

Hygroscopic Expansion of Aesthetic Restorative Materials: One-Year Report

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Abstract:

Objective: To measure the long-term linear hygroscopic expansion (LHE) of several materials using bulked and layered techniques.

Materials and Methods: Seven materials were used; Fuji Cap II, Fuji II LC, Photac-Fil Aplicap, Vitremer, Dyract, Tetric and Z100. Ten specimens (6×4 mm) were made for each material using layered and bulked techniques (each group comprises five specimens). The specimens were stored in distilled water at 37°C. The length of each specimen was measured immediately after preparation, 24 hours, one week, one month, three months, six months, nine months and one year. This was used to calculate the percentage change in the length of materials. The mean LHE and standard deviation were calculated. Repeated measure analysis and paired sample t-test were used.

Results: The type of material and time had a significant effect on LHE. Fuji Cap II and Fuji II LC exhibited no significant changes after one-year and one month, respectively. However, layered specimens of Photac-Fil Aplicap and Tetric showed constant expansion until six month, whereas bulked specimens reached the constant length at three months. Constant expansion was obtained for layered and bulked specimens of Dyract and Z100 at six month. Layered specimens of Vitremer showed no significant differences except between 24 hours and one year measurements. But in bulked specimens, the results at nine months and one year were significantly different from those obtained at three months and before.

Conclusion: Fuji II showed no significant LHE and resin-modified glass ionomer cements (RMGICs) exhibited the highest LHE. Dyract maintained an intermediate LHE in comparison with RMGIC and composite resin.

Key Words: Absorption; Water; Composite Resins; Glass Ionomer Cements; Compomers

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INTRODUCTION

The polymerization of a light-cured material will result in shrinkage of the restoration. This may lead to the formation of interfacial gaps. These are believed to cause microleakage, postoperative sensitivity, recurrent caries and eventual loss of the restorations [1,2].

After exposure of the restoration to oral fluids,

some relief from the curing shrinkage may arise from water uptake. The water that diffuses into the material causes a gradual expansion, up to a certain equilibrium value which will contribute to relaxation of shear stresses. In contrast to the rather rapid polymerization contraction and stress development, the hygroscopic relief will proceed slowly and might

even take days [3,4]. Hygroscopic expansion may compensate for the curing shrinkage thereby improving the marginal quality of the restoration and closing of the gap [5-7]. The rate and magnitude of hygroscopic expansion of a resin material depends on several variables such as the nature of the resin, the type of filler, filler loading, filler matrix adhesion and the volumetric ratio between the filler and matrix [8-10].

Results from a 7-day-study showed that the hygroscopic expansion of composites reached equilibrium after approximately four to six days depending on the materials investigated [8]. Whereas, in another study, an increased water absorption was observed during the first month for all composite resins with a further small increase up to six months [6].

The linear hygroscopic expansion of conventional and resin-modified GIC liners was measured for up to one week [11]. It was observed that the dimensions of the conventional GICs did not show any significant change after 30 minutes of immersion, while the resin-modified cements exhibited changes up to 24 hours and remained constant for the next week. The resin modified GIC liners showed a significantly higher expansion than the conventional cements, a finding which was confirmed by other studies [12,13]. It was also reported that at six months, the mean change in linear expansion was 0.16%, 0.66% and 0.32% for the microfilled composite, polyacid-

modified composite resin and dual curing composite, respectively; concluding that the hygroscopic expansion of the polyacid-modified composite resin material was significantly greater than that of the composite resin tested [14].

Investigations of linear hygroscopic expansion of the resin-modified GICs are limited, especially regarding their long-term expansion. The aim of this study was to investigate the long-term linear hygroscopic expansion of resin-modified GICs in comparison with those of a conventional GIC, a polyacid-modified composite resin and two composite resins. The magnitude of the hygroscopic expansion of specimens which were made using bulk insertion techniques was also investigated.

MATERIALS AND METHODS

The materials used in this study were Fuji Cap II, Fuji II LC, Photac-Fil Aplicap, Vitremer, Dyract, Tetric and Z 100 (Table 1).

The moulds (6×4 mm) used for specimen preparation were of the split-body type, constructed of stainless steel. Before use, a dry PTFE (Poly Tetra Fluoro-Ethylene) separating film was utilized to facilitate removal of the specimens. The mould was placed on a clean glass plate that had been coated with a PTFE film. The restorative material was mixed and handled according to the respective manufacturer's instructions. It was packed in three two-millimeter thick increments. The mould was

Table 1. Details of the materials used in this study.

Name	Description	Manufacturer	Time (seconds)			P : L Ratio	Batch No.
			Setting	Working	Curing		
Fuji Cap II	Conventional GIC	GC International, Tokyo, Japan	225	105	-	E	911225
Fuji II LC	Resin-modified GIC	GC International, Tokyo, Japan	-	195	20	3.0/1.0	P:211212 L: 29111
Photac-Fil Aplicap	Resin-modified GIC	Espe GMBH, Seefeld/Oberbay Germany	-	180	20	E	0003
Vitremer	Resin-modified GIC	3M, Health Care, St Paul USA	240	180	40	2.5/1.0	19930520
Dyract	Polyacid modified C.	Dentsply/De Trey, Surrey England	-	-	40	-	921082
Tetric	Fluoridated C. resin	Vivadent, Schaan, Liechtensein	-	-	40	-	462284
Z 100	C. resin	3M, Health Care, St. Paul USA	-	-	40	-	19940413

P=Powder, L=Liquid, E=Encapsulated, C.=Composite

overfilled with the restorative material and another glass plate was placed over it with firm pressure. Each layer of the material was light cured separately using the Visilux 2 (3M, USA) curing unit for the recommended time. Fuji Cap II was inserted into the mould in one bulk and the specimens were left for 10 minutes at 37°C and 100% humidity. Five specimens were made for each material. To assess the effect of a bulk insertion technique on the expansion of the light-cured materials, five more specimens were made for each of these materials. To prepare these specimens, the material was applied in bulk until the mould was overfilled and light-cured from both sides simultaneously using two light-curing units Visilux II and Caulk Max; L.D. (Dentsply, Germany).

After curing, any flash of excess material was removed so that the surfaces of the specimen were flush with the surfaces of the mould and were perpendicular to the long axis of the specimen. This was achieved by lapping the mould containing the test specimen on 1000-grit paper. Lapping was carried out in as short a time as possible without using water to eliminate the effect of hydration. After lapping, the specimen was removed and stored in a separate plastic bottle containing distilled water at 37°C for up to one year. Prior to storage, the length of each specimen was measured three times using a digital micrometer (Mitutoyo, Mitutoyo Corporation, Japan) and the mean of the three readings was used for calculation of

the percentage change in the length of the materials.

The specimens were removed from the water after 24 hours, one week, one month, three months, six months, nine months and one year following preparation and dried using tissue paper. The length of the specimens was again measured as mentioned above and the linear expansion of the materials was presented as the percentage of change of the specimens in relation to the baseline measurement. The mean hygroscopic expansion and standard deviation (SD) were calculated for each material at various time intervals. Repeated measure analysis was used to determine the effect of variables. P value lower than 0.05 was regarded as statistically significant. Paired sample t-test with Bonferroni correction was employed to assess the difference between the means of the two groups.

RESULTS

The results obtained are presented in Tables 2 and 3. Results indicated that material had a significant effect on the expansion ($P < 0.001$). Therefore, the results were further subjected to Tukey HSD test. Significant differences between all materials were revealed. Photac-Fil Aplicap showed the highest expansion values followed by Fuji II LC and Vitremer; whereas, Fuji Cap II exhibited the least expansion. Bulk inserted specimens showed higher expansion than layered specimens ($P < 0.001$) except for Z100.

Table 2. The linear hygroscopic expansion (%) of layered specimens in different time intervals.

Time	Fuji Cap II		Fuji II LC		Photac-Fil Aplicap		Vitremer		Dyract		Tetric		Z100	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
24 hours	0.047	0.088	1.483	0.122	2.548	0.068	1.339	0.155	0.057	0.164	0.001	0.036	0.037	0.038
1 week	0.111	0.071	1.766	0.117	2.815	0.074	1.471	0.151	0.168	0.053	0.108	0.019	0.174	0.033
1 month	0.084	0.063	1.952	0.118	2.980	0.050	1.617	0.134	0.363	0.034	0.209	0.054	0.325	0.009
3 months	0.010	0.086	1.966	0.123	2.963	0.053	1.600	0.145	0.551	0.066	0.229	0.033	0.385	0.023
6 months	0.017	0.027	2.032	0.070	3.052	0.054	1.631	0.142	0.783	0.053	0.259	0.051	0.429	0.009
9 months	0.014	0.060	2.124	0.107	3.126	0.077	1.698	0.147	0.870	0.044	0.333	0.036	0.449	0.037
1 year	0.037	0.047	2.111	0.139	3.149	0.073	1.688	0.158	0.867	0.070	0.336	0.057	0.473	0.025

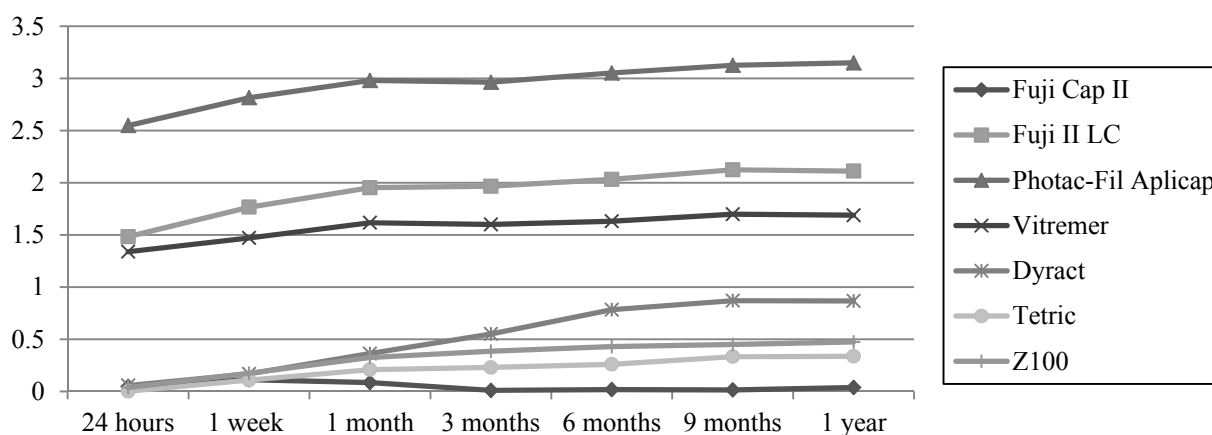


Fig 1. The linear hygroscopic expansion of layered technique in different time intervals.

The interaction between material and method of preparation was significant ($P < 0.01$). This could be explained by the fact that Z100 was the only material that exhibited similar expansion for both layered and bulk inserted specimens (0.325 vs 0.330).

Results also indicated that all materials had significant expansion during the test period. Paired sample t-test showed that the time to reach a constant level differs for each material. For instance, Fuji Cap II, Fuji II LC and Tetric achieved the constant length at three months, while this time was six months for Photac-Fil Aplicap and Z100 and nine months for Vitremer and Dyract.

The interaction between time, material and method of preparation as well as the interaction between time and method of preparation was not significant ($P = 0.330$ and $P = 0.151$,

respectively). However, the interaction between time and material was significant ($P < 0.001$), which could be elucidated by the difference in the hygroscopic expansion slope of materials (Fig 1).

DISCUSSION

Dimensional changes of restorative materials caused by hygroscopic expansion may be determined by a variety of equipment and test methods such as hydrostatic or Archimede's principle [12,15,16]; model cavities cut in brass, in which the hygroscopic expansion of the material was expressed by the displacement force generated due to water sorption [6,17]; the ability of materials in reducing the marginal gap [5]; measuring the relaxation of setting shrinkage shear stress [18]; measuring the length of specimens by means of an elec-

Table 3. The linear hygroscopic expansion (%) of bulk specimens in different time intervals.

Time	Fuji II LC		Photac-Fil Aplicap		Vitremer		Dyract		Tetric		Z100	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
24 hours	1.319	0.094	2.349	0.076	1.135	0.095	0.104	0.040	0.057	0.035	0.037	0.036
1 week	1.601	0.117	2.621	0.042	1.202	0.116	0.047	0.047	0.024	0.044	0.181	0.042
1 month	1.709	0.106	2.709	0.035	1.304	0.121	0.245	0.040	0.117	0.043	0.339	0.040
3 months	1.793	0.121	2.806	0.052	1.382	0.133	0.446	0.040	0.198	0.055	0.389	0.028
6 months	1.874	0.134	2.830	0.037	1.385	0.098	0.650	0.035	0.218	0.042	0.443	0.038
9 months	1.961	0.128	2.853	0.020	1.493	0.105	0.683	0.026	0.228	0.039	0.439	0.014
1 year	1.965	0.131	2.894	0.060	1.476	0.100	0.714	0.053	0.231	0.033	0.479	0.026

tric or a computer-controlled laser micrometer or a microscope [8,11,14,19,20]. In the present study, a micrometer with an accuracy of one micron was used to measure the change in the length of cylindrical specimens (6×4 mm). The procedure proved to be uncomplicated and the equipment was inexpensive. In addition, the advantages of using specimens with the above dimensions were that they simulated relatively large dental restorations.

In this study, unlike the conventional GIC, the resin-modified cements showed significant expansion. The pattern of such expansion differed according to the material tested. As mentioned earlier Fuji Cap II, Fuji II LC and Tetric reached a constant length after about three months while more time was necessary for Photac-Fil Aplicap and Z100 (six months). Dyract and Vitremerl required nine months to reach a constant length.

The finding that a relatively long time was required for the composite materials to reach a constant length is in agreement with that of Momoi and McCabe [6], who observed an increase in the displacement force due to water uptake during the six-month test period. They suggested that such an increase indicated that there were regions within the specimens that were not fully saturated [6]. In another study, however, after seven days of storage in water at 37°C, all composite materials showed significant hygroscopic expansion that did not significantly increase further until the 30-day storage [7].

It was observed that the dimensions of conventional GICs did not show any significant change after 30 minutes of immersion in water, while the resin modified cements exhibited changes up to 24 hours and remained constant for the next week. The composite resin used demonstrated a significantly continuous increase during the period of the study (one week). These results indicate that composite resins require a longer time than the resin-modified GICs to reach a constant length [11].

This is in agreement with the results of the present study.

The higher linear expansion for the resin-modified GICs observed in the present study is in agreement with the result of recent investigations [11]. Irie et al [20] reported that the resin-modified GIC liners showed significantly higher linear expansion than the conventional cements, the magnitude of which was in the range of 2.4% - 6.3%. In Kimishima et al's [21], Vitremer showed slightly less expansion (4.98%) than Fuji II LC (5.44%), which is in line with the results of the present study.

This high linear expansion of resin-modified GICs could be attributed to the presence of hydrophilic resin HEMA in resin-modified cements. The higher linear expansion associated with Dyract, in comparison with that of composite resins, could also be explained by the fact that this material also contained some hydrophilic monomers [22,23]. It was reported that at six months, Dyract showed a linear expansion (0.66%) greater than that of either a light-cured composite (0.16%) or a dual-cured composite resin (0.32%) [14]. In addition, it was shown that Fuji II LC produced the greatest (38 MPa) and most rapid rise in lateral stress brought about by hygroscopic expansion. Z100 and Tetric produced a linear rise up to six and four MPa, respectively. Dyract produced 7 MPa stress by one month [17]. These findings are congruent with the results of the present study where Dyract showed a hygroscopic expansion intermediate to that of the resin-modified GICs and composite resins.

The results currently recorded for Fuji Cap II must be viewed with caution. In the present study, the specimens made from Fuji Cap II were maintained at 37°C and 100% relative humidity for 10 minutes. Therefore, the first measurement was performed approximately 20 minutes after mixing (taking into account the time required for lapping). Since conventional GICs undergo setting shrinkage immediately after setting, this delay in measurement might

have had an effect on the results. For all other materials which were all of the light-curing type, the measurements were carried out within 5 minutes after curing.

Except for Z100, the difference between the linear hygroscopic expansion of the layered and bulk inserted specimens was generally significant, with the bulk inserted specimens showing less expansion. This finding is in agreement with that of Bowen et al [19], who reported that when a composite resin was placed in bulk it had more shrinkage, less hygroscopic expansion and some degree of residual shrinkage. The higher shrinkage of a material placed in bulk; therefore, might account for the lower hygroscopic expansion observed in this study. However, it is known that restorations that are inserted in bulk show wider marginal gaps and more microleakage [24].

As discussed earlier, the setting shrinkage of restorative materials results in marginal gap formation, microleakage and probably recurrent caries. Hygroscopic expansion may compensate for this shrinkage and close the marginal gap. Since the expansion occurs sometime after the shrinkage has taken place, the expansion will not lead to the re-establishment of any broken adhesive bonds and perfect closure.

During its earliest stages, expansion may simply cause a closing up of the contraction gaps caused by setting shrinkage. Continued expansion, however, may cause development of an outward pressure against the cavity walls. Estimation of the magnitude of this pressure may enable its clinical significance to be inferred. Feilzer et al [25] suggested that in the clinical situation, a slight positive stress is preferable to a tensile stress as it may improve the marginal integrity of a restoration. They found that when the experiments ended after 15 hours, a further build-up of compressive stress was observed with the resin-modified GICs [25]. Momoi and McCabe [6] reported

that the hygroscopic expansion of composite resins during a 6-month study resulted in pressure values of 3.3 to 14.5 MPa dependent on the material. They suggested that positive pressure of a similar magnitude pushing against the cavity walls may be capable of putting the supporting tooth tissues under considerable stress [6].

Using the results of this study and the modulus of material elasticity provided by another study, the magnitude of the pressure generated from the expansion of the materials tested may be calculated from the following equation:

$\text{Stress} = \text{Strain} \times E$, where E is the modulus of elasticity of a material and strain is the expansion (%) of the material at a given time [26].

Such calculations gave pressure values of 124.55 MPa for Photac-Fil Aplicap, 111.33 MPa for Vitremer, 103.41 MPa for Fuji II LC, 44.66 MPa for Dyract, 34.95 MPa for Z100, 11.04 MPa for Tetric and 0.52 MPa for Fuji Cap II; each calculation was made using the values obtained at the time when the material reached its constant length. These values are much higher than those reported by Momoi and McCabe [6], Watts et al [17].

The reason might be due to the test methods employed. These studies employed a model cavity design, in which the materials were inserted in a brass mould and the pressure required to displace the specimens was calculated. The presence of such close contact between the brass and test material might have led to a lesser water absorption, hence less hygroscopic expansion than that recorded in the present study [6,17].

CONCLUSION

1. Fuji Cap II showed the least linear hygroscopic expansion during the study. The resin-modified GICs exhibited the highest linear hygroscopic expansion among the materials tested. Photac-Fil Aplicap showed the highest hygroscopic expansion between the resin-modified cements.

2. The time to reach a constant level was varied, acquiring three to nine months depending on the material tested.
3. The initial linear expansion of Dyract was similar to that observed with composite resins. At one year, however, its linear expansion was significantly higher than the composite resins.

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