catalyst) One-up Bond F Plus (20s) – air – light (10 s)	Tokuyama Dental Tokyo, Japan	MS-12
Cleafil SE Bond	Primer: MDP, HEMA, Hydrophilic dimethacrylate dl-Camphorquinone, N,N-Diethanol-p-toluidine, water Bond: MDP, Bis-GMA, HEMA, Hydrophobic dimethacrylate dl-Camphorquinone, N,N-Diethanol-p-toluidine, Silanated colloidal silica Primer (20s) – air – Bond – light (10 s)	Kuraray Medical Kurashiki, Japan	00316A 00404A
Scotchbond Multi- Purpose,	Echant (7EE): 10% maleic acid, water Primer (7AC): HEMA, polyalkenoic acid, copolymer, water Adhesive (7AB): Bis-GMA, HEMA, Phototoinitiator Echant (15 s) – rinse & dry – Primer (30 s) – dry – Adhesive – light (30 s)	3M, St. Paul, MN USA	
OptiBond SoLo Plus	HEMA, GPDM, ethanol, water phototoinitiator Gel Etchant (15 s) – rinse and dry – OptiBond SoLo Plus (15 s) – air – light (20 s)	Kerr, Orange, CA USA	110869

HFGA-GDM: Hexafluoroglutaric anhydride-Glycerodimethacrylate adduct, GPDM: Glycerophosphatedimethacrylate
UDMA: Urethane dimethacrylate, 4-MET: 4—methacryloxyethyl trimellitic acid
4-AET: 4-acryloxyethyltrimellitic acid, 4-AETA: : 4-acryloxyethyltrimellitate anhydride
HEMA: 2-Hydroxyethyl methacrylate, TEGDMA: Tri-ethylene-glycol dimethacrylate
F-PRG filler: full-reaction-type pre-reacted glass-ionomer filler
4-META: 4—methacryloxyethyl trimellitate anhydrine, MAC-10: 11-methacryloyloxy-1, 1-undecanedicarboxylic acid
Bis-MPEPP: 2,2-Bis(4-methacryloyloxypolyethoxyphenyl)propane, MMA: methylmethacrylate
MDP: 10-Methacryloyloxydecyl dihydrogen phosphate, Bis-GMA: Bisphenol A glycidyl methacrylate

Table 3 Effect of Polishing time on interfacial gap formation in Class V restorations

Product	Medial				Bottom						Distal				Sum[a]
	Number of specimens showing gaps														
Polishing time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Flowable composite + pretreating agent															
Esthet X Flow + Xeno IV															
Immediately	5	5	4	2	0	0	0	0	0	2	3	4	2	3	**30**
After 1-day storage	4	0	1	0	0	0	0	0	0	0	0	0	0	3	**8**
Filtek Flow + Adper Prompt L-Pop															
Immediately	3	4	1	4	1	0	1	0	0	0	2	1	3	8	**28**
After 1-day storage	4	0	0	3	0	0	0	0	0	0	1	0	2	7	**17**
Point 4 Flowable + OptiBond SoLo Plus Self-Etch Adhesive System Unidose															
Immediately	6	0	2	3	1	0	0	0	0	1	4	1	3	7	**28**
After 1-day storage	8	1	0	0	0	0	0	0	0	0	0	0	0	4	**13**
UniFil LoFlo Plus + G-Bond															
Immediately	8	2	0	0	0	0	0	0	0	0	1	0	0	8	**19**
After 1-day storage	7	1	0	0	0	0	0	0	0	0	2	1	0	5	**16**
Beautifil Flow F02 + FL-Bond															
Immediately	9	2	0	0	0	0	0	0	0	1	2	0	0	6	**20**
After 1-day storage	7	1	0	1	0	0	0	0	0	0	1	1	0	5	**16**
Metafil Flo + AQ Bond Plus															
Immediately	9	2	1	0	0	0	0	0	0	0	0	1	1	8	**22**
After 1-day storage	9	1	0	1	0	0	0	0	0	0	0	0	0	6	**17**
Palfique Estelite LV Medium Flow + One-Up Bond Plus															
Immediately	7	3	0	0	0	0	0	0	0	0	0	1	1	8	**20**
After 1-day storage	7	1	0	0	0	0	0	0	0	0	1	0	0	6	**15**
Clearfil Flow FX + Clearfil SE Bond															
Immediately	5	1	1	0	0	0	0	0	0	1	1	0	0	5	**14**
After 1-day storage	4	0	0	0	0	0	0	0	0	0	1	0	0	6	**11**
As controls: Conventional composite + pretreating agent															
Silux Plus + Scotchbond Multi-Purpose															
Immediately	8	4	3	8	6	4	4	3	2	4	8	2	3	5	**64**
After 1-day storage	3	0	0	0	2	4	5	3	2	3	4	0	1	1	**28**
Herculite XRV + OptiBond SoLo Plus															
Immediately	8	4	2	2	3	1	2	0	1	1	3	1	4	10	**42**
After 1-day storage	4	0	0	3	1	0	0	0	1	0	3	1	1	8	**22**

n=10 (total measuring points, 1-14 = 140),

Table 4 Number of interfacial gaps in Class V restorations corresponding to Table 3

Restorative material	The sum of interfacial gaps for ten specimens		Alpha value*
	Immediately	After 1-day storage	
Esthet X Flow + Xeno IV	30 (0)$^{\#}$ (1-6)$^{**\ A\ B}$	8 (4)$^{\#}$ (0-2)$^{**\ D}$	<0.05
Filtek Flow + Adper Prompt L-Pop	28 (0)$^{\#}$ (2-5)$^{**\ A\ B}$	17 (2)$^{\#}$ (0-4)$^{**\ D\ E}$	<0.05
Point 4 Flowable + OptiBond SoLo Plus Self-Etch Adhesive System Unidose	28 (0)$^{\#}$ (2-6)$^{**\ A\ B}$	13 (1)$^{\#}$ (0-2)$^{**\ D\ E}$	<0.05
UniFil LoFlo Plus + G-Bond	19 (0)$^{\#}$ (1-3)$^{**\ B}$	16 (1)$^{\#}$ (0-3)$^{**\ D\ E}$	NS
Beautifil Flow F02 + FL-Bond	20 (1)$^{\#}$ (0-3)$^{**\ A\ B}$	16 (1)$^{\#}$ (0-3)$^{**\ D\ E}$	NS
Metafil Flo + AQ Bond Plus	22 (0)$^{\#}$ (1-4)$^{**\ A\ B}$	17 (0)$^{\#}$ (1-4)$^{**\ D\ E}$	NS
Palfique Estelite LV Medium Flow + One-Up Bond Plus	20 (0)$^{\#}$ (1-5)$^{**\ A\ B}$	15 (0)$^{\#}$ (1-3)$^{**\ D\ E}$	NS
Clearfil Flow FX + Clearfil SE Bond	14 (1)$^{\#}$ (0-3)$^{**\ B}$	11 (3)$^{\#}$ (0-2)$^{**\ D\ E}$	NS
Silux Plus + Scotchbond Multi-Purpose	64 (0)$^{\#}$ (3-12)$^{**\ C}$	28 (2)$^{\#}$ (0-8)$^{**\ E}$	<0.05
Herculite XRV + OptiBond SoLo Plus	42 (0)$^{\#}$ (1-8)$^{**\ A\ B}$	22 (0)$^{\#}$ (1-4)$^{**\ D\ E}$	<0.05

(n=10 (total measuring points, 1-14 = 140), NS: not significantly different (alpha>0.05). Means with the same letters were not significantly different by Tukey test. (p>0.05, non-parametric [16,17,20]).

* Significantly different by Mann-Whitney U-Test between the two sums (p=0.05).

\# Number of specimens having no interfacial gaps.

** Range of interfacial gaps.

Table 5 Shear bond strength to enamel substrate (MPa, Mean (SD), Adh.).

Restoration	Immediately	After one-day storage	p value[a]
Esthet X Flow + Xeno IV	9.7 (1.6, 0) C D E	20.9 (3.4, 0) G H	<0.001
Filtek Flow + Adper Prompt L-Pop	11.2(2.9, 0) B C D	14.8 (3.1, 0) I J	<0.05
Point 4 Flowable + OptiBond SoLo Plus Self-Etch Adhesive System Unidose	8.8 (2.8, 3) D E	13.5 (3.7, 1) J	<0.01
UniFil LoFlo Plus + G-Bond	13.0 (2.6, 0) B C	19.2 (2.8, 0) H I	<0.001
Beautifil Flow F02 + FL-Bond	13.3 (1.8, 0) B C	21.6 (2.8, 0) G H	<0.001
Metafil Flo + AQ Bond Plus	9.3 (1.5, 5) D E	18.0 (2.7, 0) H I J	<0.001
Palfique Estelite LV Medium Flow + One-Up Bond Plus	11.6 (1.1, 3) B C D	21.3 (3.5, 2) G H	<0.001
Clearfil Flow FX + Clearfil SE Bond	17.5 (2.7, 0) A	27.1 (2.0, 0) F	<0.001
Silux Plus + Scotch Bond Multi-Purpose	6.8 (2.0, 0) E	18.3 (5.0, 0) H I J	<0.001
Herculite XRV + OptiBond SoLo Plus	14.8 (4.2, 0) A B	25.3 (4.9, 0) F G	<0.001

n=10.
Adh.: number of adhesive failure modes
[a]: *t*-test
Means with the same letters were not significantly different by Tukey test. (p>0.05).

Table 6 Shear bond strength to dentin substrate (MPa, Mean (SD), Adh.).

Restoration	Immediately	After one-day storage	p value[a]
Esthet X Flow + Xeno IV	11.7 (2.5, 0) [B C]	17.6 (3.4, 0) [E F G]	<0.001
Filtek Flow + Adper Prompt L-Pop	9.4 (2.1, 0) [C]	12.3 (3.0, 0) [H I]	NS
Point 4 Flowable + OptiBond SoLo Plus Self-Etch Adhesive System Unidose	10.2 (2.7, 0) [B C]	13.2 (2.8, 0) [G H I]	<0.05
UniFil LoFlo Plus + G-Bond	11.2 (2.0, 0) [B C]	19.2 (2.7, 0) [E F]	<0.001
Beautifil Flow F02 + FL-Bond	15.5 (2.5, 1) [A]	19.9 (4.8, 0) [E F]	<0.05
Metafil Flo + AQ Bond Plus	11.4 (2.1, 0) [B C]	16.5 (2.2, 0) [F G H]	<0.001
Palfique Estelite LV Medium Flow + One-Up Bond Plus	10.2 (1.2, 2) [B C]	20.1 (2.3, 1) [E F]	<0.001
Clearfil Flow FX + Clearfil SE Bond	13.4 (2.4, 0) [A B]	22.2 (3.7, 0) [E]	<0.001
Silux Plus + Scotch bond Multi-Purpose	6.0 (2.4, 0)	8.6 (5.5, 4) [I]	NS
Herculite XRV + OptiBond SoLo Plus	9.6 (2.9, 0) [C]	13.5 (4.1, 0) [G H I]	<0.05

n=10, Adh.: Number of adhesive failure modes,
[a]: *t*-test. NS: No significant difference between two results (p>0.05)
Means with the same letters were not significantly different by Tukey test. (p>0.05).

Table 7 Flexural strength of restorative materials (MPa, Mean (SD)).

Restoration	Immediately	After one-day storage	p value[a]
Esthet X Flow	51.0 (4.0) [A]	113.2 (9.5) [D]	<0.001
Filtek Flow	50.9 (7.5) [A]	106.7 (5.5) [D E]	<0.001
Point 4 Flowable	58.5 (5.0) [A B C]	107.8 (8.5) [D E]	<0.001
UniFil LoFlo Plus	53.3 (3.6) [A C]	88.2 (3.3) [F]	<0.001
Beautifil Flow F02	63.0 (6.1) [B]	95.5 (6.9) [E F]	<0.001
Metafil Flo	57.9 (4.4) [A B C]	116.8 (9.1) [D]	<0.001
Palfique Estelite LV Medium Flow	39.7 (5.0)	116.3 (10.2) [D]	<0.001
Clearfil Flow FX	62.7 (4.5) [B]	115.6 (10.4) [D]	<0.001
Silux Plus	59.3 (4.1) [B C]	65.1 (7.2)	NS
Herculite XRV	75.5 (9.3)	135.9 (10.5)	<0.001

n=10
[a]: *t*-test.
NS: No significant difference between two results (p>0.05)
Means with the same letters were not significantly different by Tukey test. (p>0.05).

Table 8 Flexural modulus of restorative materials (GPa, Mean (SD)).

Restoration	Immediately	After one-day storage	p value[a]
Esthet X Flow	2.27 (0.28) [A]	6.44 (0.32) [D E]	<0.001
Filtek Flow	1.72 (0.26) [B]	5.32 (0.42) [F G]	<0.001
Point 4 Flowable	3.52 (0.58) [C]	6.95 (0.44) [D]	<0.001
UniFil LoFlo Plus	1.79 (0.16) [B]	3.73 (0.29)	<0.001
Beautifil Flow F02	2.56 (0.39) [A]	4.99 (0.39) [G]	<0.001
Metafil Flo	2.34 (0.44) [A]	5.88 (0.25) [E F]	<0.001
Palfique Estelite LV Medium Flow	1.57 (0.22) [B]	5.88 (0.31) [E F]	<0.001
Clearfil Flow FX	2.66 (0.30) [A]	5.75 (0.35) [F]	<0.001
Silux Plus	3.77 (0.14) [C]	5.86 (0.47) [E F]	<0.001
Herculite XRV	4.77 (0.13)	11.88 (0.70)	<0.001

n=10
[a]: *t*-test.
Means with the same letters were not significantly different by Tukey test. (p>0.05).