The Effects of Various Clinical Factors on Marginal Enamel Micro-Cracks Produced around Composite Restoration

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In this study, enamel micro-cracks produced around composite restorations were observed on surfaces and vertical sections, using a stereomicroscope and a scanning electron microscope (SEM). The effects of various clinical factors, i.e. the curing system, the marginal form and the polishing period after filling, on the incidence of marginal enamel micro-cracks were examined. Enamel micro-cracks were observed on all of the class 1 and 5 composite restorations when the cavity had no marginal bevel and the restorations were polished immediately after filling. Enamel micro-cracks distributed approximately parallel to the cavity margin and located 0.01-0.3 mm from the restored cavity margin. The occurrence of enamel micro-cracks was higher in light-cured composite resin restorations than in chemical-cured ones, for non-beveled cavities when polished 10 min or 24 hours after filling. The occurrence of micro-cracks was reduced by marginal beveling and delayed polishing.

Key words: Composite resin, Enamel micro-crack, Microleakage

INTRODUCTION

At present, composite resin is widely used in dental practice. The improvement of the bonding system has reduced marginal leakage, and clinical results have been markedly improved. In the enamel walls where the bond strength is high, the contraction gap is small, but high stress by polymerization shrinkage of the composite resin still concentrates at marginal areas. Since the enamel itself is fragile, the risk of developing micro-cracks in the enamel is high during polymerization shrinkage, as reported by Asmussen, Jørgensen and Øilo et al. These micro-cracks in the enamel margin were also detected in past studies of marginal microleakage after composite resin restoration. Clinically, the margin sometimes appears whitish after adjustment of the marginal area on the day of the composite resin restoration. This so-called “white margin” appears to be associated with micro-cracks of the enamel margin. Following the recent introduction of new bonding systems which provide a high bond strength to cavity walls, the incidence of contraction gap has been reduced. In contrast, the risk of developing enamel micro-cracks of the margin has increased.

The purpose of this study is to observe the frequency of enamel micro-cracks produced around class 1 and 5 light-cured composite restorations. The influence of various clinical factors, i.e. the curing system, the marginal form and the polishing period after filling, on the occurrence of marginal enamel micro-cracks are also evaluated.
MATERIALS AND METHODS

Observation of enamel micro-cracks around class 1 and 5 restorations in vitro

In fresh human teeth, within 24 hours after extraction, five class 1 and 5 cavities were prepared using tungsten carbide burs #330*1 and #2*2, respectively. Marginal beveling was not performed. Immediately after preparation, replica models were taken using a vinyl polysiloxane impression material*3 and epoxy resin*4. The teeth were then etched for 30 seconds with 40% phosphoric acid*5. After the teeth were rinsed by water spray, a bonding agent*6 was applied. The cavities were subsequently filled with a light-cured composite resin (either a posterior type*7 or an anterior type*8), followed by 60-seconds of irradiation by a light curing unit*9. The marginal excess was removed with finishing diamond points*10,*11, and the margin was polished with silicon points*12 while applying water, 10 minutes after filling. Replica models were taken immediately after polishing. The surface of the tooth, excluding the cavity margin, was then covered with a nail enamel. Subsequently, the teeth were immersed in a 0.2% aqueous solution of fuchsin (37°C) for 24 hours. Then, the margin of the restored teeth was observed under a stereomicroscope*13. The roots of the teeth were then resected, and the crown was vertically cut using a low speed diamond saw*14 under running water. The vertical section was polished with #1200 silicon carbide paper and alumina paste (grain size: 0.6 μm), then replica models were taken. The prepared sections were examined for leakage and marginal micro-cracks under a stereomicroscope.

The replica models were observed under a scanning electron microscope (SEM)*15 after cavity preparation, marginal polishing and vertical section, respectively.

Observation of enamel micro-cracks on experimental cavity under various conditions

The experimental conditions are shown in Table 1.

Since it was difficult to gather so many fresh extracted human teeth for this study, fresh human teeth within 24 hours after extraction and human teeth stored in water for less than one year after extraction were compared on the occurrence of enamel micro-cracks, as a preliminary experiment. There was no difference in occurrence of enamel micro-cracks between them.

Therefore, human teeth, stored in water for less than one year after extraction, were

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*1 JET carbide bur FG330, Shofu Inc., Kyoto, Japan
*2 JET carbide bur FG2, Shofu Inc., Kyoto, Japan
*3 Hydrophilic exaflex, GC Co., Ltd., Tokyo, Japan
*4 Epon-812, TAAB, Berkshire, England
*5 K-etchant, Kuraray Co., Ltd., Osaka, Japan
*6 Clearfil photo bond, Kuraray Co., Ltd., Osaka, Japan
*7 Clearfil photo posterior, Kuraray Co., Ltd., Osaka, Japan
*8 Photo clearfil bright, Kuraray Co., Ltd., Osaka, Japan
*9 Quick light VL-1, Kuraray Co., Ltd., Osaka, Japan
*10 Superfine diamond point SF 318, Shofu Inc., Kyoto, Japan
*11 Mary diamond ff C-22, Hinatawata Co., Ltd., Tokyo, Japan
*12 Silicone point M-2 & M-3, Shofu Co., Ltd., Kyoto, Japan
*13 Microflex HFX-II A, Nikon Co., Ltd., Tokyo, Japan
*14 Hard tissue cutting machine BRONWILL-77, Bronwill Vwr., USA
*15 MINI-SEM MSM-9, Hitachi-Akashi Co., Ltd., Tokyo, Japan
Table 1 The treatment procedures of each groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>Teeth</th>
<th>Composite resins</th>
<th>Marginal forms</th>
<th>Polishing periods after filling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stored teeth</td>
<td>Chemical-cured</td>
<td>Non-beveled</td>
<td>10 min.</td>
</tr>
<tr>
<td>2</td>
<td>Stored teeth</td>
<td>Chemical-cured</td>
<td>Beveled</td>
<td>10 min.</td>
</tr>
<tr>
<td>3</td>
<td>Stored teeth</td>
<td>Chemical-cured</td>
<td>Non-beveled</td>
<td>24 hours</td>
</tr>
<tr>
<td>4</td>
<td>Stored teeth</td>
<td>Chemical-cured</td>
<td>Beveled</td>
<td>24 hours</td>
</tr>
<tr>
<td>5</td>
<td>Stored teeth</td>
<td>Chemical-cured</td>
<td>Non-beveled</td>
<td>1 week</td>
</tr>
<tr>
<td>6</td>
<td>Stored teeth</td>
<td>Chemical-cured</td>
<td>Beveled</td>
<td>1 week</td>
</tr>
<tr>
<td>7</td>
<td>Stored teeth</td>
<td>Light-cured</td>
<td>Non-beveled</td>
<td>10 min.</td>
</tr>
<tr>
<td>8</td>
<td>Stored teeth</td>
<td>Light-cured</td>
<td>Beveled</td>
<td>10 min.</td>
</tr>
<tr>
<td>9</td>
<td>Stored teeth</td>
<td>Light-cured</td>
<td>Non-beveled</td>
<td>24 hours</td>
</tr>
<tr>
<td>10</td>
<td>Stored teeth</td>
<td>Light-cured</td>
<td>Beveled</td>
<td>24 hours</td>
</tr>
<tr>
<td>11</td>
<td>Stored teeth</td>
<td>Light-cured</td>
<td>Non-beveled</td>
<td>1 week</td>
</tr>
<tr>
<td>12</td>
<td>Stored teeth</td>
<td>Light-cured</td>
<td>Beveled</td>
<td>1 week</td>
</tr>
<tr>
<td>13</td>
<td>Fresh teeth</td>
<td>Light-cured</td>
<td>Non-beveled</td>
<td>10 min.</td>
</tr>
</tbody>
</table>

used. From these teeth, canines and premolars possessing healthy enamel surfaces were selected for the study.

A cylindrical cavity extending into the dentin (about 2 mm in diameter and 1.5 mm in depth) was prepared in the center of the labial surface of the experimental teeth, using a high-speed tapered fissure carbide bur*16. The half of the cavities were not beveled, and the remaining half were straight beveled using a fine particle diamond point*10. This was done to examine the influence of marginal forms.

One chemical-cured*17 and one light-cured composite resin*8 for anterior teeth were used. Each resin was used in combination with the bonding system*6,18 supplied with each resin kit.

After applying the bonding system in accordance with the manufacturer's instructions, cavities were filled with the chemical-cured or light-cured composite resin. The light-cured resin was photocured for 60 seconds. Ten minutes after filling, or 24 hours or 1 week after storage in water, the excess resin was removed from the margin with a flame-shaped diamond point*11. The resin restorations were polished with silicon points*12 under pouring water. Then, teeth were immediately immersed in 0.2% aqueous solution of fuchsin for 24 hours.

Thereafter, the dye penetration into marginal enamel micro-cracks and marginal contraction gaps of the experimental teeth were examined under a stereomicroscope. A stain between the enamel cavity wall and the resin was regarded as indicating marginal-gaps. A stain within the marginal enamel was assessed as representing micro-cracks. The circumference around the cavity was divided into 12 segments. The percentage of the segments showing enamel micro-cracks or marginal-gaps in all segments was scored as shown in Fig. 1. The example in Fig. 1 shows 4/12 = 33.3%. The sample tooth shown in Fig. 2 had a

*16 JET carbide bur FG 171, Shofu Inc., Kyoto, Japan
*17 Clearfil F3, Kuraray Co., Ltd., Osaka, Japan
*18 Clearfil new bond, Kuraray Co., Ltd., Osaka, Japan
micro-crack score of 50% (6/12) and a marginal-gap score of 16.7% (2/12).

The mean scores of micro-cracks and marginal-gaps were calculated for each group from the results on five specimens. The data were statistically analyzed by one-way analysis of variance for detection of significant differences at a level of 0.05.

RESULTS

Observation of enamel micro-cracks around class 1 and 5 restorations in vitro

Enamel micro-cracks were observed around all of class 1 and 5 non-beveled cavities when they were restored with light-cured composite resin.

Figure 3 shows stereomicroscopic pictures of the occlusal surface of class 1 (Fig. 3-a) and the labial surface of class 5 (Fig. 3-b) restorations. The black line, CM, shows dye penetrated cavity margin, and the black line, EC, shows the dye penetrated enamel micro-crack. Black lines, suggestive of micro-cracks, were observed within the marginal enamel about 0.05-0.3 mm from the cavity margin. These lines were approximately parallel to the cavity margin.

SEM pictures of the replica models of the class 1 cavity margin and occlusal surface with light-cured composite resin polished immediately after filling are shown in Fig. 4. As shown in Fig. 4-a and b, no enamel micro-crack was observed in the enamel cavity margin. SEM observation of the replicated surface polished immediately after filling with light-cured composite resin (Fig. 4-c and d) revealed that the resin was in close contact with the enamel cavity margin (CM), but that enamel micro-cracks (EC) were present about 50 μm from the cavity margin.

SEM pictures of the replica models of the class 5 cavity margin and labial surface with
Fig. 3  Stereomicroscopic pictures of the occlusal surface of a class 1 cavity and the labial surface of a class 5 cavity with a light-cured composite resin polished immediately after filling.
(a): class 1 restoration  
(b): class 5 restoration  
(E: enamel  R: resin  CM: cavity margin  EC: enamel micro-crack)

Fig. 4  SEM pictures of the replica models of the class 1 cavity margin and the occlusal surface with a light-cured composite resin polished immediately after filling.
(a): Restored cavity  
(b): High magnification of (a)  
(c): Occlusal surface of the restored tooth  
(d): High magnification of (c)  
(E: enamel  R: resin  CM: cavity margin  EC: enamel micro-crack)
light-cured composite resin polished immediately after filling are shown in Fig. 5. As shown in Fig. 5-a and b, no enamel micro-crack was observed in the enamel cavity margin. SEM observation of the replicated surface polished immediately after filling with light-cured composite resin (Fig. 5-c and d) revealed that the resin was in close contact with the enamel cavity margin (CM), but that enamel micro-cracks (EC) were present, relatively close, about 20 μm from the cavity margin.

Figure 6 shows the stereomicroscopic pictures in low magnification of vertically sectioned Class 1 and 5 (Fig. 6-b) restorations after fuchsin staining. In the class 1 restoration, micro-cracks were observed on both sides of the enamel (Fig. 6-a). Micro-cracks on one side were distributed along the enamel prism and invade all layers of the enamel to the enamel-dentin border, while micro-crack on the other side reached half way into the enamel. In the class 5 restoration (Fig. 6-b), a micro-crack occurring in cervical enamel invaded the enamel-dentin border, while the micro-cracks in incisal enamel were limited to the surface.

Figure 7 shows the SEM high magnification pictures of micro-cracks on the replicated vertical section of a class 1 restoration. Some cracks were parallel to the cavity wall extending to the dentin and other cracks were distributed along the enamel prism and
reached the border between the resin and the cavity wall.

Figure 8 shows a highly magnified SEM view of micro-cracks on the replicated vertical section of a class 5 restoration. The resin is in tight contact with the enamel in the cavity margin, but an enamel micro-crack occurred closely to the cavity margin (about 10 \( \mu \text{m} \)). This crack is parallel to the cavity wall and invades all layers of the enamel to the enamel-dentin
Observation of enamel micro-cracks on experimental cavity under various conditions

The results of micro-crack and marginal-gap assessments are shown in Figs 9 and 10. When the cavity margin was not beveled and the resin was polished 10 minutes or 24 hours after filling, the occurrence of micro-cracks was higher in the light-cured resin than in the chemical-cured resin. However, the occurrence of marginal-gaps did not significantly differ between light-cured and chemical-cured resins. The occurrence of enamel micro-cracks and...
marginal-gaps did not differ significantly between light-cured and chemical-cured resins, in the other cases. When the resin was polished 10 minutes or 24 hours after filling, the occurrence of micro-cracks and marginal-gaps were lower in the beveled group than in the

![Graph showing incidence of enamel micro-cracks and marginal-gaps](image)

**Fig. 10** The incidence of enamel micro-cracks and marginal-gaps around light-cured composite restoration.

![Graph showing comparison of incidence of enamel micro-cracks and marginal-gaps between teeth stored in water for less than one year and fresh teeth](image)

**Fig. 11** Comparison of the incidence of enamel micro-cracks and marginal-gaps between teeth stored in water for less than one year and fresh teeth within 24 hours after extraction with a light-cured composite resin polished immediately after filling.
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non-beveled group. When the polishing was delayed until 1 week after filling, the occurrence of micro-cracks reduced. When the cavity margin was not beveled and the resin was polished 10 minutes or 24 hours after filling, the occurrence of micro-cracks was significantly higher than that of marginal-gaps.

For teeth stored in water less than one year after extraction and fresh teeth within 24 hours after extraction (Fig. 11), the occurrence of marginal-gaps in the former was less than that in the latter, while the occurrence of micro-cracks did not differ between them.

DISCUSSION

There has been much research on preventing contraction gaps by polymerization shrinkage of composite resin. Many bonding systems were recently developed\(^9\). Polymerization shrinkage, however, occurs in composite resins during the curing process. In the dentin cavity walls where the bond strength with composite resin is insufficient, this shrinkage will produce a contraction gap, which will cause marginal leakage. It is a problem for restoration in cases having dentin margins such as root surface caries. In the enamel cavity walls which show a relatively high bond strength to composite resin, the stress by the polymerization shrinkage will concentrates on the enamel margin area, and can cause micro-cracks. When micro-cracks are produced in the enamel margin by polymerization shrinkage, leakage may begin in this area and extend to the dentin cavity wall, as shown in this study. It can cause many clinical problems such as pulp irritation and secondary caries. Conventional leakage tests were usually aimed at evaluating the adhesive strength of bonding systems to enamel and dentin. Enamel micro-cracks have been considered a factor which complicates accurate assessment of leakage data\(^7\). It is necessary to evaluate various clinical factors on the occurrence of enamel micro-cracks to prevent this microleakage.

When the composite restoration is polished on the same day, a phenomenon known as "white margin" is sometimes observed in the cavity margin enamel. This phenomenon has been attributed to the protrusion of excessive resin outside the cavity margin. There is a possibility, however, that this is also caused by a modification of light transmission through the enamel in the presence of micro-cracks.

Micro-cracks in the enamel were frequently parallel to the circumference of the cavity, indicating that they were perpendicular to the direction of polymerization shrinkage of the resin. Some cracks were parallel to the enamel prism. In the class 5 restorations, micro-cracks occurring in the cervical enamel wall were sometimes more distinct than those of the incisal enamel wall. These findings suggest that the onset of micro-cracks in the enamel is closely related to the shape of the cavity margin\(^4\) and width of the enamel wall.

Factors influencing the enamel micro-cracks have not been fully clarified yet. In the present study, the occurrence of micro-cracks was higher in the light-cured composite resin than in the chemical-cured one when the cavity margin was not beveled and the resin was polished 10 minutes or 24 hours after filling. The light-cured composite resin contracts towards the outer surfaces of the restoration close to the light source, in contrast to the chemical-cured composite resin in which shrinkage occurs toward the center of the material. The internal stress of light-cured composite resin during polymerization develops rapidly\(^11\),
immediately after photoactivation. Therefore, the internal stress of light-cured composite resin is concentrated in the superficial marginal enamel, probably resulting to higher occurrence of micro-cracks.

Marginal beveling was shown to reduce the occurrence of micro-cracks and microleakage. When the marginal enamel are beveled to give transverse sections of enamel prisms, the bond strength between enamel and resin increases\(^{12,13}\). Furthermore, because the beveled region can be firmly bonded to the resin, the marginal enamel is reinforced, resulting in an increased resistance of this region to polymerization shrinkage.

When the teeth were polished 1 week after filling instead of 10 minutes or 24 hours after filling, the occurrence of micro-cracks and microleakage was reduced. The polymerization shrinkage acts as a tensile stress on the marginal enamel. The presence of excessive resin over the cavity margin suppresses the shrinkage of the resin and hence reduces the occurrence of enamel micro-cracks. If the marginal excess resin is removed by polishing immediately after filling, the exerted force during polymerization shrinkage, which serves as an internal stress, can cause enamel micro-cracks. Furthermore, if polishing is delayed until 1 week after filling, hygroscopic expansion occurs in the resin restoration\(^{7,14-15}\), and the internal stress is released. For these reasons, enamel micro-cracks are less likely to occur when the marginal excess resin is removed 1 week after filling.

From the viewpoint of preventing marginal leakage, it has been recommended that composite resin restorations be polished 24 hours or more after restoration\(^{16-17}\). From the results in this study, adjustment of the marginal area on the day of filling should be minimized. It is recommended that the restored tooth be polished 1 week after filling, when the inside of the filling material has been hygroscopically expanded, the mechanical and bond strength of resin has fully increased and it is easier to detect any clinically uncomfortable symptoms. However, adjustment of the marginal area on the day of filling is indispensable in the occlusal posterior restoration. Therefore, further improvement in composite resin to minimize polymerization shrinkage is necessary. It is essential, at present, for the dental profession to attempt to prevent micro-cracks in the enamel by reforming the cavity shape or altering resin filling techniques.

CONCLUSION

Enamel micro-cracks produced around class 1 and 5 light-cured composite restorations were observed using stereomicroscope and SEM. The influence various clinical factors, i.e. the curing system, the marginal form and the waiting period between filling and polishing have on the occurrence of marginal enamel micro-cracks was also studied. The following results were obtained.

1) Enamel micro-cracks were observed around all of experimental class 1 and 5 light-cured composite restorations, when the cavity margin was not beveled and the restorations were polished immediately after filling. Micro-cracks occurred in the enamel parallel to the cavity margin about 0.01-0.3 mm from the margin.

2) The occurrence of micro-cracks was more frequent in the light-cured composite resin than in the chemical-cured one, when the cavity margin was not beveled and the resin was
polished 10 minutes or 24 hours after filling. However, the occurrence of marginal-gaps did not differ significantly between light-cured and chemical-cured composite resins, under the conditions listed above.

3) Marginal beveling reduced the occurrence of enamel microcracks, in cases polished 10 minutes or 24 hours after filling.

4) When the polishing was delayed until 1 week after filling, the occurrence of microcracks in the non-beveled restoration was reduced.

5) The occurrence of micro-cracks did not differ between fresh teeth within 24 hours after extraction and teeth stored in water for less than one year.

REFERENCES


歯科用接着性モノマー（N-methacryloyloxy-5-aminosalicylic acid, MASA）の
溶血性及びりん脂質リポソームとの相互作用の NMR, DSC 研究
藤沢浩一郎*, 蕨田泰夫**, 門磨義則**
*東京医科歯科大学歯学部総合診断部
**東京医科歯科大学医用品学研究所

最近 MASA は接着性プライマーとしてレジン修復システムに用いられている。MASA の生物学的活性をモニターするため、アルブミン及びコラーゲン存在下ジペルミトイルホスファチジルコリン (DPPC)/MASA リポソーム系の NMR ケミカルシフト (δr) 及び DSC 相転移温度 (Tm) を研究した。その結果、蛋白の存在はリポソームの δr 及び Tm に変化を与えないかった。また MASA とリン脂質 (DPPC) との相互作用も小さいことが明らかになった。MASA の溶血性はポリベンジン剤としては広く用いられているリン酸モノマー (MDP) に比べ著しく小さかった。以上の所見は MASA プライマーは象牙質－歯髄システムに対して生体適合性があることを示唆した。

コンポジットレジン修復時に生ずる窩縁部エナメル質微小亀裂に及ぼす
臨床的因子に関する研究
韓 崔麟, 岡本 明, 岩久正明
新潟大学歯学部歯科保存学第一教室

本研究では、コンポジットレジン修復時に生ずるエナメル質微小亀裂を、歯牙表面及び縁断面において、実体顕微鏡及び SEM を用いて観察した。さらに、エナメル質微小亀裂の発生に及ぼす臨床的因子、すなわち、重合方法、窩縁形態及び研磨時期の影響について検討した。

エナメル質微小亀裂は、ペルルを付与せず充填直後に研磨を行った 1 級及び 5 級の光重合型コンポジットレジン修復物において、全例に認められた。エナメル質微小亀裂は、窩縁線にほぼ平行で、窩縁線より 0.01～0.3 mm 離れた部位に観察された。エナメル質微小亀裂の発生は、ノン・ペルル窩縁で充填後 10 分あるいは 24 時間後に研磨を行った群において、光重合型のほうが化学重合よりも著しかった。エナメル質微小亀裂の発生は、ペルルの付与及び研磨時期を選らせることにより減少した。

歯の形状の三次元計測（第 11 報）
— 口蓋を考慮したクラウン形状設計のための CAD について —
木村 博, 荻村泰治, 高橋純造
大阪大学歯学部歯科工学講座

「6 号歯のクラウン補綴のための形状設計の CAD 化につき研究した。「6 号にクラウン用の支台歯形成がされている、15～7 号歯の石こう模型と、修復用に用いる「6 号完全歯の計測を行った。
クラウンデータは「6 の支台歯に適合し「5～7 の接合歯と

の調整を行った。その後、「6 のデータの座標は「6 支台歯
のそれと変換した。適合したクラウンの端部は、「6 支台
歯の辺縁と結合した。さらに、対合歯との咬合関係を FGP 法を応用して調
整した。FGP は、パイトワックスに記録し計測した。