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Class I Gap-formation in Highly-viscous Glass-ionomer Restorations: Delayed vs Immediate Polishing

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Clinical Relevance

Delaying polishing for one day resulted in improved gap-formation for Class I restoration of highly-viscous conventional and conventional glass-ionomer cements

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SUMMARY

This *in vitro* study evaluated the effects of delayed versus immediate polishing to permit maturation of interfacial gap-formation around highly viscous conventional glass-ionomer cement (HV-GIC) in Class I restorations, together with determining the associated mechanical properties. Cavity preparations were made on the occlusal surfaces of premolars. Three HV-GICs (Fuji IX GP, GlasIonomer FX-II and Ketac Molar) and one conventional glass-ionomer cement (C-GIC, Fuji II, as a control) were studied, with specimen subgroups (n=10) for each property measured. After polishing, either immediately (six minutes) after setting or after 24 hours storage, the restored teeth were sectioned in a mesiodistal direction through the center of the model Class I restorations. The presence or absence of interfacial-gaps was measured at 1000x magnifi-

cation at 14 points (each 0.5-mm apart) along the cavity restoration interface (n=10; total points measured per group = 140). Marginal gaps were similarly measured in Teflon molds as swelling data, together with shear-bond-strength to enamel and dentin, flexural strength and moduli. For three HV-GICs and one C-GIC, significant differences ($p<0.05$) in gap-incidence were observed between polishing immediately and after one-day storage. In the former case, 80-100 gaps were found. In the latter case, only 9-21 gaps were observed. For all materials, their shear-bond-strengths, flexural strength and moduli increased significantly after 24-hour storage.

INTRODUCTION

As a restorative material, conventional glass-ionomer cements (C-GIC) have certain desirable properties. C-GIC includes chemical bonding to enamel and dentin substrates, the release of anticariogenic fluoride into adjacent hard tissues and a low coefficient of thermal expansion similar to that of dentin.[1-2] However, C-GICs are susceptible to fracture and exhibit low wear resistance. Therefore, these deficiencies have limited their use to areas subject to low masticatory stresses.[2] Because of low fracture toughness, mechanical strength and the brittleness of C-GICs, efforts were made to improve their mechanical properties by adding powder.[3-5] Highly-viscous C-GICs (HV-GICs) were developed to overcome early moisture sensitivity and the low mechanical properties associated with conventional materials. They were then designed as an alternative to amalgam for posterior preventive restoration.[1-2] Highly-viscous or high powder-liquid ratio C-GICs, such as Fuji IX GP, Ketac Molar and GlasIonomer FX-II, provide a condensable feel and are specifically used for the atraumatic restorative treatment (ART) technique introduced by the World Health Organization (WHO) for use in developing countries.[6-7] Indications for these cements in general practice are to small Class I cavities, deciduous teeth and long-term temporaries.[2,8-12]

The polishing period is another factor that may influence sealability around a cervical or cavity restoration. Polishing after storage in water for one day resulted in improved gap formation for cervical restorations or dentin cavities of a resin-modified glass-ionomer cement (RM-GIC) or a C-CGI.[13-17] Due to the structure of RM-GIC or C-GIC and its hydrophilic nature, water sorption and subsequent swelling may lead to partial compensation of the shrinkage. The preservation of sealing around a restoration would benefit most if water sorption and setting shrinkage could proceed simultaneously. However, water sorption occurs only at a later stage compared with setting shrinkage.[18] Currently, no information is available regarding interfacial-gap formation behavior around Class I restorations of a C-GIC.

In the oral environment, C-GICs must also withstand masticatory and parafunctional stresses. These stresses vary markedly in clinical situations. Thus, thresholds in the mechanical properties needed for success may vary considerably from case to case, with stronger C-GICs being required where greater stresses are anticipated. Flexural tests are appropriate for assessing the mechanical properties of restorative and luting cements.[9,13,16] In previous studies, C-GICs were proposed to improve their marginal seal by enhancing their flexural strength and bonding ability after 24-hour water-storage.[13] Appropriate elastic moduli and proportional limit values are also desirable.[16]

Therefore, this study evaluated both gap-formation integrity around butt-joints in model restorations, analogous to Class I restoration of HV-GICs and determined the early development of their flexural and adhesive properties, compared with those of a C-GIC. An important clinical variable was to be assessed in this connection; namely, the effect of an immediate versus a 24-hour-delayed finishing procedure on these properties. Hence, a major hypothesis to be tested was that premature finishing would significantly reduce interfacial integrity relative to delayed finishing. Several additional properties, including shear-bond-strength, were also to be measured to further elucidate the effects of water-uptake over 24 hours upon intrinsic and interfacial material behavior and to discriminate between the different types of material.

METHODS AND MATERIALS

The basic properties of three HV-GICs and one C-GIC, as a control, are summarized in Table 1. Human premolars, extracted for orthodontic reasons, were used in this experiment. After extraction, each tooth was immediately stored in distilled water at 4°C for one to two months before use.

Four C-GICs, which were placed according to the manufacturers' instructions, were investigated (Table 1). Dentin Conditioner was applied for 20 seconds and rinsed with water. Ketac Conditioner was applied for 10 seconds and rinsed with water. The cavity was filled with mixed GIC using a syringe tip (Centrix C-R Syringe System, Centrix, CT, USA) covered with a plastic strip and stored in an incubator at 37°C and 100% relative humidity for four minutes after mixing as setting procedure. The restored teeth were then coated with a varnish (Fuji Varnish, GC, Tokyo, Japan).

Gap-Formation Around Class I Restorations

Preparing and Polishing Procedures

A Class I cavity, having a length of 3.5 mm, a width of approximately 2 mm and a depth of 1.5 mm, was pre-

Table 1: *Restorative Materials and Conditioner Agents Investigated*

Material	Manufacturer	Batch #	Powder/Liquid, Components, Surface Treatment
Restorative Materials			
Fuji IX GP	GC Corp Tokyo, Japan	P: 0404301 L: 0404301	3.6 P: fluoroaluminosilicate glass L: copolymer of acrylic and maleic acids, polybasic carboxylic acid, water
GlasIonomer FX-II	Shofu Dental Corp Kyoto, Japan	P: 120304 L: 050302	2.6 P: fluoroaluminosilicate glass L: copolymer of acrylic acid and tri-carboxylic acid, water
Ketac Molar Aplicap	3M ESPE AG Seefeld, Germany	169574	Precapsulated P: fluoroaluminosilicate glass L: polycarbonic acid, tartaric acid, oligomers, water
Fuji II (as a control)	GC Corp Tokyo, Japan	P: 0309091 L: 0309121	2.7 P: fluoroaluminosilicate glass L: copolymer of acrylic and maleic acids, polybasic carboxylic acid, water
Conditioner Agents			
Dentin Conditioner	GC Corp Tokyo, Japan	151021	Polyacrylic acid, water Apply with brush for 20 seconds, rinse, gently dry for five seconds
Ketac Conditioner	3M ESPE Seefeld, Germany	AG 00026	Polyacrylic acid, water Apply with brush for 10 seconds, rinse, gently dry for five seconds

Table 2: *Effect of Polishing Time on Gap Formation Around Class I Restorations*

		Number of Specimens Showing Gaps														Sum
		Mesial				Bottom						Distal				
Restoration	Polishing Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Fuji IX GP	Immediate	10	5	2	4	2	1	7	7	7	3	7	6	9	10	**80** (NS)* a#
	After one-day storage	2	0	0	0	0	1	1	0	0	0	0	0	0	5	S** **9** (S)b
GlasIonomer FX-II	Immediate	9	5	4	4	2	5	6	5	7	7	7	3	6	10	**80** (NS) a
	After one-day storage	5	0	0	0	0	1	0	0	0	0	1	0	0	5	S **12** (NS) b
Ketac Molar Aplicap	Immediate	10	6	6	5	6	5	7	9	5	7	8	9	6	10	**99** (NS) c
	After one-day storage	4	0	0	2	0	1	0	2	2	1	4	2	0	3	S **21** (NS) d
Fuji II (as a control)	Immediate	10	5	4	4	5	7	10	10	6	3	7	6	7	10	**94**
	After one-day storage	7	0	0	2	0	2	1	1	0	2	1	0	1	4	S **21**

N=10 (total measuring points, 1-14 = 140)
**: vs Fuji II (Mann-Whitney U-Test, S: Significant difference, NS: Not significant difference, α=0.05)*
#: Means with the same letters were not significantly different by Tukey test. (p>0.05, non-parametric[14-17,19]).
***: Immediate vs after one-day storage (Mann-Whitney U-Test, S: Significant difference, α=0.05)*

pared on the human premolar surface using a tungsten carbide bur (200,000-rpm) and a fissure bur (8,000-rpm) under wet conditions (Figure 1). The cavosurface walls were finished to a butt joint. This design differed from a Class I clinical cavity in that the cavity corners were geometric-box angles used to prepare a constant-volume model. One cavity was prepared in each of 80 teeth (4 materials x 2 polishing or inspecting times 10x repeats = 80). The surfaces of the designated restorations were polished immediately after setting, using abrasive points (Silicone Mide, Shofu, Kyoto, Japan), while rinsing with distilled water to avoid desiccation and breakdown. The other designated specimens were stored after setting in distilled water at 37°C for 24 hours. The restoration surfaces were then polished, as described above.

Inspection Procedures

Each tooth was sectioned in a buccolingual direction through the center of the restoration using a low-speed diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA). The presence or absence of marginal gaps was measured at 14 points (each 0.5-mm apart) along the cavity restoration interface (n=10; total points measured = 140) using a traveling microscope (1000x, Measurescope, MM-11, Nikon, Tokyo, Japan) (Figure 1). The number of gaps in each position was totaled and expressed as a sum for each sample.[14-15,17]

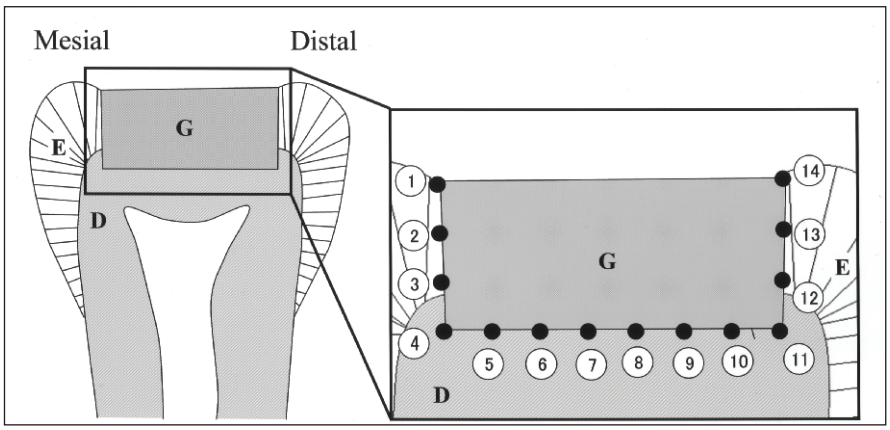

Figure 1. *Class I restoration and each measurement location for gap-formation. E: Enamel substrate, D: Dentin substrate, G: Glass ionomer restorative material.*

Marginal Gap in Teflon Cavity

Since Teflon does not react with GICs, it was used as a mold to measure the degree of setting shrinkage (immediately after setting) and any hygroscopic expansion (after one-day storage in water) of the GICs. Each prepared Teflon mold (n=10), with a depth of 1.5 mm and a diameter of 3.5 mm, was placed on a silicone oil-coated glass plate and filled with GIC using a syringe tip, then covered with a plastic strip until set. The sum of the maximum gap-width and the opposing gap width (if any) was expressed as the marginal gap in the Teflon cavity.

Shear Bond Strengths to Enamel and to Dentin

Wet grinding of the buccal surfaces was performed with up to 1000 grit silicon carbide abrasive paper until a flat enamel or superficial dentin area, 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, CT, USA). The mold was covered with a plastic strip and the material hardened by light irradiation, as described above. For each material, 10 specimens were prepared. The prepared specimens were secured in a mounting jig. Either six minutes from the start of the mixing procedure or after 24 hour water-storage, the shear force was transmitted by a flat (blunt) 1 mm broad shearing edge making a 90° angle in the direction of the load (or the back of the load plate). Shear force was applied (Autograph DCS-2000, Shimadzu, Kyoto, Japan) at a crosshead speed of 0.5 mm/minute. The stress at failure was calculated and recorded as the shear-bond strength. The failed specimens were examined under a light microscope (4x; SMZ-10, Nikon, Tokyo, Japan) to determine the total number of adhesive failure surfaces.[16]

Flexural Strength and Flexural Modulus of Elasticity

Teflon molds (25x2x2 mm) were used to prepare the flexural specimens (n=10/group). Each GIC setting was described above. The flexural properties were measured, both immediately after setting and after 24 hour storage, using the three-point bending method with a 20 mm-span and a load speed of 0.5 mm/minute (5565, Instron, Canton, MA, USA) as outlined in ISO 9917-2 (1996) and the flexural modulus was calculated (Software Series IX, Instron).

All procedures, except for cavity preparation, were performed in a thermo-hygrostatic room kept at 23 ± 0.5°C and 50 ± 2% relative humidity. Ten specimens were made for each material, storage period and property investigated. The results were analyzed statistically using the Mann-Whitney U test, Tukey Test (non-parametric),[14-17,19] Tukey Test, *t*-Test or Fisher Exact Test (Sigmastat 3.1, Systat Software, Inc, Point Richmond, CA, USA).

RESULTS

Table 2 summarizes the interfacial gap formation observed in Class I specimens with three HV-GICs and a normal C-GIC (as a control), when the specimen was polished immediately after light-activation and after delayed polishing. For all materials, the sum of the gaps was significantly less with delayed polishing compared to immediate polishing.

Table 3 summarizes the marginal gap width among the four GICs and Teflon molds under two conditions. The two columns represent the linear (diametral) setting shrinkage-strain immediately after setting and after one-day storage. The data for polishing after one-day storage was significantly better compared with immediate polishing. With both the immediate and after one-day stages, the values of Fuji IX GP and GlasIonomer FX-II were significantly less than for Fuji II.

Table 3: *Effect of Polishing Time on Marginal Gap-width in a Teflon Mold (micrometer)*

Restoration	Mean (SD)		*p*-value*
	Immediately	After One-day Storage	
Fuji IX GP	**14.3** (2.3) (S)#	**9.3** (2.2) (S)	<0.001
GlasIonomer FX-II	**14.3** (3.5) (S)	**9.5** (1.7) (S)	<0.05
Ketac Molar Aplicap	**17.0** (2.4) (S)	**11.8** (3.0) (NS)	<0.001
Fuji II	**20.0** (3.3)	**12.9** (3.0)	<0.001

*N=10, Diameter in Teflon mold: 3.5 mm. *: t-test.*
#: vs Fuji II (t-test, S: Significant difference, NS: Not significant difference, p>0.05)

Table 4: *Shear Bond Strength to Enamel Surface (MPa) Immediately After Setting and One-day Storage*

Restoration	Mean (SD)		*p*-value*
	Immediately	After One-day Storage	*p*-value#
Fuji IX GP	**2.50** (0.64)[ab] 0/2/8**	**8.29** (1.87)[c] 0/3/7	<0.00 NS
Glass Ionomer FX-II	**2.78** (0.58)[a] 0/0/10	**8.41** (1.52)[c] 0/0/10	<0.001 NS
Ketac Molar Aplicap	**1.83** (0.53)[b] 0/8/2	**5.99** (2.90)[c] 0/7/3	<0.001 NS
Fuji II (as a control)	**2.93** (0.90)[a] 0/2/8	**6.44** (1.97)[c] 0/3/7	<0.001 NS

**: t-test. #: Fisher Exact test. NS: Not significantly different (p>0.05)*
***: Number with each fracture mode, adhesive failure at the bonding site/mixed failure/cohesive failure, N=10*
Means with the same letters were not significantly different by Tukey test. (p>0.05)

Table 5: *Shear Bond Strength to Dentin Surface (MPa) Immediately After Setting and After One-day Storage*

Restoration	Mean (SD)		*p*-value*
	Immediately	After One-day Storage	*p*-value#
Fuji IX GP	**1.38** (0.55)[a] 0/0/10**	**8.80** (1.12)[c] 0/0/10	<0.001 NS
Glass Ionomer FX-II	**2.12** (0.45)[b] 0/0/10	**5.45** (1.03)[d] 0/0/10	<0.001 NS
Ketac Molar Aplicap	**1.42** (0.59)[a] 0/0/10	**7.17** (1.99)[cd] 0/0/10	<0.001 NS
Fuji II (as a control)	**2.20** (0.67)[b] 0/0/10	**8.59** (2.00)[c] 0/0/10	<0.001 NS

**: t-test. #: Fisher Exact test. NS: Not significantly different (p>0.05)*
***: Number with each fracture mode, adhesive failure at the bonding site/mixed failure/cohesive failure, N=10*
Means with the same letters were not significantly different by Tukey test (p>0.05)

Table 6: *Flexural Strength (MPa) Immediately After Setting and After One-day Storage*

Restoration	Mean (SD)		*p*-value*
	Immediately	After One-day Storage	
Fuji IX GP	**1.83** (0.79)[a]	**29.18** (5.39)[b]	<0.001
GlasIonomer FX-II	**1.70** (0.53)[a]	**17.29** (1.87)[c]	<0.001
Ketac Molar Aplicap	**1.89** (0.88)[a]	**19.33** (5.38)[c]	<0.001
Fuji II (as a control)	**2.00** (1.59)[a]	**15.33** (2.07)[c]	<0.001

**: t-test, N=10*
Means with the same letters were not significantly different by Tukey test (p>0.05)

Table 7: *Flexural Modulus (GPa) Immediately After Setting and After One-day Storage*

Restoration	Mean (SD)		*p*-value*
	Immediately	After One-day Storage	
Fuji IX GP	**1.30** (0.34)[a]	**14.54** (1.97)[b]	<0.001
GlasIonomer FX-II	**1.82** (0.43)[a]	**12.63** (1.92)[b]	<0.001
Ketac Molar Aplicap	**1.98** (0.95)[a]	**14.43** (4.34)[b]	<0.001
Fuji II (as a control)	**1.57** (1.01)[a]	**12.63** (4.10)[b]	<0.001

**: t-test, N=10*
Means with the same letters were not significantly different by Tukey test (p>0.05)

Table 4 summarizes the shear bond strength to the enamel surface and mode of fracture, respectively. Immediately after setting, the value of the shear bond strength of Ketac-Molar was significantly less than the normal C-GIC (Fuji II). However, there was no difference among the four GICs after one-day storage. The data for polishing after one-day storage were significantly better compared to polishing immediately. For all groups, no significant differences in fracture mode were observed between immediate and 24 hour polishing.

Table 5 summarizes the shear bond strength to the dentin surface and mode of fracture, respectively. Immediately after setting, the value of the shear bond strength of Fuji IX GP and Ketac-Molar were significantly less than Fuji II. After one-day storage, the value of shear bond strength was not significantly different among the three C-GICs, except for GlasIonomer FX-II. The data for polishing after one-day storage were significantly better compared with that for polishing immediately. For all groups, no significant differences in fracture mode were observed between immediate and 24 hour polishing.

All the materials showed significantly higher flexural strength after one day than immediately after setting (Table 6).

Table 7 summarizes the flexural modulus under two conditions. The tendency of the results was similar to flexural strength—increasing after storage. All the materials showed significantly higher value than when the specimens were measured immediately after setting.

DISCUSSION

This study used a model cavity for the geometry of typical Class I cavities. This approximates only the Class I morphology and is not the typical morphology for a C-GIC; it has the advantage of a constant volume and reproducible geometry that is beneficial for an *in vitro* scientific study.

This study demonstrated that polishing four GICs should not be performed immediately after the filling and setting procedure; instead, polishing should be delayed to a later time to prevent interfacial gap-formation between the material and the Class I cavity. In contrast to the marginal gap of approximately 80-100 gaps when the specimen was polished immediately after setting, the gap was near zero when the specimen was polished after storage in water for one day. GICs shrink during the setting reaction, interfacial gaps form an adhesion between the tooth-cavity and glass-ionomers do not resist shrinkage-stress.[13,20-21] However, after one-day water storage, shrinkage-stresses of the materials are effectively compensated for or even converted into expansion-stress due to water uptake and swelling.[1-2,4,18] Water absorption of C-GICs reportedly affects cavity adaptation and reduces microleakage.[3,13] Although hygroscopic expansion may not be sufficient to compensate for setting shrinkage, it plays an important role in reducing shrinkage caused by the cement setting reaction and thus improves interfacial gap-formation in the restoration.[14-15]

With respect to polishing condition, the marginal gap measured using the Teflon mold showed a similar pattern to that obtained using the Class I restoration, as mentioned above. The marginal gap observed even after the specimen was stored in water for one day indicated that hygroscopic expansion did not fully compensate for setting-shrinkage.

The bond-strength, flexural-strength and flexural-modulus of one-day storage were significantly higher than what was measured immediately for all C-GICs, and inter-relationships have been reported previously.[3,13,22] As expected, cements show higher bond and mechanical strengths when fully set than during the setting reaction. Also, the pH, an index of the extent of the hardening reaction for GICs, gradually increases for 24 hours.[1-2,23] Therefore, it can be presumed that completion of the setting reaction of a GIC requires at least 24 hours.

After one-day storage, an HV-GIC (Fuji IX GP) performed significantly better than its corresponding conventional C-GIC (Fuji II). Increasing the powder-liquid ratio is the primary reason for improving these results, as the two C-GICs are otherwise very similar. This improvement is achieved by a reduction in the size of the glass particle. However, GlasIonomer FX-II and Ketac Molar Aplicap did not clearly show this pattern. This may be explained by differences in density, distribution or content of the powder, and the polyacrylic or maleic acid concentration or molecular weight of polyacrylic or maleic acid of the liquid. A number of variations led to an HV-GIC with improved physical properties.[24]

CONCLUSIONS

For C-GICs, investigating interfacial gap-formation after 24 hour storage had value. The greater interfacial integrity of GICs resulted from harmony between good bond-strength, low-setting shrinkage or possibly some hygroscopic expansion. With HV-GICs, it is thus generally advisable to adjust the occlusion immediately after initial setting and perform a final contouring and finishing using the delayed polishing procedure. It is thought that an HV-GIC is the most useful and significant restorative material for some pediatric or geriatric patients.

A more extensive approach to the evaluation of sealing efficacy with C-GICs would require longer-term durability testing or load cycling.

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