Wear and repair of stainless steel crowns

**ABSTRACT**

**Aim** The purpose of this study was to determine the wear of stainless steel crowns (SSCs) in children, and compare the extent of microleakage in SSCs that had been repaired using either a cermet glass-ionomer cement (GIC) or a packable composite resin (CR).

**Materials and methods** For the first aim, the occlusal surface thickness of 31 harvested SSCs (21 primary first and 10 second molars) and 18 unused SSCs was measured, and then examined under scanning electron microscopy. For the second aim, standardised holes were prepared on the occlusal surfaces of 20 SSCs, and then repaired using either a cermet GIC or packable CR. After their repair, the extent of microleakage was determined using 0.5% basic fuchsin and stereomicroscopy.

**Results** The thickness of all the harvested SSCs was 5.3 µm less than that of the unused SSCs (p<0.02), and there were no significant differences between the thickness and occlusal wear rates of harvested SSCs from the first and second primary molars. Although neither of the two repair materials completely prevented microleakage, the number of specimens in which microleakage occurred after repair with a cermet GIC was significantly lower than the number of specimens in which a packable CR was used (p<0.05).

**Conclusion** We concluded that the occlusal surfaces of SSCs for first and second primary molars display wear. Although perforated SSCs can be repaired using either a cermet GIC or a packable CR, less microleakage occurs in SSCs that were repaired with a cermet GIC than those with a packable CR.

**Keywords:** Stainless steel crown, wear, repair, stainless steel crown wear, stainless steel crown repair.

**Introduction**

The term "wear" can be simply defined as the process of material removal from a surface when two surfaces rub against one another [DeFreest, 1996]. In dentistry, the wear of restorative materials in the mouth occurs at sites of occlusal contact and during mastication [Mair et al., 1996]. According to Christensen [1996], amalgam, glass-ionomer cement (GIC), resin-modified glass-ionomer cement (RMGIC), composite resin (CR), and stainless steel (SS) are the most commonly used materials for restoring primary teeth. A number of studies have reported on the wear of these materials, except SS, when used to restore primary teeth [Wendell and Vann, 1988; Espelid et al., 1999; Lo et al., 2001].

Prefabricated SS crowns (SSCs) have been used to restore primary and permanent teeth for almost 50 years. Some investigators have reported that the occlusal surface of SSCs can display extensive wear and even become perforated because of long-term intraoral service or the excessive masticatory forces of children with bruxism [Braff, 1975; Croll, 1983; Croll and Phillips, 1986]. Roberts and Sherriff [1990] reported that the rate of perforation of the occlusal surface of SSCs was 1.5%, and emphasised that occlusal wear was the major reason for occlusal surface perforation and clinical failure of the SSCs. Yilmaz et al. [2006] have compared the in vivo occlusal wear, denting, and perforation of the 152 SSCs that were placed on the first and second primary molars of children from images that were taken by an intraoral camera. They found that the occlusal surface of 19 (12.5%) of the 152 SSCs showed signs of wear and were dented, and that the occlusal surface of 2 of the 19 SSCs with occlusal surface changes were perforated. In another study, Zinelis et al. [2008] assessed the morphological alterations on the occlusal surfaces of 17 harvested SSCs under scanning electron microscopy (SEM). Of the 17 SSCs, they noted that the morphological changes on the occlusal surfaces of 12 SSCs were similar to those that were described by Yilmaz and his colleagues [2006]. However, neither the Yilmaz nor the Zinelis studies tracked the clinical wear rates of the SSCs.

In order to limit the wear of SSCs, Croll [1983] suggested using a silver solder to increase the thickness of their occlusal surface so that they would be resistant to occlusal wear and prevent loss of the underlying tooth structure. Nonetheless, clinical failures of SSCs have been reported in primary molar teeth that were restored with SSCs after endodontic treatment. In fact, Messer and Levering [1988] reported that pulpotomised primary molars that were restored with SSCs had a greater risk of clinical failure than primary molars with vital pulps that were restored with SSCs. In order to access the pulp of a tooth that requires endodontic treatment after its restoration with an SSC, the occlusal surface of the SSC needs to be perforated [Croll, 1999]. Since the perforated SSC needs either replacing or repairing after the endodontic treatment, the latter of the two alternatives is preferred because a repaired SSC conserves the structure of the restored tooth, the repair is less time consuming, and the cost of the repair is cheaper than the cost of replacing the perforated SSC [Mjör, 1993].

Reports on the effectiveness of repairs to perforated SSCs are limited. Braff [1975] described the repair of SSCs with defective margins using amalgam. Although high-copper amalgam restorations have been shown to be more resistant to marginal deterioration and corrosion than their low-copper amalgam counterparts, an initial interfacial gap between the amalgam and tooth surface that is great enough to permit microleakage can be created with amalgam restorations [Bauer and Henson, 1984]. However, there is concern among health authorities and patients on the use of dental amalgam, especially in children, because mercury can leach from
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dental amalgam into the mouth. Hence, packable CRs, sometimes called condensable CRs, were introduced as an alternative to amalgam for restoring cavities, especially in the stress-bearing posterior teeth. Packable CRs are more advantageous than hybrid CRs because of their ability to bond enamel and dentin, their higher filler load and filler distribution, and the application technique is similar to that used with amalgam [Cavalcani et al., 2005; Manhart et al., 2000]. In addition to packable CRs, Croll and Phillips [1986] and Croll [1999] suggested that silver GICs (cermets, such as Ketac-Silver™) or resin-modified GICs (Vitremer®) may also be used to repair a perforated occlusal surface of an SSC. However, these reports provided no descriptions or explanations on the effectiveness of the repair.

The quality of a repaired restoration is related to the magnitude of the bond strength that exists at the interface between the restoration and the repair material [Lewis et al., 1998]. Cavalcani et al. [2005] reported that that the bond and the quality of the seal between the restoration and the repair material can be considered adequate when microleakage at their interface does not occur. The extent of microleakage of a repaired restoration can be determined in vitro using dyes in order to predict the performance of restorative materials in the oral environment and indicate the lack of a perfect seal, which is the primary clinical cause of a restorative failure [Baure and Henson, 1984]. To the best of our knowledge, there are no published studies on the microleakage of repaired SSCs. Against this background, this study was undertaken in order to determine the wear of SSCs in children, and compare the extent of microleakage in SSCs that have been repaired using either a GIC cermet or a packable CR.

Materials and methods

The study comprised two parts: an in vivo component, which involved previously cemented SSCs that were harvested from exfoliated primary teeth, and an in vitro component, which involved freshly extracted human primary first molars.

In vivo measurement of wear

The in vivo study was conducted at the Department of Paediatric Dentistry, Faculty of Dentistry, Ataturk University, Eruzum, Turkey. The aims of this study were explained to each child and his/her parents, and the harvested SSCs were obtained after consent of each child. The inclusion criteria for a harvested SSC were:

- In addition, the primary tooth with the SSC had to have been physiologically exfoliated, no restoration had been done on the antagonist tooth, and the child did not have abnormal dental condition, such as a cross-bite, an open bite, or a deep bite.
- SSCs that were harvested from xerostomic children, children with bruxism, or children whose primary molars had already been endodontically treated were excluded from the study.

Thirty-one SSCs from 21 primary first molars and 10 primary second molars were collected, and then stored in tap water at 37°C for 1-2 weeks. At the end of the storage period, the SSCs were rinsed under tap water, and any dental plaque was removed using a rubber cap without polishing paste. The cement residues on the inner surfaces of each SSC were removed using an ultrasonic cleaner. The thickness (µm) of the occlusal surface of each SSC was measured using calipers (Schnelltaster System, Kröplin, Germany). Twelve measurements were done for each crown, and the mean of these 12 measurements was used in the subsequent analysis. The control group comprised 18 unused SSCs (nine primary first molars and nine primary second molars) of the same brand as the harvested SSCs. The thickness (µm) of the occlusal surface of these 18 unused SSCs was measured in the identical manner that was described for the harvested SSCs.

In order to improve the validity and reproducibility and control random error of the first set of thickness measurements [Houston, 1983], the thickness measurements were repeated one week later. The data from unused and harvested SSCs were analyzed using an independent samples t test where significance was set at 95% (SPSS version 11.0, SPSS Inc., Chicago IL, USA).

In addition, the occlusal surfaces of the unused and harvested SSCs were evaluated under a scanning electron microscope (JSM-6400 JEOL, Tokyo, Japan). For this purpose, each specimen was first ion-beam sputter-coated with a gold-palladium alloy (SEM Coating Unit E 500, POLARON Equipment Limited, Barcelona, Spain) before being examined, and then micrographed.

In vitro determination of the presence and measurement of microleakage

The in vitro part of the study comprised 20 freshly extracted human primary first molars whose root resorption was less than 2/3, and which were free of caries and developmental defects, and had not undergone restoration. The tissue remnants on the root surfaces were removed with a scaler before embedding the roots 1 mm below the cement-enamel junction in acrylic resin blocks; 1.5 mm of the occlusal surface and one-third of the occlusal surfaces of the buccal and lingual cusps of each tooth were removed using a 169 L diamond bur. All undercutson the mesial and distal surfaces were removed [Yilmaz et al., 2006]. SSCs (D2, REF:ND-96 3M Dental Products, St. Paul, MN, USA) were fitted, and then uniformly contoured and cramped (003-139-00 and 003-114-00 Dentaurum, Germany). The SSCs were cemented using a luting GIC (Aqua Meron) because luting GICs have widely been used for cementation of SSCs [Garcia-Godoy and Bugg, 1987; Yilmaz et al., 2006]. The cement (3.3-3.8:1 powder:liquid in grams) was first mixed in...
accordance with the manufacturer’s recommendations, and then applied to the inner surfaces of the crowns. The SCCs were then placed in their correct position on the embedded preparations, and left to harden for 10 min under a constant pressure of 5 kg. After crown cementation, the excess cement was removed with a dental explorer, and the specimens were then stored in distilled water at 37° C for 24 hours until required.

Crown perforation and the repair procedures

A standardised 4x3x2 mm hole was made on the occlusal surface of each SSC using a fissure diamond bur in a high-speed hand piece with water spray cooling (Dia Tessin Vanetti SA, Gordevio, Switzerland). The 20 specimens were then randomly distributed into the two equal groups for assessing the presence and measurement of microleakage after the repair of the SSCs using two different repair materials. In each group, 34.5% phosphoric acid gel was applied for 30 seconds to the cavities in order to etch the hole’s surfaces before repair.

Group I: After acid-etching of the hole’s surfaces, the acid was removed from the surface by water spraying for 30 seconds, and the surfaces of the hole were then air-dried using oil-free compressed air. A cermet GIC (Ketac-Silver, 3M ESPE, Seefeld, Germany) was mixed in an amalgamator for 10 seconds, and then injected into the hole. The restoration was then covered with a GIC protective varnish.

Group II: After acid-etching of hole’s surfaces and removing the acid by water spraying for 30 seconds, the surfaces of the hole were then dried using polyurethane pellets. When dry, a bonding agent (Prime & Bond® NT™, Dentsply Caulk, Milford, DE, USA) was then applied to the hole’s surfaces with a brush and left undisturbed for 20 seconds before light-curing for 10 seconds. Excess bonding agent was gently removed with oil-free compressed air. A packable RC (SureFil®, Dentsply, Weybridge, UK) was placed in an amalgamator that was used to pack the RC into the hole. The CR was then polymerised for 40 seconds using a light-curing unit before polishing the repair with Sof-Lex discs.

All repaired specimens were then kept in distilled water at 37° C for 24 hours before thermocycling when each thermocycle consisted of 500 cycles for 20 seconds at 5° C and 500 cycles for 20 seconds at 55° C. Following thermocycling, the repaired specimens were first placed in a 0.5% basic fuchsin for 24 hours. Each specimen was then sectioned in a mesial-distal direction along its long axis through the center of the restoration using a low-speed saw in order to obtain two ~0.6 mm-thick sections. The extent of microleakage in both the mesial and distal parts of each specimen was evaluated using a stereomicroscope (Nikon SM Z-V multi-point-sensor system, Japan) at 20x magnification. Two successive microleakage measurements (µm) were made on both the mesial and distal parts of each specimen, and the average of the two measurements was used in subsequent analysis. Forty measurements were made for each repair material, and the extent of microleakage was scored at the luting GIC-repair material interface and the luting GIC-repair material-tooth’s hard tissue interface. In addition, three samples from each type of repaired specimens were randomly selected in order to evaluate the sealing ability of the two cements at the luting GIC-repair material-tooth’s hard tissue interface under the scanning electron microscope. For this purpose, each specimen was first ion-beam sputter-coated with a gold-palladium alloy SEM Coating Unit E 500, POLARON Equipment Limited, Barcelona, Spain) before being examined, and then micrographed.

The microleakage data from the two groups were analysed using an independent-samples t test and Fischer’s exact test (SPSS version 11.0, SPSS Inc., Chicago IL, USA). Statistical significance was set at 95%.

Results

In vivo measurements of wear

Table 1 shows the mean thicknesses of the occlusal surfaces of the unused and harvested SSCs. The reproducibility of the thickness measurements was greater than 0.95. The thickness of the all harvested SCCs was 5.3 µm less than that of the unused SCCs, and this reduction in thickness was statistically significant (p<0.02). The mean occlusal wear rate of the 31 harvested SCCs was 3.2 µm/year. Specifically, the thickness of the 21 harvested SCCs from primary first molars was 4.0 µm less than that of the unused primary first SCCs and the mean occlusal wear rate of these 21 harvested SCCs was 2.4 µm/year. The thickness of the 10 harvested SCCs from primary second molars was 3.2 µm less than that of the equivalent unused SCCs, and their occlusal wear rate was 2.0 µm/year. Lastly, the thickness of the occlusal surfaces and rates of occlusal wear for harvested SSCS from the primary first molars were not significantly different from those of the primary second molars (p>0.05). SEM micrographs of the occlusal surfaces of the unused and harvested SSCs are shown in Figures 1 and 2. Compared to the smooth occlusal surfaces of the unused SSCs (Fig. 1), the occlusal surfaces of the harvested SSCs were rough and showed signs of wear (Fig. 2). The wear on the occlusal surfaces of the harvested SSCs was in both the occlusal contact area (OCA) and the contact-free area (CFA) (Fig. 2).

In vitro determination and measurement of microleakage

The extent of microleakage and the sites of microleakage occurrence in the specimens that were repaired by the two types of repair materials are shown in Table 2. Although neither of the two repair materials completely prevented

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
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<tbody>
<tr>
<td>Unused SCCs</td>
<td>18</td>
<td>172.3</td>
<td>6.1</td>
</tr>
<tr>
<td>Primary first</td>
<td>9</td>
<td>167.9</td>
<td>4.0</td>
</tr>
<tr>
<td>Primary second</td>
<td>9</td>
<td>176.7</td>
<td>4.3</td>
</tr>
<tr>
<td>Harvested SCCs</td>
<td>31</td>
<td>167.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Primary first</td>
<td>21</td>
<td>163.9</td>
<td>6.4</td>
</tr>
<tr>
<td>Primary second</td>
<td>10</td>
<td>173.5</td>
<td>6.5</td>
</tr>
</tbody>
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SSC: stainless steel crown; N, sample size; SD, standard deviation.

Table 1 - The thickness (µm) of the occlusal surfaces of unused and harvested stainless steel crowns.
microleakage, which occurred at the luting GIC-repair material interface and the luting GIC-repair material-tooth's hard tissue interface (Fig. 3, 4; Table 2), the number of specimens in which microleakage occurred after being repaired using cermet GIC was significantly lower (p<0.05) than the number that were repaired with a packable CR. In addition, there were no significant differences between the extent of microleakage in SSCs that were repaired using a cermet GIC or a packable CR (p>0.05) (Table 2). Specifically, in those SSCs that were repaired using cermet GIC, microleakage was seen in 25% of the repaired specimens, and the extent ranged from 0-825 µm (Table 2). In those SSCs that were repaired using a packable CR, microleakage was seen in 50% of the repaired specimens, and the extent of microleakage ranged from 0-825 µm (Table 2). Figure 5 is a SEM image of the luting GIC-repair material interface, and it can be seen that the connection between the two materials is almost unified. However, this was not the case for specimens that were repaired with the packable CR: gaps were observed at the luting GIC-repair material interface (Fig. 6).

Discussion

Time is an important determinant in the extent of wear of surfaces [Mair et al., 1996]. It has been previously reported that at least 6-12 months are required to produce a measurable amount of wear in in vivo wear investigations [Ratledge et al., 1994]. Therefore, signs of wear in the harvested SSCs would be expected in our study because the average age of the harvested SSCs was 19.6 months. In addition, the wear of dental materials is influenced by the properties of the opposing material [Monsky and Taylor, 1971]. The wear of a restored tooth can be influenced by contact with the enamel of the antagonistic tooth [Robert, 1982]. Zantner et al. [2004] stated that the type of antagonistic surface is an important determinant of wear of the surface where wear is being measured. For dental surfaces, such as a restoration on a tooth, the number of microcontacts between the filler particle of the restoration, and the surface of the antagonist may influence the wear behaviour [Zantner et al., 2004]. If a dental restoration had been made on the antagonist tooth, our results on wear on the occlusal surface of the SSCs would have reflected the wear of two different dental restorative materials, and not one, which was the aim of our study. In order to satisfy this aim, one of our inclusion criteria was that the antagonist of the tooth with the harvested SSCs had to be a natural tooth that had not undergone restoration.

The wear rates of restorative materials that are used for restoration of primary teeth, such as a CR or GIC, have been evaluated in several clinical studies [Lo et al., 2001; Wendell et al., 2002; Zantner et al., 2004].
WEAR RATE AND REPAIR OF SSCS

and Vann, 1988]. Wendell and Vann [1988] found that the mean wear rate for a posterior CR in the primary molars was 93 µm/2 years. Lo et al. [2001] noted that net mean occlusal wears for two different GICs in primary teeth varied from 85-87µm/2 years. The wear rates of the harvested SSCs that were used in our study are 10 times less on an annual basis than those of the two reported studies. This difference could possibly be due to the different types of restorative materials that were used to repair the SSCs. It is possible that the wear rate of an SSC that was repaired with a CR is lower than that of an SSC that was repaired with a GIC, but this has yet to be established.

In this study, we found that the mean occlusal wear rates for harvested SSCs from the primary first and second molars were not different from each other. This finding is intriguing because Karibe et al. [2003] reported that the occlusal forces on primary first molars are lower than those on primary second molars. In addition, we found that the wear of the occlusal surface of the harvested SSCs was in both the OCA and CFA, which is in agreement with the observations of Lutz et al. [1984].

Although dental practitioners generally do not prefer SSCs for restoring primary teeth [Christensen, 1996], SSCs have higher clinical success rates than the other restorative materials [Braff, 1975; Messer and Levering, 1988]. However, SSCs can be perforated during their use or need to be perforated when an underlying tooth that was restored with SSC needs re-treatment because of recurrent caries or an endodontic treatment failure. In both instances, the perforated SSC can be repaired with a restorative material. In the present study, the perforated SSCs were repaired using either a cermet GIC or a packable CR. We chose a cermet GIC to repair the artificially-perforated SCC because it has been claimed that a cermet GIC can be used to repair a perforated SCC [Croll and Phillips, 1986]. For comparison, we chose a packable CR to repair the artificially-perforated SCC because it bonds both the GIC and the tooth’s hard tissue [McLean et al., 1985].

Microleakage occurs due to exposure and resultant loss of the cement to oral fluids in the marginal area. We found that the extent of microleakage in the SSCs that were repaired by a cermet GIC was lower than that of SSCs that were repaired by a packable CR. This difference may be explained by a surface change on the luting GIC after acid-etching of the hole’s surfaces with phosphoric acid. The acid dissolves the matrix of the hardened luting GIC and produces a rough and porous surface on the GIC [Hinoura et al., 1987; Jamaluddin and Pearson, 1994]. These surface changes result in an almost unified connection or an effective seal between the two materials. Our microleakage results are in agreement with those of Jamaluddin and Pearson [1994], who measured the microleakage of GICs that were treated with polyacrylic acid, phosphoric acid, or polyacrylic acid plus phosphoric acid as a conditioning agent prior to the repair. In addition, the smaller number of SSCs that displayed microleakage after their repair with the cermet GIC when compared to the number of SSCs that displayed microleakage after their repair with the RC may be due to the fact that cermet GIC can be injected into a hole. Since the repair material is injected, it is placed in direct contact with the surface that is to be repaired. As a result, the seal is more effective than that provided by a packable CR, which is packed into the hole under pressure. When a packable CR is used as the repair material, packing under pressure may not always result in direct contact with the surface that is to be repaired, and the seal is not always absolute. We also observed that the seals were not absolute in all specimens,

<table>
<thead>
<tr>
<th>REPAIR MATERIAL</th>
<th>EXTENT OF MICROLEAKAGE</th>
<th>SITES OF MICROLEAKAGE OCCURRENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (µm)</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of repaired specimens with no microleakage</td>
</tr>
<tr>
<td>Cermet GIC</td>
<td>90.4</td>
<td>179.7</td>
</tr>
<tr>
<td>Packable CR</td>
<td>248.7</td>
<td>275.7</td>
</tr>
</tbody>
</table>

GIC, glass-ionomer cement; CR, composite resin; SD, standard deviation

**TABLE 2** - The extent of microleakage and the sites of microleakage occurrence.

![FIG. 5 - View of the occlusal surface of a harvested SSC (a. magnification X12; b. magnification X250).](image)

![FIG. 6 - Gaps in the bond between the luting GIC and the packable CR (magnification X400) (RM: Repair material, C: Luting GIC).](image)
and that microleakage occurred within the repair materials rather than at the interface between cermet GIC and luting GIC. Lastly, the occurrence and extent of microleakage at the interface between the cermet GIC and/or the tooth’s hard tissue may have been influenced by the different types of luting GIC and cermet GIC that were used in this study.

In order to obtain a high quality bond and an effective seal between an acid-etched luting GIC and a packable CR, the bonding agent must be able to penetrate and create retentive tags in the rough and porous GIC surface after its curing [Hinoura et al., 1987]. However, we found that the extent of microleakage was higher in those SSCs that were repaired by a packable CR (Group II) than that of SSCs that were repaired with a cermet GIC (Group I). In addition to the reasons that were already proposed, the microleakage that can occur after repair of the SSCs with a packable CR can be attributed to several factors, such as the viscosity of the bonding agent and polymerisation contraction forces of CRs. We think that another underlying reason for microleakage in the Group II specimens may be due to insufficient wetness and low surface energy of the roughened and porous surface after acid-etching of the luting GIC. When these factors are combined with the method of applying a packable CR to repair a perforated SSC, gaps and voids are more likely to occur between a packable CR and the etched luting GIC surface. In addition, polymerisation contraction stress adversely affects the maintenance of the bond interface between composite resins and dental hard tissues [Chen et al., 2001]. Chen et al. [2001] found that packable CRs exhibited significantly higher contraction stress than conventional hybrid CRs. Therefore, we think that the polymerisation contraction stress of the packable CR may have also contributed to the increased occurrence of microleakage in the SSCs that were repaired with the CR that was used in this study.

Conclusions

1. Occlusal wear may be seen in SSCs that are used to restore primary teeth over time.
2. The wear rate of SSCs on first primary molars is slightly higher than that of SSCs on second primary molars.
3. Although perforated SSCs can be repaired using either a cermet GIC or a packable CR, less microleakage occurs in SSCs that were repaired with a cermet GIC than those that were repaired with a packable CR.

References


