Experimental Comparison of Hygroscopic Expansion in Three Different Composite Resins

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Abstract

**Background and Aim:** These days dental composites are very popular because they look good and are similar to human teeth regarding color. Hygroscopic expansion is one of the physical properties of dental composites. A dental composite may lose its efficiency as a restoration material because of water absorption. The objective of this study was to compare the hygroscopic expansion of three dental composites.

**Materials and Methods:** In this experimental study, to assess the effective factors of hygroscopic expansion, we used three different dental composites (Kalore, P90 and Z250). The length of these composites in water and saliva were measured eighteen times in a three-month period. For analyzing the data, we used the marginal modeling technique in which the correlation between response data can be accounted for.

**Results:** The results of marginal modeling showed that the type of composite is significantly related to hygroscopic expansion ($P<0.05$); demonstrating the highest hygroscopic expansion for P90 and the lowest for Z250. In addition, time as an independent variable had a statistically significant effect on hygroscopic expansion ($P<0.05$). However, we found no significant difference between the hygroscopic expansion of saliva and water ($P>0.05$).

**Conclusion:** Overall, our findings showed that hygroscopic expansion is significantly related to the type of composite and time. Therefore, we should utilize the composites with lower hygroscopic expansion (such as Z250) for filling the patients’ teeth.

**Key Words:** Composite resin, Hygroscopic expansion, Longitudinal studies

Introduction

In the past years, research has been conducted towards finding an ideal substance from the esthetics and strength point of view leading to improvement in dental restorative methods. This process has resulted in the production of composite resins using the acid etch technique [1]. In the last decades, there has been remarkable progress in dental composites, one of which is the big revolution in composites in 1960, in which demethacrylate as BisGMA, TEGDMA or UDMA were used in composites [2]. Despite these improvements, methacrylate-based composites have restrictions such as shrinkage after polymerization due to closeness and adhesion of the monomer molecules during polymerization. This matter may cause nonconcurrence of margins leading to
microleakage, sensitivity after restoration and finally decrease in the longevity of the composite [3, 4]. From the late 1950s, resin composites were introduced as dental restorative materials [5]. In addition to esthetic properties, these materials have the ability to bond to the dental structure without the need to remove the normal tissue. As a result of the ability to bond to the dental structure by the bonding system, the use of composites has increased conservatively in dentistry. Therefore, composites are used in different and static fields such as anterior and posterior caries, occlusion, cementation of indirect restoration, sticking orthodontic brackets and static changes in the teeth [6, 7].

In general, composite resins are a combination of hard non mineral particles that are attached by soft composite resins. They consist of three main parts:

1- Non mineral filler that is formed of particles such as glass, quartz or attached silica.

2- Monomer system including the starter system for beginning polymerization through the free radical reaction and stabilizer for the maximum stabilizing of the non cured composite and chemical stabilizing of the cured composite.

3- The adhesion factor which is usually organosilane chemically bonds the filler and the matrix resin.

The function of the composite depends on the consisting components. Some of the properties depend on the filler and the adhesive factor and other properties depend on the composite resin. Properties such as strength, hardness, resistance against grinding and the thermal expansion index depend on the type of filler and the adhesive factor. The color stabilizing and predilection to softness are related to the resin. Properties such as polymerization shrinkage and water absorption are related to both the resin matrix, and the type of filler and adhesive factor [8-10]. As a result of polymerization and the pressure due to that destruction, the composites are sealed marginally, causing distance, sensitivity after restoration, color change of the restoration margins and even secondary decay. One other complication due to polymerization shrinkage is displacement of the cusps which may lead to dental sensitivity, cracks or even dental fracture [11, 12].

Water absorption and hygroscopic expansion is one of the physical properties of the composites. After water absorption, the quality of the composite may change and its efficiency as a restorative material may not exist. In addition, if the hygroscopic expansion does not destruct the structure of the composite, it may compensate the polymerization shrinkage. On the other hand, there have been limited studies regarding hygroscopic expansion and dimensional changes in low-shrinkage composites. Since these composites have been introduced with the claim of decreasing polymerization shrinkage, evaluating the hygroscopic expansion and comparing it with the polymerization shrinkage in these material is of great importance [13].

Regarding the high variety of the number of available composites, there have been several articles published based on comparison of the different properties such as microhardness, microleakage and thermal expansion. In none of these studies, the shrinkage or the hygroscopic expansion of the three mentioned composites have been compared with each other. Martin et al. and Rutterman et al. have compared shrinkage and hygroscopic expansion between different composite resins. They reached the conclusion that these composite resins have different shrinkage and hygroscopic expansions which are mostly due to the base resin used in these composites. They also showed that in the evaluated composites, the hygroscopic expansion does not have the ability to compensate the shrinkage [14, 15].

As a sample, in the national studies, Sadaghiani et al. evaluated the effect of the distance of the LED and halogen light curing machine on the microleakage of Z250 composite and reached the conclusion that the microleakage of all the sam-
amples hardened in zero distance was significantly higher than the samples hardened in 5 mm distance. Besides, the findings in this study showed that the ratio of the surface microleakage to the depth in the LED machine is higher than halogen [16]. Another important point in the mentioned studies is that in the majority of them single variable statistical tests such as analysis of variance was used to compare different properties of the composite. Based on the above mentioned matters, the objective of this study was to use an appropriate statistical method to analyze the longitudinal data in order to evaluate the change in the hygroscopic expansion of three Z250, P90 and Kalore composites in a three-month period in two saliva and distilled water environments.

Materials and Methods

This experimental study was conducted to evaluate the effective factors on the hygroscopic expansion of three Z250, P90 and Kalore cylindrical composites and the details of the composite properties are demonstrated in Table 1. Of each composite, ten 6×4 mm (length 6 mm and diameter 4 mm) cylindrical samples were made and were then placed in normal saliva and distilled water for three months. The length of these cylindrical samples were measured 18 times–24 hours, 48 hours, 5 days, one week, 9 days, 11 days, two weeks, 18 days, 20 days, three weeks, one month, 6 weeks, two months, ten weeks, 78 days, 80 days and three months after preparation. For each condition (environment-composite), five samples were considered and in order to increase the accuracy in each measurement step, each sample was measured twice. In this study, to evaluate the linear hygroscopic expansion, a digital micrometer with a measurement accuracy of 1 micron was used.

For describing the data, the mean and standard deviation of hygroscopic expansion for each composite in the two environments together with the appropriate linear graphs have been used. Besides, for simple comparison of the composites, the one way analysis of variance (ANOVA) and for comparison of the two maintaining environments, t test for two independent samples was used. Since multiple measurements on each composite lead to dependent response; therefore, analysis of these data needs methods that consider these dependencies [17, 18]. Thus, in order to define the simultaneous effect of the three independent variables; namely, the type of composite, the maintaining environment and time on hygroscopic expansion in 18 described times, the the marginal modeling approach which is one of the most common and efficient methods for the analysis of longitudinal data was used.

Results

In Table 2, the mean and standard deviation of each composite’s hygroscopic expansion is displayed in distilled water and oral saliva environments. The reported statistics are the mean of the measurements in 18 repeated times. Therefore, to understand the difference between the studied composites, we have demonstrated graphs 1 & 2 in which the change in the mean hygroscopic expansion regarding the maintaining environment and time may be observed more clearly. It may be deduced that Z250 composite has the least and P90 composite has the highest hygroscopic expansion. The results from t student test show that there is a significant difference statistically between distilled water and saliva environments (p=0.001).

The results from variance analysis show that the difference between the three composites is statistically significant (p<0.001). As mentioned before the main reason for the significant difference in these two tests is the high number of observations −18 times measurement for each sample. Although the data were measured repeatedly in a period of time and subsequently had internal dependence, using such tests may not obtain accurate results because in single variable tests such as t test or one way analysis of variance we are
not able to evaluate the effect of time. In order to adjust this defect, applying complicated statistical models to analyze the data and to measure the dependence structure of the collected measure. Although the data were measured repeatedly in a period of time and subsequently had internal dependence, using such tests may not obtain accurate results because in single variable tests such as t test or one way analysis of variance we are not able to evaluate the effect of time. In order to adjust this defect, applying complicated statistical models to analyze the data and to measure the dependence structure of the collected measurements in the time period seems necessary. For the purpose of evaluating the type of composite, time and the maintaining environment on the hygroscopic expansion simultaneously, we used the marginal modeling approach which is one of the most prevalent methods used for analysis of longitudinal dependent data. In this model, the internal dependence structure of the data is considered as a parameter in the model. The marginal model used is:

\[ Y_{it} = \theta + \beta_1 \text{Time}_i + \beta_2 \text{Composite}_i \times \text{Environment}_i + \epsilon_{it}, \quad i = 1, 2, \ldots, 30; t = 1, 2, \ldots, 18 \]

In which \( Y_{it} \) stands for the hygroscopic expansion of the \( i \)th composite in \( t \)th time [21-23]

The results of this fitting have been demonstrated in Table 3.

The results show that pass of time has a significant effect on hygroscopic expansion of the composite (\( p<0.001 \)). In addition, the type of composite has a significant effect on the hygroscopic expansion statistically; this is to say that the difference between Z250 composite and P90 composite was significant (\( p=0.008 \)), but this model did not show a statistically significant difference between P90 composite and Kalore composite \( (p=0.085) \). On the other hand, there was no significant difference statistically between the two maintaining environments of distilled water and normal saliva regarding hygroscopic expansion \( (p=0/777) \).

### Table 1: Properties of the Studied Composites

<table>
<thead>
<tr>
<th>Composite</th>
<th>Type</th>
<th>Manufacturer</th>
<th>Batch No.</th>
<th>Color Shade</th>
<th>Monomer</th>
<th>Filler (Wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtek Z250</td>
<td>Micro-Hybrid</td>
<td>3M ESPE, St Paul, MN, USA</td>
<td>N132502</td>
<td>A3</td>
<td>Bis-GMA, UDMA, Bis-EMA, Silorane (3,4-epoxycyclohexylethyl cyclopropylmethylsiloxyan, Bis-3,4-epoxycyclohexylethyl-phenylmethylsilane)</td>
<td>Silicon dioxide, Zirconium dioxide (82%)</td>
</tr>
<tr>
<td>Filtek P90</td>
<td>Micro-Hybrid</td>
<td>3M ESPE, St Paul, MN, USA</td>
<td>N146379</td>
<td>A3</td>
<td>Diels, UDMA, Dimethacrylate comonomer</td>
<td>Silicon dioxide, ytterbium Trifluoride (76%)</td>
</tr>
<tr>
<td>GC Kalore</td>
<td>Nano-Hybrid</td>
<td>GC-International Tokyo-Japan</td>
<td>0906021</td>
<td>A3</td>
<td>DuPont monomer, UDMA, Dimethacrylate comonomers</td>
<td>Perpolimerized filler (lanthaniied fluoride), fluoioluminosilicate glass, strontium/barium glass, Silicone dioxide (82%)</td>
</tr>
</tbody>
</table>

### Table 2: Mean and standard Deviation (mm) of Hygroscopic Expansion of Composites in Saliva and Distilled Water

<table>
<thead>
<tr>
<th>Environment</th>
<th>Normal Saliva</th>
<th>Distilled Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Composite</strong></td>
<td><strong>Z250</strong></td>
<td><strong>Distilled Water</strong></td>
</tr>
<tr>
<td>5.96 ± 0.013</td>
<td>5.97 ± 0.010</td>
<td></td>
</tr>
<tr>
<td>5.98 ± 0.021</td>
<td>6 ± 0.027</td>
<td></td>
</tr>
<tr>
<td>5.98 ± 0.021</td>
<td>5.97 ± 0.014</td>
<td></td>
</tr>
</tbody>
</table>
Discussion

Although there have been many studies in the field of water absorption, hygroscopic expansion and dissolution of composite, relating the present study to those is a difficult thing to do due to the different time spans, variety of composites and the different measurement methods [24]. The considerable matter is that in studies related to hygroscopic expansion, the evaluated samples were of different sizes because after floating in water, different sized samples need different times in order to reach equilibrium—the smaller the sample is, the shorter the time necessary for it to reach equilibrium is. Certainly the chemical structure of the substance is important, because the more the substance has propensity to absorb water the later it reaches equilibrium [24, 25]. In this study, the samples were cylinders 6 mm in length and 4 mm in diameter. The advantage of using such sized samples are that they are similar to big dental restorations and the dimensions are comparable to many of the restorations which are performed in clinic. This finding that composites need a long duration of time to reach dimensional equilibrium has been confirmed by the present study and so many other studies. In 1994, Momoi and McCabe evaluated the hygroscopic expansion of composites for 6 months.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>Estimation</th>
<th>Standard Deviation</th>
<th>P</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>--</td>
<td>5.980</td>
<td>0.0077</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Type of Composite</td>
<td>Z250</td>
<td>-0.022</td>
<td>0.0083</td>
<td>0.008</td>
<td>0.978</td>
</tr>
<tr>
<td></td>
<td>Kalore</td>
<td>-0.017</td>
<td>0.0099</td>
<td>0.085</td>
<td>0.983</td>
</tr>
<tr>
<td></td>
<td>P90</td>
<td></td>
<td>Reference category</td>
<td></td>
<td>Reference category</td>
</tr>
<tr>
<td>Maintaining Environment</td>
<td>Distilled water</td>
<td>-0.002</td>
<td>0.0069</td>
<td>0.777</td>
<td>0.998</td>
</tr>
<tr>
<td></td>
<td>Normal saliva</td>
<td></td>
<td>Reference category</td>
<td></td>
<td>Reference category</td>
</tr>
<tr>
<td>Time</td>
<td>--</td>
<td>0.001</td>
<td>0.0001</td>
<td>&lt;0.001</td>
<td>1.001</td>
</tr>
</tbody>
</table>
through measurement of the entered force from
the composite to the wall of the brass generator
[26]. The results showed that in the course of 6
months, the force increased. This matter con-
formed unsaturated areas in the samples. The
mentioned study was in accordance with many
studies such as the present study [27, 28]. Based
on the results of the past studies, in the first
days, the composites have a high speed of water
absorption and hygroscopic expansion, but in
order to reach equilibrium more time is neces-
sary [29]. In 1979, Pearson on a study regarding
the maintenance time of composites in a water
environment, showed that the amount of water
absorption and hygroscopic expansion occurs in
the first two weeks and reaches equilibrium dur-
ing 8 weeks [30]. Martin et al. in a 64-day study
mentioned that 63% of the expansion happens in
the first 10 days and after 10 days although the
expansion does not reach equilibrium, it does
decrease [14]. Decrease in the amount of linear
expansion through time may be due to two rea-
sons; first, saturation of the composite polymer
network and second, increase in the amount of
dissolution of the composite particles. Rutterman
et al. mentioned that with the increase of the
sample’s floating time in water, the dissolution
increases and the hygroscopic expansion de-
creases [15]. Although in our study the equili-
brium time is incongruent to other studies,
graphs 1 and 2 clearly show the primary increas-
ing trend of the hygroscopic expansion and sub-
sequently its relative decrease from the fifteenth
measurement (10 weeks) to the end. In this
study, the three types of composite showed di-
mensional changes in which the substance had a
statistically significant effect on the amount of
expansion. On the contrary, the environment had
no significant effect on the linear expansion sta-
tistically. The highest amount of hygroscopic
expansion belonged to composite P90 which is
congruent to the results of their study in 2011
[29]. The present study actually showed that
Z250 composite has the least hygroscopic ex-
pansion; therefore, is better than the other two
composites regarding this matter. Z250 com-
posite has UDMA monomers (urethane hydrophili-
groups), Bis-GMA (hydroxyl groups) and hy-
drophilestericbonds. P90 composite has silo-
rane monomer which is a hydrophobic mono-
mer. Some studies have introduced this com-
posite as a composite with low expansion and an
estimated polymerization expansion of less than
1% volume [31]. Thus, the high hygroscopic ex-
pansion of P90 composite despite the existence
of siloxane molecule which has a hydrophobic
property may put the surrounding dental tissues
under a great amount of pressure consequently
leading to pain, crack and even dental fracture
[26]. Some other studies on P90 composite have
reported approximately similar results, although
in none of these studies this composite has di-
rectly been compared with two other composites
in the same environmental circumstance as this
study.

Some studies have mentioned the high sealing
ability of P90 composite [26, 31, 32]. In Palin et
al.’s study, in which the solution containing the
samples (distilled water) was changed every two
weeks, the water absorption of P90 composite
was significantly lower than Z250 composite
[33]. Regarding Kalore composite, the present
study showed that in distilled water, this com-
posite has a low hygroscopic expansion (ap-
proximately similar to Z250 composite), but in nor-
mal saliva environment, it has a high hygroscop-
ic expansion (roughly comparable to P90 com-
posite).

In Wei et al.’s study, a high hygroscopic ex-
pansion has been reported for this composite [29].
The results of this study indicated that two nor-
mal saliva and water maintaining environments
had no significant difference statistically regard-
ing hygroscopic expansion. Although some stu-
dies have mentioned the decrease of water ab-
sorption and hygroscopic expansion in saliva as
a result of decrease in the osmotic slope, in most
of these studies artificial saliva was used as the
maintaining environment [34]. For instance,
Martin et al. and also Musaje et al. evaluated the
amount of water absorption and solution of the composites in distilled water and artificial saliva in a two month period and they reached this conclusion that the composites maintained in artificial saliva have a higher increase in weight and a lower solubility compared to composites maintained in water [14, 35].

Finally, we have to mention that some of the times the results of student’s t test and variance analysis were not in accordance with the results of the statistical model used for this study. This was due to the fact that none of the single variable tests consider the effect and passing of time, but the marginal model considers the simultaneous effect of time, composite and maintaining environment on hygroscopic expansion; therefore, the results are more precise and valid statistically.

Conclusion
Overall, the results show that the type of composite and the passing of time have a significant effect on hygroscopic expansion statistically. So it is better to use composites with a lower hygroscopic expansion such as Z250 for dental restoration. In addition, for analysis of the data of the composites’ hygroscopic expansion—usually collected as repeated measurement in a period of time—advanced statistical models, in which dependence between the data and also the effect of time is measurable, should preferably be used.

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