Wear characteristics of trimethylolpropane trimethacrylate filler-containing resins for the full crown restoration of primary molars

Kanae WADA1, Eri IKEDA2, Junichiro WADA3, Go INOUE1, Munenaga MIYASAKA5 and Michiy o MIYASHINA1

1 Division of Pediatric Dentistry, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, 5-45, Yushima 1-chome, Bunkyo-ku, Tokyo 113-8549, Japan
2 Department of Periodontology, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, 5-45, Yushima 1-chome, Bunkyo-ku, Tokyo 113-8549, Japan
3 Section of Removable Partial Prosthodontics, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, 5-45, Yushima 1-chome, Bunkyo-ku, Tokyo 113-8549, Japan
4 Division of Cariology and Operative Dentistry, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, 5-45, Yushima 1-chome, Bunkyo-ku, Tokyo 113-8549, Japan
5 Division of Department of Restorative Sciences, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, 5-45, Yushima 1-chome, Bunkyo-ku, Tokyo 113-8549, Japan

Corresponding author, Kanae WADA; E-mail: wadadohs@tmd.ac.jp

Although the demand for aesthetic restoration of primary molars has increased, the full-crown restorations using resin and the details of the wear characteristics of trimethylolpropane trimethacrylate (TMPT) filler containing resins for primary molars are not well understood. This study was conducted to determine whether new light-cured composite resin (Fantasista) and 4-META/MMA-TBB resin (Bondfill SB) are appropriate for full crown restoration of primary molars by evaluating their wear characteristics. Both resins products contain TMPT filler. The properties of the resins were evaluated through in vitro impacting-sliding wear tests; the wear properties of the opposing enamel specimens used in the tests were also studied. The properties of the resins were compared with those of Litefill, MetafillC, and Clearfil FII, which had been evaluated previously. Fantasista exhibited simple shape of wear that was suggestive of a higher wear resistance than that of Litefill. Fantasista caused the least damage to the antagonistic primary enamel.

Keywords: Composite resins, Primary molars, Trimethylolpropane trimethacrylate filler, Wear

INTRODUCTION

Preformed stainless steel crowns (SSCs) have traditionally been used for the full crown restoration of primary molars with severe caries, in particular for those subjected to endodontic treatments. However, the demand for aesthetically pleasing restorations has been increasing steadily. In recent years, preveneered SSCs1) are being used for the esthetic crown restorations of primary molars. Nevertheless, clinical reports indicate that the veneer readily chips away from the surfaces of such SSCs after four years2).

Although composite resins are good for use in the full crown restoration of primary molars as they can satisfy the aesthetic expectations of younger patients, it has long been thought that composite resins are not suitable materials for the full crown restoration of primary molars because they do not exhibit wear resistance similar to those of primary enamel. In addition, they are considered to be harder than primary enamel, and therefore, when used in full crown restorations, should result in the considerable attrition of the opposing primary teeth. In fact, when using the conventional composite resins in clinical reports, a significant amount of wear was observed on the primary enamel or composite resin or both. The problem has been posed clinically3,4).

Longitudinal 24-month follow-up study of eight cases has been reported full-crown composite resin restorations for primary molars, evaluating the clinical outcomes of the restorations reported that there were not the problem and it functioned well in children5). Using the indirect composite onlay restorations in a 4-year-old patient in primary molars until exfoliation in clinical case report, during the 4-year evaluation the indirect composite onlay restorations functioned well in primary molars6). The authors deem that use of composite resins in the full crown restoration of primary molars is a potential alternative treatment method and should satisfy the aesthetic expectations of child patients and their family, but only if the resins have the optimal wear resistance and cause wear of the enamel of the opposing teeth similar to or less than that under physiological conditions. The primary tooth crowns usually undergo physiological attrition with the aging as a characteristic physiological phenomenon. The wear characteristics of composite resins do not necessarily have to be the same as those of permanent teeth. Therefore, in a previous study, we had determined the wear characteristics of occluding enamel and of composite resin materials and had also evaluated the wear characteristics of enamel-enamel specimens as controls that were thought to be appropriate for the full crown restoration of primary molars7). Moreover, we had found that light-cured resin composites were more suitable for the full crown restorations of primary
Table 1 Materials of upper specimens mentioned in this study

<table>
<thead>
<tr>
<th>Material</th>
<th>Filler type</th>
<th>Particle shape</th>
<th>Particle size (μm)</th>
<th>Content (%)</th>
<th>Monomers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fantasista (FS)</td>
<td>TMPT strontium glass colloidal silica</td>
<td>Irregular</td>
<td>20</td>
<td>1</td>
<td>UDMA TEGDMA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Bondfill SB (BF)</td>
<td>TMPT</td>
<td>Irregular</td>
<td>10–15</td>
<td>less than 10</td>
<td>MMA, 4-META, polyfunctional methacrylate</td>
</tr>
<tr>
<td>LITE-FILL IIP (LP)†</td>
<td>Silica barium glass</td>
<td>Irregular</td>
<td>2.7</td>
<td>86</td>
<td>UDMA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metafil C (MC)†</td>
<td>TMPT colloidal silica</td>
<td>Irregular</td>
<td>20</td>
<td>66</td>
<td>UDMA TEGDMA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clearfil FII (CF)†</td>
<td>Quartz</td>
<td>Irregular</td>
<td>5</td>
<td>77</td>
<td>Bis-GMA TEGDMA</td>
</tr>
</tbody>
</table>

All the data were provided by the manufacturers. †: These were cited from reference 7.
Table 2  Composition of BF

<table>
<thead>
<tr>
<th>Component of Bondfill SB</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teeth Primer</td>
<td>4-META, acetone, water, reducing agent</td>
</tr>
<tr>
<td>Monomer</td>
<td>MMA, 4-META, polyfunctional methacrylate</td>
</tr>
<tr>
<td>Powder</td>
<td>PolyMMA, TMPT, pigment</td>
</tr>
<tr>
<td>Catalyst V</td>
<td>TBB, TBB-O, hydrocarbon</td>
</tr>
</tbody>
</table>

MMA: methyl methacrylate; 4-META: 4-methacryloyloxyethyl trimellitate anhydride; TBB: tri-n-butylborane; TBB-O: partially oxidized tri-n-butylborane

All the data were provided by the manufacturers.

Tsukuba, Japan). FS were cured in the quartz mold by visible light radiation (Optilux 501, Kerr, Orange, CA, USA) following the manufacturer’s instructions⁷. The hemispherical upper specimens of BF were prepared using a silicon mold after being mixed. All the upper specimens were polished with a silicon bar and checked using a laser microscope for the presence of cracks, which could be formed during preparation. Flattened enamel surfaces of primary molars were used as the lower antagonistic specimens during the wear tests to simulate the molar occlusal surface. Mandibular first primary molars were used as the lower specimens; the cuspal side of buccal surface was employed in the tests as appropriate thickness could be obtained in this specific area. The sliding direction of the upper specimen was standardized as the mesio-distal direction of the buccal surface of the first lower primary molar.

Evaluation of upper specimens

1. Images of worn surfaces
The worn surfaces of the upper FS and BF specimens were examined using a scanning microscopy (SEM) (H-4500, Hitachi High-Technologies, Tokyo, Japan) and were statistically analyzed for significant differences (α=0.05) through multiple comparisons between the different treatments using the Bonferroni method.

2. Worn surface areas
The worn surface areas of the upper FS and BF specimens were imaged after every 5,000 cycles using a laser scanning microscope (ILM21, Lasertec, Tokyo, Japan).

3. Volumetric loss (VL) and Images showing VL
The changes in the volumes or VL of the upper FS and BF specimens were determined from microfocus X-ray computed tomography (micro-CT) (Inspexio SMX-90CT, Shimadzu, Kyoto, Japan). Images of the specimens were obtained using a 3D image analysis system (TRI/3D-BON, Ratoc System Engineering, Tokyo, Japan), which was set with 0.016 isotropic voxels⁷ (Fig. 1). The VL values for each group were statistically analyzed by repeated-measures one-way analysis of variance (ANOVA) and Tukey’s test for post hoc multiple pairwise comparisons (α=0.05).

The VL of the upper specimens corresponding to LP, MC, and CF had already been shown in the previous study⁷, but images showing the VL of the upper specimens of LP, MC and CF had not been obtained yet. Therefore, in this study, images showing the VL of the upper specimens corresponding to FS, BF, LP, MC, and CF were obtained using a 3D image analysis system (TRI/3D-BON, Ratoc System Engineering) (Fig. 1). This system was employed to analyze worn area three dimensionally.

Evaluation of lower specimens

1. Images of the worn enamel surfaces and the areas of wear on the enamel surfaces
Images of the worn enamel surfaces of the lower FS and BF specimen were obtained using 3D laser scanning microscopy (VK-9700, 9710, Keyence, Osaka, Japan) with the magnification of 200-fold, and the long and short axes of the worn enamel surface areas were measured⁷. The areas of wear on the enamel surfaces were statistically analyzed by repeated-measures one-way ANOVA with Tukey’s test (α=0.05).

2. Widths and depths of cracks on worn enamel surfaces
The widths and depths of the cracks formed on the worn enamel surfaces of the lower FS and BF specimens were calculated from the images of the specimens obtained using color 3D laser scanning microscopy (VK-9700, 9710, Keyence). Regression analysis and Pearson’s correlation were used to correlate the width and the depth of the cracks, as illustrated by the regression equation. The regression equation for the worn surface area for each specimen was analyzed statistically.

Comprehensive evaluation and rankings of the materials
The worn surface areas and volumetric losses of the upper FS and BF specimens, as well as the areas of wear on the enamel surfaces and the widths and depths of the cracks formed on the worn enamel surfaces of the lower FS and BF specimens, were compared with the
Fig. 1 Schematic illustrations that show how the volumetric losses in the specimens were determined through 3D analysis.

(A): The red image represents the sample before the wear test, while the green image represents it after the wear test. The red and green images were both obtained using micro-CT. (B): 3D reconstructed image of the red area in A (i.e., the image of the test sample before the wear test). (C): 3D reconstructed image of the green area in A (i.e., the image of the test sample after the wear test). (D): The yellow area is formed by overlaying the red and green areas in A; these represent the sample before and after the wear test, respectively. The red area shows the loss due to wear. (It is determined from the difference between the volumes from before and after the wear test.) (E): 3D reconstructed image of D. (F): 3D reconstruction of the volumetric loss resulting from the wear test, which is the blue part in E.

RESULTS

On the whole, the data of FS and BF in this study were compared with CF, LP, and MC, which had been characterized in the previous study.

Upper specimens
1. Images of worn surfaces
Figure 2 shows SEM images of the worn surfaces of the upper specimens. The FS specimens exhibited smooth wear and contained few facets. The BF specimens also exhibited smooth wear but contained a few facets.

2. Area of surface wear
Figure 3 shows the changes in the areas of surface wear of the FS and BF specimens after every 5,000 cycles. The data for the LP, MC, and CF specimens were taken from our previous study. After 20,000 cycles, CF showed significantly higher wear than did the other four materials (\( p<0.01 \)). There were significant differences between BF and the other three materials (FS, LP, and MC) (\( p<0.01 \)). However, there was no significant difference among FS, LP, and MC.

3. VL and images of VL
Table 3 shows the VL values of FS and BF after 20,000 cycles. Again, the data for LP, MC, and CF were taken from our previous study. There was no significant difference in the VL values among FS, BF, LP, and MC. However, there were significant differences between CF and the other materials (\( p<0.001 \)).

Figure 4 shows images of the VL of the FS, BF, LP, and MC specimens. The BF and LP specimens exhibited complex 3D wear. The FS and MC specimens also exhibited 3D wear but the shape of the worn area was simpler than that in the case of the BF and LP specimens.

Lower specimens
1. Images of the worn enamel surfaces and the areas of wear on the enamel surfaces
Figure 5 shows images of the worn enamel surfaces that were opposite the upper specimens during the wear tests. The observation of images of the worn enamel surfaces opposing LP indicated that the surface is rather rough and has some scratches. Images of the worn enamel surfaces opposing MC and FS showed that the surface is rather smooth but has a few scratches. On the other hand, images of the worn enamel surfaces opposing BF demonstrated that the surface is rather smooth and has few scratches.

Table 4 shows a comparison of the areas of wear of the enamel surfaces that were opposite the various upper specimens; the areas were calculated after 20,000 cycles. The data for CF, MC, and LP are from our previous study. CF showed significantly higher wear than did the other materials (FS, BF, LP, and MC) (\( p<0.001 \)). There was no significant difference between FS and LP. However, there was a significant difference between FS and MC (\( p=0.015 \)). There were also significant differences between BF and the other three materials (FS, LP, and MC) (\( p<0.001, p<0.001, \) and \( p=0.001 \), respectively).

2. Widths and depths of cracks
Figure 6 is a scatter plot that shows the widths and depths of the cracks on the worn enamel surfaces opposite the upper specimens. The data for CF, LP, and
Fig. 2  SEM images of the upper specimens after the wear test. The specimens were subjected to 20,000 cycles. The upper section is imaged at a magnification of ×45; scale size is 667 μm. The lower section extended to the top right corner of the upper section, which was imaged at a magnification of ×150; scale size is 200 μm. W: worn surfaces, N: unworn surfaces. The arrow points to a facet.

Table 3  Volumetric losses of the upper specimens

<table>
<thead>
<tr>
<th></th>
<th>Mean (×10⁻² mm³)±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS</td>
<td>2.12±(0.84) b</td>
</tr>
<tr>
<td>BF</td>
<td>6.76±(0.38) b</td>
</tr>
<tr>
<td>LP †</td>
<td>3.04±(0.52) b</td>
</tr>
<tr>
<td>MC †</td>
<td>2.51±(0.94) b</td>
</tr>
<tr>
<td>CF †</td>
<td>56.64±(22.17) a</td>
</tr>
</tbody>
</table>

The data shown are the means (and standard deviations) of the VL values of the upper specimens after 20,000 cycles. †: These were cited from reference 7. Data with the same letters are not statistically different.

MC were taken from our previous study 7. The cracks on the worn enamel surfaces opposite the FS and BF specimens were narrow and shallow. In contrast, the LP specimens exhibited a tendency to cause deeper and wider cracks than did the FS, BF, CF, and MC.
Fig. 4 3D images showing the volumetric losses in the test specimens. The LP specimens exhibited complex 3D shapes of wear, while the FS specimens exhibited simple 3D shapes.

Fig. 5 Images of the worn enamel surfaces that were opposite the upper specimens, obtained using color 3D laser microscopy. The dark and bright zones represent the unworn and worn areas of the enamel surfaces, respectively. Scale bar=500 μm. The images for LP and MC were taken from our previous study.

Table 4 Areas of the wear enamel surfaces

<table>
<thead>
<tr>
<th></th>
<th>Mean (mm²)±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS</td>
<td>1.32±(0.46) a</td>
</tr>
<tr>
<td>BF</td>
<td>3.06±(0.41) c</td>
</tr>
<tr>
<td>LP †</td>
<td>1.22±(0.45) a</td>
</tr>
<tr>
<td>MC †</td>
<td>2.07±(0.58) b</td>
</tr>
<tr>
<td>CF †</td>
<td>5.23±(0.61) d</td>
</tr>
</tbody>
</table>

A comparison of the areas of the wear enamel surfaces that were opposite the upper specimens of CF, LP, MC, FS, and BF. The areas were calculated after 20,000 cycles. †: These were cited from reference 7. Data with the same letters are not statistically different.

Specimens. The scatter plots of the widths and depths of the cracks resulted in the following regression equations: FS=0.13X+0.76 (r=0.76, NS), BF=0.34X+1.25 (r=0.85, NS), LP=0.12X+3.07 (r=0.94, p<0.001), MC=0.14X+5.59 (r=0.69, NS), CF=0.09X+6.73 (r=0.82, p<0.05). There was no significance difference between the regression equations.

Comprehensive evaluation
Table 5 shows the rankings given to CF, LP, MC, FS, and BF on the basis of their characteristics. LP and MC had been assigned high scores, and CF had been assigned a low score in our previous study7. However, when the five materials were compared in the present study, FS as an upper-specimen material received an overall ranking of 1. LP and MC as upper-specimen materials also received an overall ranking of 1. BF as an upper-specimen material received an overall ranking of 4. FS as a lower-specimen material received an
DICUSION

On the whole, the data of FS and BF in this study were compared with CF, LP, and MC, which had been characterized in the previous study.

The method employed for determining the VL values from the worn area of the specimens has been described elsewhere and is based on the assumption that the VL value is almost the same as the volume of the contact lens-like portion that does not include any cracks 9). The area of wear was observed at the projection of the sectional area that was seen axially; the VL value was calculated by measuring the worn area and the height at which the material was denuded from the tip of the hemispherical upper specimens to the lowest point of the remaining material 9). In this study, we observed the shapes of wear of the specimens as images showing the VL in a 3D manner. Further, the resulting images also indicated the deepest points on the worn surfaces as well as whether the surfaces contained cracks; hence, LP exhibited a complex 3D shape of wear, which contained cracks, so LP was clearly more breakable than FS. Thus, the 3D images allowed us to see the wear practically and to determine the changes in the materials. Moreover, if a specimen contains cracks, micro-CT 3D images showing the VL allow accurate observations of the wear.

In our previous study, we had found that the TMPT filler-containing resin product MC exhibited the smoothest wear surface, with the surface containing few cracks 7). In addition, it was reported that the microfiller composites MC demonstrated significantly less wear than the hybrid and micro hybrid composite 5). Suzuki and Leinfelder have reported that carbon double bonds are formed on the surfaces of TMPT particles when TMPT is used as a filler; these bonds can react with the
resin matrix monomers, improving filler retention\(^{11}\). An improved wear resistance of composite resins was reported to be achieved by containing TMPT filler\(^{12}\). It is therefore likely that the TMPT particles that are present in the composite resin FS form carbon double bonds that prevent the particles from being dislodged, resulting in a smooth surface and few facets, as is the case with MC. However, a few facets were seen in the BF specimens even though they contained TMPT. BF is a modified 4-META/MMA-TBB resin, contains less than 10% TMPT, and has MMA as the main monomer, as shown in Table 1.

The brush-dip technique means that powder and liquid are mixed with the brush. However, as the brush-dip technique was used for preparing the specimens, the TMPT content in the BF specimens seemed to be much lower than 10%. Therefore, in the case of BF, owing to its low TMPT content, the report of Suzuki et al. was not related. It is likely that this is the reason why a few facets were seen in the BF specimens of filler content and monomer type than in the FS and MC specimens of filler content and monomer type.

4-META/MMTA-TBB resins are usually used for bonding the tooth structure and restorative materials. It is also used in direct restorations\(^{13}\). 4-META/MMTA-TBB resins have low wear resistances\(^{13}\). BF contains TMPT as the filler, which can be expected to affect both the bonding characteristics and the wear resistance of the resin\(^{14}\). During the comprehensive evaluation, as shown in Table 5, BF as a lower-specimen material received an overall ranking of 4. The cracks on the worn surface of the antagonistic enamel during the ISWT of BF were narrow and shallow, and resulted in smoothly worn enamel surfaces. However, the area of worn enamel was bigger than in the case of the light-cured resins LP, MC, and FS. BF as an upper-specimen material also received an overall ranking of 4. The wear resistance of BF was higher than that of the chemically cured composite resin CF but lower than those of the light-cured composite resins LP, MC, and FS. BF exhibited a complex 3D shape of wear that was suggestive of fragility when stressed for long periods. Therefore, BF might not be suitable for full crown restoration of primary molars.

During the comprehensive evaluation, as shown in Table 5, FS as an upper-specimen material received an overall ranking of 1. LP and MC as upper-specimen materials both also received an overall ranking of 1. FS exhibited a low area of wear as well as low volumetric loss; these values were similar to those of LP and MC. It is likely that FS is not fragile, because it exhibited smooth wear surfaces, and these surfaces contained few facets. It can also be assumed that FS remains stable even when stressed for long periods, exhibiting high wear resistance; these results were similar to those for MC. In contrast, LP can be considered more breakable than FS, because LP exhibited a complex 3D shape of wear that contained irregularities and facets on the worn surfaces. These upper-specimen results suggest that FS can be considered a more appropriate material for full crowns for primary molars than LP. It has been reported that the wear resistance of a composite is affected by its total filler content\(^{15}\) and by the silanization method of the filler (i.e., by the silane-coupling agent that is used between the resin matrix and the filler interface)\(^{16}\). The results of the present study were not what one would expect on the basis of the filler contents of the materials tested. In addition, it is known that the mechanical properties of polymeric composite materials depend critically upon the conditions of the interfaces formed between the surfaces of the inorganic filler particles and the polymerized organic resin in which the filler particles are embedded\(^{16}\). In addition, the resin matrix (i.e., the monomer structure) has a significant effect on the mechanical properties of composite resins\(^{17}\). We suggest that the wear resistance of composites is influenced by the method of silanization of the filler and the resin matrix, but not by the total filler content.

During the comprehensive evaluation, as shown in Table 5, FS as a lower-specimen material received an overall ranking of 1, while LP and MC as lower-specimen materials received overall rankings of 1 and 3, respectively. However, LP showed a tendency to cause deeper and wider cracks, and resulted in deeper scratches on the wear surfaces of the antagonistic enamels than did FS. As the reason that a difference was shown in FS and MC in lower specimen ranking, the MC's area of wear enamel surfaces on lower specimens was significantly bigger than FS. As a result, lower specimen ranking was observed as a significant difference. These areas of wear on lower specimens of the enamel surfaces were influenced by wear outline on upper specimens. The MC among three composite resins such as MC, LP and FS was shown the tendency of big area of wear on upper specimens. FS group scored the lower wear area, this can be attributed to the presence of strontium glass imbedded in the resin matrix. This ingredient might have affected the wear behavior of upper and lower FS specimens. Thus, FS caused the least damage to the antagonistic primary enamel. It has also been reported that the abrasion of enamel by composite resins is affected by the size of the filler particles\(^{18,19}\), the hardness (quality) of the filler material\(^{19,20,21}\), and the strength of the matrix/filler bonding\(^{19}\). It usually assumed that fillers with particles that are spherical and small cause less damage to the enamel of permanent teeth than do those with irregular and large particles. Thus, the sizes and forms of the filler particles varied significantly. These factors did not have an effect on the degree of abrasion of enamel. It has been reported that resins containing quartz-based fillers tend to damage the enamel of permanent teeth\(^{18,19}\). Moreover, during the wear process, the filler particles dislodge from the resin matrix, becoming abrasive and accelerating the wear of the enamel\(^{20}\). Further, even if the particles were to become dislodged during testing, TMPT is an organic material and is soft. Therefore, MC, FS, and BF are likely to cause fewer scratches to the antagonistic primary enamel than LP and CF. We suggest that the degree of abrasion of enamel by composite resins is affected by the hardness (quality) of the fillers and by the strength of
the matrix/filler bond but not by the size and shape of
the filler particles.

To summarize, FS exhibited a simple shape of wear
that were suggestive of a higher wear resistance than
that of LP. Further, FS caused the least damage to the
antagonistic primary enamel. These results suggest that
the light-cured composite resin product FS might be a
more appropriate resin for the full crown restorations of
primary molars. Further, the 4-META/MMA-TBB resin
product BF might not be ideal for use in the full crown
restoration of primary molars.

ACKNOWLEDGMENTS

The authors are grateful to Dr. Yuzo TAKAGI, Professor
Emeritus, Division of Pediatric Dentistry, Tokyo Medical
and Dental University, for his valuable suggestions.
The authors also thank Dr. Tatsushi ITO, Professor
Emeritus, Tokyo Medical University, and Noriko ITOH,
Professor, Nihon University, for their support.

REFERENCES

1) Fuks AB, Ram D, Eidelman E. Clinical performance of
esthetic posterior crowns in primary molars: a pilot study.
2) Ram D, Fuks AB, Eidelman E. Long-term clinical performance
of esthetic primary molar crowns. Pediatr Dent 2003; 25: 582-
584.
3) Hickel R, Kadow C, Paschos E, Buerkle V, Garcia-Godoy F,
Manhart J. Longevity of occlusally-stressed restorations in
4) Puppin-Rontani RM, de Goes MF, Voelske CE, Garcia-
Godoy F. Clinical performance and SEM evaluation of direct
composite restorations in primary molars. Am J Dent 2006;
19: 255-261.
5) Wada K, Miyashin M. New techniques for producing esthetic,
direct full-crown composite resin restorations for primary
molars: a 24-month follow-up of eight cases. Eur J Paediatr
6) Villalta P, Oliveira LB, Imparato JC, Rodrigues CR. Indirect
composite onlay restorations in primary molars: a clinical
7) Wada K, Miyashin M, Nango N, Takagi Y. Wear of resin
composites and primary enamel and their applicability to full
crown restoration of primary molars. Am J Dent 2011; 24: 67-
73.
8) Zantner C, Kielbassa AM, Martus P, Kunzelmann KH.
Sliding wear of 19 commercially available composites and
9) Suzuki S, Suzuki SH, Cox CF. Evaluating the antagonistic
wear of restorative materials when placed against human
10) Lambrechts P, Debels E, Van Landuyt K, Peumana M, Van
Meerbeek B. How to simulate wear? Overview of existing
11) Suzuki S, Leinfelder KF. An in vitro evaluation of a
copolymerizable type of microfilled composite resin.
12) Suzuki S, Cox CF, Leinfelder KF, Snuggs HM, Powell CS.
A new copolymerized composite resin system: a multiphased
495.
13) Shinokai K, Suzuki S, Leinfelder KF, Katoh Y. Effect of
surface-penetrating sealant on wear resistance of luting
14) Naito K. Bonding and wear characteristics of a tri-n-
butylborane initiated adhesive resin filled with pre-
116.
15) Condon JR, Ferracane JL. In vitro wear of composite with
varied cure, filler level, and filler treatment. J Dent Res 1997;
76: 1405-1411.
16) Nihei T, Dabanoglu A, Teranaka T, Kurata S, Ohashi K,
Kondo Y, Yoshino N, Hickel R, Kunzelmann KH. Three-body-
wear resistance of the experimental composites containing
filler treated with hydrophilic silane coupling agents. Dent
17) Kagawuchi M, Fukushima T, Horibe T. Effect of monomer
structure on the mechanical properties of light-cured
18) Suzuki S, Leinfelder KF. Wear of enamel cusps opposed by
posterior composite resin. Quintessence Int 1993; 24: 885-
890.
19) Condon JR, Ferracane JL. Evaluation of composite wear with
a new multi-mode oral wear simulator. Dent Mater 1996; 12:
218-226.
JR, Vanherle G. In vitro vibrational wear under small
displacements of dental materials opposed to annealed
21) Ambjornsen E, Holland RI. In vitro abrasion of two acrylic