

# Effects of mechanical cyclic loading on marginal leakage of posterior composite restorations

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**Abstract :** The effects of mechanical cyclic loading on marginal leakage of posterior composite restorations were evaluated using cyclic loading machine which simulated mastication. Three types of class I cavities were prepared in extracted human molars: un-based wide type, fully-based wide type and un-based narrow type. After placing chemically-cured and light-cured composite resins, specimens were occlusally subjected to mechanical cyclic loading parallel to the axial direction in an aqueous solution of 0.2% basic fuchsin. Marginal leakage was evaluated on the bucco-lingually-sectioned surfaces under a stereo microscope. Marginal leakage was significantly greater in the 1.3kg, 24 hours ( $1.4 \times 10^5$  cycles) cyclic loading group in comparison with control group. However, no statistical difference was observed between 1.3kg, 24 hours loaded group and more loaded group. Light-cured composite restorations showed superior sealing ability immediately after placement, when compared with those which were chemically-cured, while, both types of composite restorations showed good sealing ability when a load was applied after soaking the restored teeth in water one week. Neither cavity size nor the presence of a cement base had any appreciable effect on marginal leakage. These results indicated that the application of cyclic loading to simulate mastication appeared to be of significance for evaluation of marginal sealing accompanied by the strain or distortion of tooth and restorative materials in posterior restorations.

**抄録 :** 口腔の咀嚼に近似した繰り返し荷重試験機を用いて、繰り返し荷重が臼歯用コンポジットレジン修復物の辺縁封鎖性に及ぼす影響について検討した。ヒト抜去大臼歯に3種の1級窩洞、すなわち無裏層大型窩洞、裏層大型窩洞および無裏層小型窩洞を形成し、各種接着性コンポジットレジンを通法通り充填した。次いで、0.2%塩基性フクシン水溶液浸漬下で修復歯の咬合面より歯軸に平行に繰り返し荷重を加え、歯牙を頬舌方向に切断後、実体顕微鏡下で切断面における辺縁漏洩度をスコア評価した。その結果、1.3Kg、24時間(98回/分)荷重を加えた群の辺縁漏洩度は対照群と比較して有意に増大した。しかしながらそれ以上荷重の大きさおよび回数を増加させても漏洩度に有意差は認められなかった。充填直後に荷重を加えた場合、化学重合型コンポジットレジンが高い漏洩度を示したのに対し、光重合型コンポジットレジン優れた辺縁封鎖性を示した。一方、1週間水中浸漬後荷重を加えた場合は両コンポジットレジンともに低い漏洩度を示した。窩洞形態別では大型窩洞と小型窩洞の間で、また裏層の有無で辺縁漏洩度に有意差は認められなかった。以上の成績から、咀嚼を模した繰り返し荷重試験は修復物の変位変形に伴う辺縁封鎖性を検討する上で意義ある試験法であることが明らかとなった。

## Introduction

Recently, composite resin has widely used as a posterior restorative material instead of amalgam,

because of increasing the patients' aesthetic demands and the environmental impact of mercury contamination. Particularly, light-cured composite resin is mainly used nowadays because of its remarkable advantages. This material allows the generous working time<sup>1)</sup> and internal porosity is avoided since the material is supplied as one paste and need no spatulation. In addition, the superficial layer has increased

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hardness and wear resistance<sup>2)</sup>. However, in composite resin material, internal stress is induced at the interface between composite resin and the cavity wall because of the polymerization shrinkage during the curing process, which tends to detach the composite resin from the cavity wall<sup>3)</sup>. Therefore, the composite/tooth bond may be disrupted and there will be a marginal leakage of composite restorations. It has been generally adopted a thermo-cycling for evaluation of the marginal leakage of composite resin restorations to simulate intraoral conditions<sup>4)</sup>. However, the load cycling test simulating mastication is also thought to be important since the restored teeth are subjected to repetitive biting force immediately after restoration. Jørgensen *et al.*<sup>5)</sup> first employed the mechanical cyclic loading for investigating the deformation of cavities in laboratory studies. They demonstrated the permanent or transitory gap formation in class III and V composite restorations that were axially loaded at small and moderate loads, which indicated a risk of percolation at the tooth/restoration interface. Qvist<sup>6)</sup> reported that 71% of buccal and lingual class V composite restorations on third molars with antagonists showed evidence of bacterial penetration, while those with no antagonists showed only 25%

## Materials and methods

Three light-cured composite resins: Photo Clearfil A (PCA), Lite-fil P (LFP), Pyrofil Light Bond (PYR), and a chemically-cured composite resin, Clearfil Posterior (CFP), were used for this study (Table 1). Etching and bonding agents were standard products supplied by the manufacturers. One hundred and forty extracted, sound, human molars were used in this study. These teeth were stored in 10% formalin solution after extraction. Three types of class I restorations (Fig. 1) were tested: un-based (I) and fully-based (II) wide cavities, with a width of about two-thirds of the distance between the buccal and lingual cusps, simulating those in which the cusp of the antagonistic tooth comes into direct occlusal contact with the composite resin, and narrow cavities (III) with a width of about one-third of the distance between the buccal and lingual cusps, simulating those in which the occlusal contact is on the enamel around the restorations. After applying protective varnish (Protect Varnish, Kuraray Corp., Okayama, Japan) on the entire occlusal enamel surface to avoid over-extended acid etching around the cavity margins and to guide the

Table 1: Composites used in this study.

| Code | Product Name       | Cure | %Filler | Composition        | Batch Number       | Manufacturer  |
|------|--------------------|------|---------|--------------------|--------------------|---------------|
| CFP  | Clearfil Posterior | C    | 80.2    | Universal Catalyst | PU-2252<br>PC-2152 | Kuraray Corp. |
| PCA  | Photo Clearfil A   | L    | 83.0    | Paste resin        | HAS-1006           | Kuraray Corp. |
| LFP  | Lite-Fil P         | L    | 82.1    | Paste resin        | 038838             | Shofu Corp.   |
| PYR  | Pyrofil light Bond | L    | 81.5    | Paste resin        | 177-806            | Sankin Corp.  |

C: Chemically-cured    L: Light-cured    %Filler is in weight %.

bacterial penetration in clinical study. Therefore, it is obvious that the mechanical cyclic loading affects the marginal sealing of composite resin restorations. The purpose of this *in vitro* study was to determine the effect of mechanical cyclic loading on marginal leakage of posterior composite restorations using a newly designed cyclic loading machine which simulates mastication.

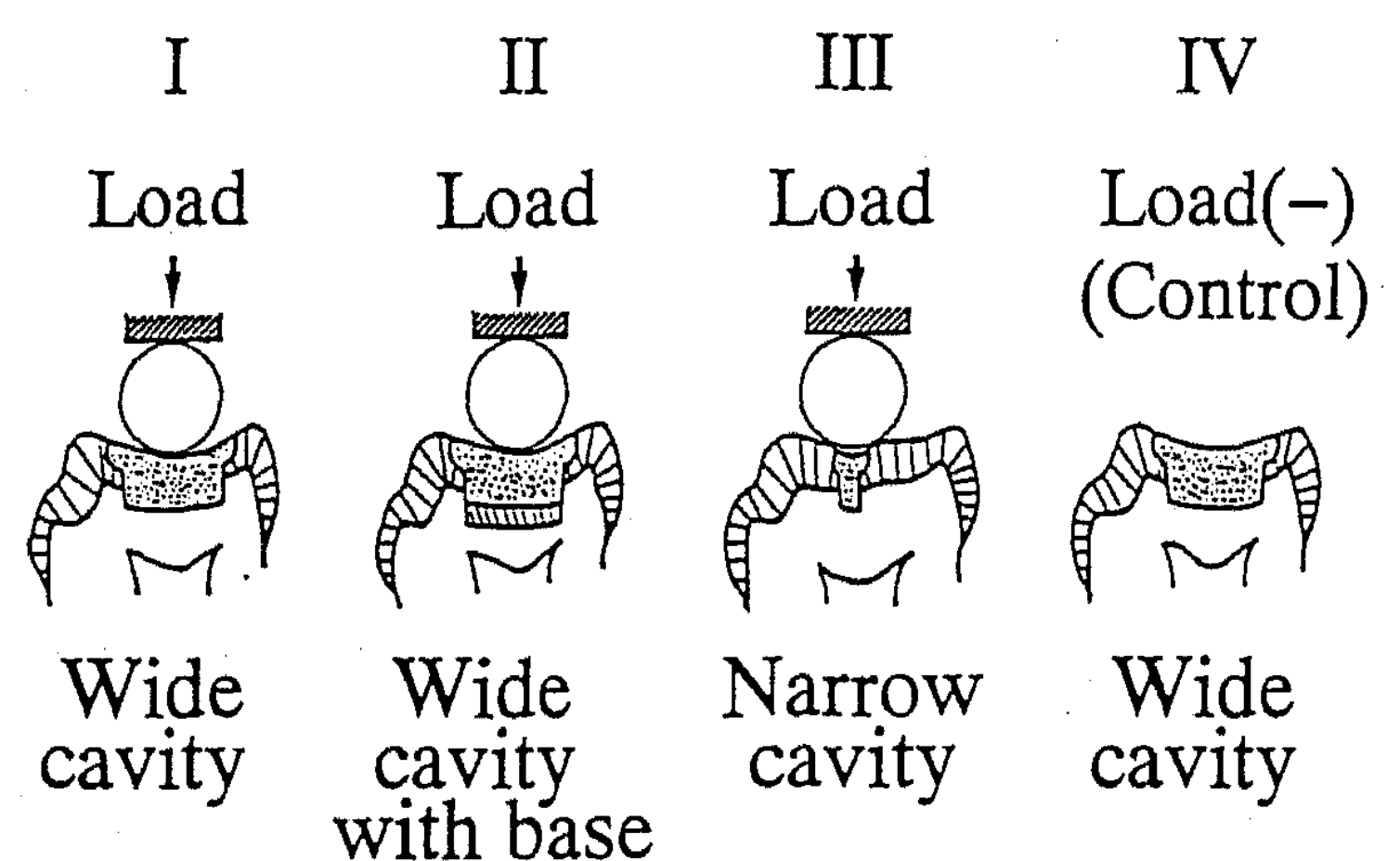


Fig. 1: Experimental cavities.

removal of the marginal excess of resin, class I cavities were prepared using pear-shaped tungsten carbide burs (# 008 and # 014, Shofu Corp., Kyoto, Japan) with a depth of 2mm for un-based cavities and 3mm for fully-based cavities. A periodontal probe was used to confirm the preparation depth. Hydraulic polycarboxylate cement (Unident SMFP, Sankin Corp., Tokyo, Japan) was used to base the entire cavity floor to an adjusted depth of 2mm. Then, concave bevel was prepared along the cavity margins, using fine-grain round diamond burs (# 010 and # 013, Hinatawada Corp., Tokyo, Japan); these burs were used in narrow and wide preparations, respectively. The entire cavity wall was etched for 60 seconds using each manufacturer's standard etching agent, washed with water for 30 seconds, dried for 20 seconds and the accessory bonding agent applied according to the manufacturer's specifications. Composite resin was then placed in the cavities with a slight excess. Polymerization of light-cured composite resins was completed by 90-second irradiation using a visible light unit (Optilux VCL 100, Demetron Research Corp., Danbury, CT, USA). The excess resin was then removed with tungsten carbide finishing burs (# 009 and # 018, Shofu Corp., Kyoto, Japan) to assure easy visibility of the outline of the cavity under the color tint of the protective varnish.

A machine was designed in order to investigate the effect of cyclic loading on marginal leakage of the restorations. Fig. 2 is an overview of cyclic loading machine with a tooth specimen embedded in a specimen holder. The apparatus employs a cam to convert the rotation of the motor into the vertical motion of the plunger, the lower end of which consists of a steel rod. The tip of this rod contacts the specimens. Fig. 3 shows the cycle pattern of this machine obtained during the actual dynamic movement. This force was recorded by a gnatho dynamometer (MPM 240, Nihon Kodan Corp., Tokyo, Japan) placed at the lower end of the plunger when the weight at the upper end was adjusted to 1.0kg. The shape of this force curve resembles one-half of a sine wave, with the time required for 1 cycle being approximately 0.61 seconds, which translates to 98 revolutions per minute or about  $1.4 \times 10^5$  cycles per day. This cycle is within the range of mastication rates at meals reported by Bates *et al.*<sup>7)</sup> and is adjustable by changing the gear ratio between a motor and a cam. The load could be adjusted freely

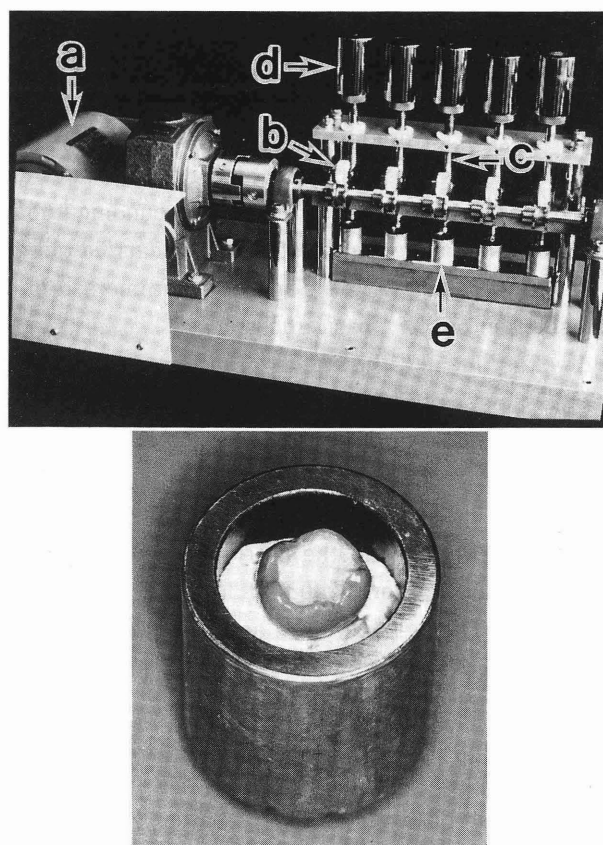


Fig. 2: Cyclic loading machine with a tooth specimen embedded in a specimen holder. (a) Motor (b) Cam (c) Plunger (d) Weight (e) Specimen holder

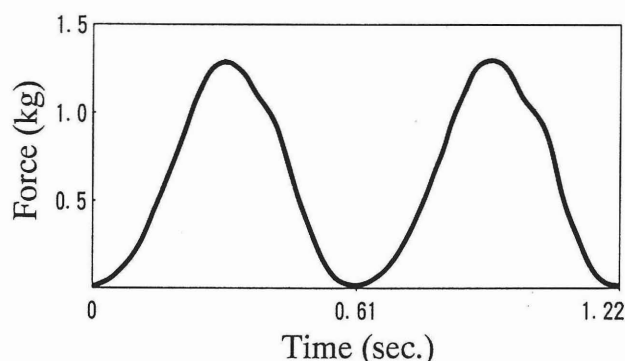


Fig. 3: The cycle pattern of the force when the weight of the upper end of the plunger is adjusted to 1.0kg.

from several hundred grams to several kilo-grams by increasing or decreasing the weight placed on the upper end of the plunger. Five specimens can be tested at one time on this machine, after being immersed in a dye solution which traces marginal leakage. In this study, the cyclic loading test was carried out with a steel ball interposed between the plunger and the composite resin or the inclines of the tooth cusp slopes



to create a single or two-occlusal contact in wide or narrow preparations, respectively. The restored teeth were embedded in the specimen holder with a plaster and were then covered with two layers of nail varnish except in the areas of the composite resin and an approximate 1mm margin of the surrounding tooth surface. The load cycling test was then carried out at room temperature with the specimens immersed in a dye solution of 0.2% basic fuchsin.

As experiment 1, the effects of different magnitude of the load and different load cycling time on marginal leakage of posterior composite restorations were evaluated. A chemically-cured composite resin (CFP), and a light-cured composite resin (PCA) were filled in wide preparations, and the marginal leakage scores were compared among different loads of 1.3, 2.5, 3.5 and 4.7kg. These loads were actual dynamic forces added to tooth specimen when the weight on the upper end of the plunger was adjusted to 1, 2, 3 and 4kg, respectively. And the marginal leakage scores were also compared between  $1.4 \times 10^5$  cycles (24 h) and  $2.8 \times 10^5$  cycles (48 h) loading.

As experiment 2, the effect of delayed cyclic loading on marginal leakage was evaluated. As in the above experiment, wide preparations were filled with a chemically-cured composite resin (CFP) and a light-cured composite resin (PCA), in this instance, marginal leakage was compared between teeth stressed on the day of placement and those treated in a similar fashion after storage in water at 37°C for 1 week. Load-cycling was applied for 24 hours.

Next, as experiment 3, the effect of cavity form on marginal leakage was evaluated. A chemically-cured composite resin (CFP) and three light-cured composite resins (PCA, PYR, and LFP) were applied in three types of class I preparations (Fig. 1), with the cyclic loading test being performed immediately after placement.

The tooth specimens tested under various experimental conditions were sectioned longitudinally and bucco-lingually into four segments using a hard-tissue cutting machine (Bronwill Model 77, VWR, USA). Six sectioned surfaces of each specimen were examined under stereo microscope at 40x magnification. Marginal leakage was then scored according to the following criteria (Fig. 4): For enamel wall, penetration to part of the concave bevel--0.5; penetration to the bevel floor--1.0; penetration to the enamel-dentin

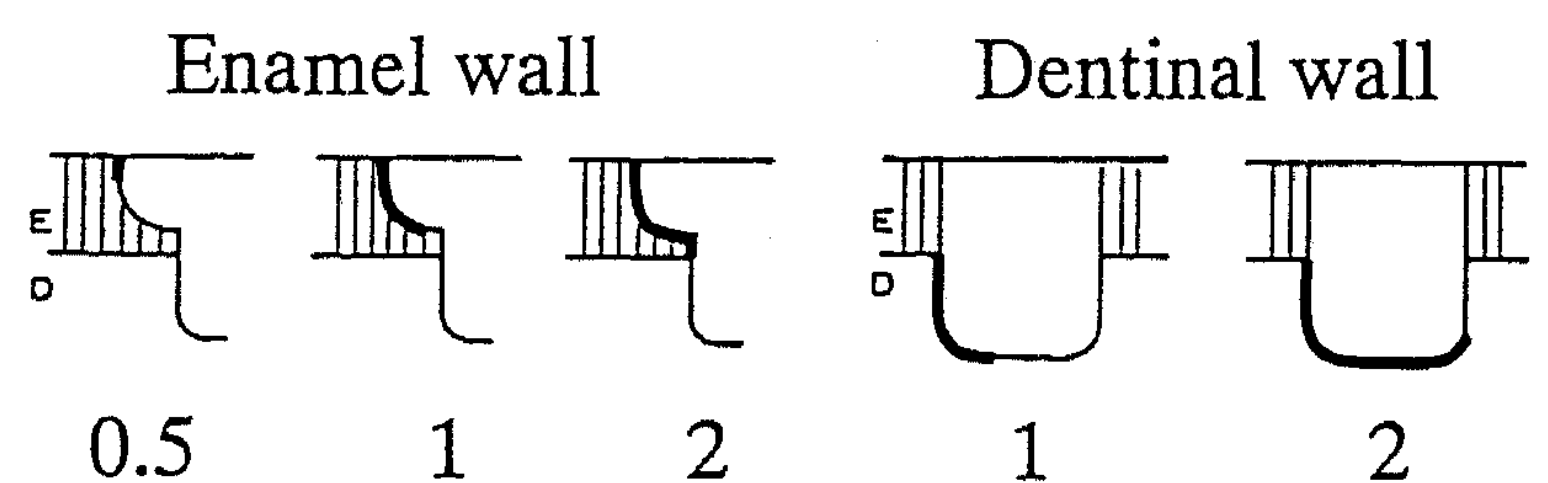


Fig. 4: Score of dye penetration.

junction--2.0. For dentinal wall, no penetration to the middle of the cavity floor--1.0; penetration to the middle of the cavity floor or further--2.0. According to this scoring system, when leakage was observed on the entire cavity wall on a cross-section, the maximum score possible was 6 points. The degree of leakage in each tooth specimen was expressed as the mean score of the six sections. Throughout the experiment, five specimens were tested in each group and the results obtained from each experiment were subjected to Scheffe's multiple comparison test of one-way analysis of variance.

## Results

Table 2 shows the effect of different magnitude of the load on marginal leakage. When load was increased from 1.3 to 4.7kg, the scores for a chemically-cured composite resin were increased from 0.37 to 1.63, and those for a light-cured composite resin were also increased from 0.35 to 0.92, respectively. A significant difference was shown between the 0kg loaded group and the 1.3kg and more loaded groups in both types of composite resins, however, no significant difference was observed among the 1.3, 2.5, 3.5 and 4.7kg loaded groups ( $p=0.05$ ). Table 3 shows the effect of cyclic loading times on marginal leakage. The

Table 2: Score of marginal leakage according to different loads.

| Weight*<br>(Kg) | Load**<br>(Kg) | Clearfil Posterior<br>Mean $\pm$ S.D. | Photo Clearfil A<br>Mean $\pm$ S.D. |
|-----------------|----------------|---------------------------------------|-------------------------------------|
| 0(Control)      | 0(Control)     | 0.03 $\pm$ 0.04                       | 0.05 $\pm$ 0.03                     |
| 1               | 1.3            | 0.37 $\pm$ 0.10                       | 0.35 $\pm$ 0.09                     |
| 2               | 2.5            | 0.53 $\pm$ 0.12                       | 0.42 $\pm$ 0.16                     |
| 3               | 3.5            | 0.70 $\pm$ 0.36                       | 0.54 $\pm$ 0.32                     |
| 4               | 4.7            | 1.63 $\pm$ 0.42                       | 0.92 $\pm$ 0.21                     |

Means connected by lines are not significantly different ( $p>0.05$ ).

\*Weight was placed on the upper end of the plunger.

\*\*Load was measured by a gnathodynamometer at the lower end of the plunger.

Table 3: Score of marginal leakage by cyclic loading time.

| Cyclic loading time         | Clearfil Posterior<br>Mean $\pm$ S.D. | Photo Clearfil A<br>Mean $\pm$ S.D. |
|-----------------------------|---------------------------------------|-------------------------------------|
| 0 (Control)                 | 0.03 $\pm$ 0.04                       | 0.05 $\pm$ 0.03                     |
| 1.4 $\times 10^5$ (24-hour) | 1.65 $\pm$ 0.52                       | 0.35 $\pm$ 0.17                     |
| 2.8 $\times 10^5$ (48-hour) | 2.09 $\pm$ 0.39                       | 0.40 $\pm$ 0.14                     |

Means connected by lines are not significantly different ( $P>0.05$ ).

leakage score of the chemically-cured composite resin for the  $1.4 \times 10^5$  times (24-h) loaded group was 1.65 and that for the  $2.8 \times 10^5$  times (48-h) group was 2.09. On the other hand, the leakage scores for a light-cured composite resin were 0.35 for the 24-h loaded group and 0.40 for the 48-h loaded group. A significant difference was shown between the control group and  $1.4 \times 10^5$  times loaded group in both types of composite resins, however, no difference was shown between  $1.4 \times 10^5$  and  $2.8 \times 10^5$  times loaded groups. Table 4 shows the effect of delayed cyclic loading on marginal leakage. When load was applied on the day of placement, the marginal leakage score for chemically-cured composite resin was 1.65, while the score was significantly reduced to 0.35 after water-immersion for 1 week. On the other hand, the leakage scores for light-cured composite resin were 0.35 and 0.19 for the groups of on the day of and 1 week after placement, respectively. The effect of cavity form on marginal leakage was shown in Table 5. When cyclic loading of 1.3kg was applied for 24 hours, no significant difference was observed in marginal leakage, whether cavities were wide or narrow in each composite material group. There was also no significant difference between based and un-based preparations. In all specimens of the based group that scored 3 or more (advanced leakage extending to the dentin), the dye solution penetrated to the interface between the bottom surface of the composite resin and the base cement, but not to the interface between the base cement and the dentinal wall.

Table 4: Score of marginal leakage by delayed cyclic loading.

|                         | Clearfil Posterior<br>Mean $\pm$ S.D. | Photo Clearfil A<br>Mean $\pm$ S.D. |
|-------------------------|---------------------------------------|-------------------------------------|
| On the day of placement | 1.65 $\pm$ 0.52                       | 0.35 $\pm$ 0.17                     |
| 1 week after placement  | 0.35 $\pm$ 0.16                       | 0.19 $\pm$ 0.07                     |

Means connected by a line are not significantly different ( $P>0.05$ ).

Table 5: Score of marginal leakage by cavity form.

| Cavity form    | Clearfil Posterior<br>Mean $\pm$ S.D. | Photo Clearfil A<br>Mean $\pm$ S.D. |
|----------------|---------------------------------------|-------------------------------------|
| Wide           | 1.65 $\pm$ 0.52                       | 0.35 $\pm$ 0.17                     |
| Wide with base | 1.03 $\pm$ 0.58                       | 0.29 $\pm$ 0.12                     |
| Narrow         | 0.95 $\pm$ 0.52                       | 0.10 $\pm$ 0.05                     |
| Wide (No load) | 0.03 $\pm$ 0.04                       | 0.05 $\pm$ 0.03                     |

| Cavity form    | Lite - Fil P<br>Mean $\pm$ S.D. | Pyrofil Light Bond<br>Mean $\pm$ S.D. |
|----------------|---------------------------------|---------------------------------------|
| Wide           | 1.21 $\pm$ 0.68                 | 0.70 $\pm$ 0.33                       |
| Wide with base | 0.76 $\pm$ 0.32                 | 0.64 $\pm$ 0.18                       |
| Narrow         | 0.83 $\pm$ 0.24                 | 0.48 $\pm$ 0.21                       |
| Wide (No load) | 0.33 $\pm$ 0.12                 | 0.28 $\pm$ 0.09                       |

Means connected by lines are not significantly different ( $p>0.05$ ).

## Discussion

Normal individuals exert a maximum biting force of approximately 50kg on molars and 20kg on premolars<sup>8</sup>). However, under routine conditions, a person with natural dentition seldom masticates at these levels. Usually, the actual amount of biting force is 1/4 to 1/2 of the maximum, ranging anywhere from 1 to about 10kg, depending on the type of food<sup>9,10</sup>). Furthermore, bite pressure during mastication is never constant, the greatest amount of time being spent chewing at lower pressures, with higher pressures used only for brief periods<sup>7</sup>). Mastication is usually performed at a rate of 60-120 times/minute or about 1 or 2 times/second<sup>7</sup>). Studies conducted by various researchers into the marginal sealing of composite resins under dynamic stress yielded markedly different magnitudes and frequencies for the loads applied; Jørgensen *et al.*<sup>5</sup>) applied loads of 0.5-16 kg for 2 minutes at 5-second intervals; Munksgaard *et al.*<sup>11</sup>) applied loads of 2-16kg, 11 times; Stewart *et al.*<sup>12</sup>) applied loads of 5, 15 or 31 lbs 5,000 times; Mandras *et al.*<sup>13</sup>) applied loads of 18 pounds 66,000 times at 17stroke/10sec and Rigsby *et al.*<sup>14</sup>) applied load of 34 Mpa 60,000 times. These studies were about class V composite resin restorations. For class I or II restoration, Raadal<sup>15</sup>) studied the microleakage around class I preventive composite fillings under the condition of loads up to 147 N 20 times at 7-second intervals. Darbyshire *et al.*<sup>16</sup>) employed loads of 4.5-111.3 N 4,000 cycles at 5 cycles/min for evaluating the microleakage of MOD resin restorations. In this study, the magnitude of the load was made adjustable



freely within a range of anywhere from several hundred grams to several kilograms estimating for masticatory forces reported by Anderson<sup>9,10</sup>). The force curve shown in Fig. 3 resembles the masticatory profile recorded by Ahlgren and Öwall<sup>17</sup>), who graphically illustrated the principal by placing strain gauges at the location of restorations in the mouths of several subjects and having them chew on various foods. In deciding the magnitude of the repetitive force, a comparison was made between the effects of different loads on marginal leakage of chemically-cured and light-cured composite resins as experiment 1. The results highlighted the statistical difference between the loaded and un-loaded groups with regard to marginal leakage when the load was adjusted to 1.3kg, while no difference was observed when more load was applied. The load of 1.3kg seemed to correspond most nearly to the force exerted when masticating soft food. As concerns the load-cycling time, statistical difference was observed between control group and the  $1.4 \times 10^5$  cycles group. The preliminary studies showed that the mean daily frequency of mastication was about 2,000. The stress cycle of  $1.4 \times 10^5$  times is considered to be roughly equivalent to the total number of times that a normal individual would masticate during a 70-day period. Thus, it was believable that the relative lightness of the load applied was more than amply compensated by the number of tests conducted. Even after such light mechanical loading, leakage was significantly greater in the 24 hour loading group, indicating deterioration of marginal sealing. Therefore, the cyclic loading test simulating mastication is considered to be significant for evaluation of marginal sealing accompanied by the strain or distortion of tooth and restorative materials in addition to the conventional thermal cycling test which is effective for evaluation of marginal sealing against stress due to temperature-related volume changes.

The leakage score for chemically-cured composite resin was 1.65 points when a load was applied immediately after placement, while the score was significantly reduced when a load was applied after soaking the restored teeth in water one week. On the other hand, the leakage scores for light-cured composite resin were below 0.5 points whether a load was applied immediately after or one week after placement. These results were thought to be due to the differences in curing system. The polymerization of

light-cured composite resin begins on the irradiated surface and advances toward deeper areas, thus the degree of polymerization decreases with increasing distance from the top surface<sup>18</sup>), then adhesion between composite resin and the tooth structure is strongest at the superficial layers of the restorations. Moreover, the polymerization of light-cured material will be almost completed under a enough light irradiation, thus the stable adhesion between composite/tooth was obtained. In contrast to the light-cured composites, the polymerization of chemically-cured composite begins wholly by mixing and this material takes more time for a complete polymerization than light-cured version. It was reported that the polymerization of chemically-cured composite resin continued for seven days with increasing the mechanical and bonding strength<sup>19</sup>). Therefore, high score of marginal leakage of chemically-cured composite resin on the day of placement is due to the lack of sufficient both mechanical and bonding strength, while improvement of marginal sealing after immersion in water for 1 week is due to the hygroscopic expansion reported by Hansen<sup>20</sup>) and Bowen *et al.*<sup>21</sup>) in addition to the gradual increase of the rate of polymerization.

In larger cavities, the consequent increase in the degree of polymerization shrinkage brings about the increase in the internal stress at the resin/tooth interface, leading to greater likelihood that a gap will open. In such a case, incremental placement technique is generally used to minimize the effect of polymerization shrinkage. In this study, the bulk placement technique was used in both wide and narrow cavities to make the effect of maximum polymerization shrinkage. The differences of these two cavities are considered to be the contact point of the force and the way of transmission through the composite resin, and the volume of the fillings. The force applied to wide cavities may firstly deform the composite resin, and extend to the composite/tooth interface and surrounding tooth enamel and dentin, with being absorbed and weakened to some degree. In narrow cavities, the force was applied on the enamel of cuspal incline. It is obvious that the components of force perpendicular to the long axis of the tooth will tend to increase the bucco-lingual width of the occlusal cavity<sup>22</sup>). In this study, the higher leakage score was expected in wide cavity than in narrow cavity because the modulus of elasticity of composite resin was lower than that of

tooth enamel and the progressive tooth removal increased cusp flexibility. But the result showed no significant difference between wide and narrow cavities for all four materials tested. This may be because the difference of polymerization contraction force of composite resin produced by the difference of an amount of fillings in wide and narrow cavities was not so large as the composite/tooth adhesive bond was affected.

With regard to marginal leakage, the lack of any apparent differences, between fully-based and un-based preparations suggests that the base itself does not affect marginal leakage. However, Farah *et al.*<sup>23)</sup> studied the effects of cement base on the stresses and deflections in posterior class I composite restorations under mechanical loading. They demonstrated the deflections in the composite were highest when it was supported by a base with a low modulus of elasticity such as calcium hydroxide cement. Munksgaard and Irie<sup>24)</sup> also reported that marginal sealing was reduced when the cavity floor was covered with a base of calcium hydroxide cement. Farah *et al.*<sup>23)</sup> noticed that an ideal situation would be to have a cement base with a modulus of elasticity equal to that of the composite material. Modulus of elasticity of carboxylate cement was much lower than that of composite resin, however, it was indicated that the marginal seal of composite resin was not damaged under such a condition. Moreover, when the leakage extended to the dentinal wall in based preparation, the dye solution penetrated the interface between the composite resin and cement base, but not the interface between the cement and the dentinal floor, which suggests that the base material plays an important role in preventing the advancement of leakage to dentin.

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