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ABSTRACT

Wear phenomena of ceramic inlays are not fully understood. The aim of the present study was to evaluate ceramic wear, antagonist enamel wear, and luting cement wear over 8 years. The two-fold null hypothesis was that there would be (1) no difference in wear behavior between ceramic and enamel, and (2) no influence of filler content of luting composites on composite wear. From 96 restorations, 36 Class II inlays from 16 participants were selected. For inlays with opposing enamel cusps ($n = 17$), replicas of inlays and enamel were scanned with a 3-D laser scanner. Luting gaps of inlays ($n = 36$) were analyzed with a profilometer, including 3-D data analysis. Ceramic and enamel wear increased between 4 and 8 years, with significantly higher values for enamel after 6 years ($p < 0.05$). Luting gap wear increased continuously up to 8 years ($p < 0.05$), with no influence of luting composites ($p > 0.05$) and location of teeth ($p > 0.05$).

KEY WORDS: glass ceramics, resin composites, clinical trial, wear, antagonist.

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INTRODUCTION

The clinical performance of ceramic inlays has been well-documented (Qualtrough and Wilson, 1996; Fradeani *et al.* 1997; Fuzzi and Rappelli, 1999; Molin and Karlsson, 2000). Long-term wear behavior of ceramic inlays is not fully understood, and, as has been reported from clinical observations with porcelain-fused-to-metal crowns, feldspathic ceramics cause considerable antagonist wear (Clelland *et al.*, 2001; Oh *et al.*, 2002). Therefore, positive step formations, as well as wear of opposing enamel over time, represent possible consequences with inlays as well.

However, no *in vivo* long-term data have been published on wear of ceramic inlays vs. enamel. Simulations of 5 years of clinical service *in vitro* caused ceramic abrasion values of 22-88 μm and opposing enamel wear of 75-224 μm (Krejci *et al.*, 1993, 1994a). Clinical studies have reported considerable wear within the luting gap of bonded inlays, a potential problem in terms of marginal staining and recurrent caries (Åberg *et al.*, 1994; Gladys *et al.*, 1995; Hayashi *et al.*, 1998). Finally, luting composite wear, as it progresses, could cause marginal fractures, due to missing support of brittle substrates, such as enamel and ceramics (Heymann *et al.*, 1996).

The aim of the present study was to evaluate wear phenomena of ceramic inlays, over 8 years, in terms of ceramic inlay wear, antagonist enamel wear, and luting cement wear. The two-fold null hypothesis was that there would be (1) no difference in wear behavior between ceramic and enamel, and (2) no influence of filler content of luting composites on composite wear.

MATERIALS & METHODS

Ninety-six IPS Empress (Ivoclar Vivadent, Schaan, Liechtenstein) inlays and onlays were placed according to a detailed protocol (approved by the accredited ethics committee of the University of Erlangen), with written consent of the individual participants, and clinically evaluated (Krämer and Frankenberger, 2005). Impressions (Permagum, 3M Espe, Seefeld, Germany) were taken, and replicas (Epoxy Die, Ivoclar Vivadent) were manufactured at 0.5-, one-, two-, four-, six-, and eight-year recall sessions.

Seventeen inlays (from 10 participants: 11 premolars, 6 molars, 8 maxillary, 9 mandibular) and their corresponding antagonists were selected according to the following criteria: (1) The restorative situation of the antagonist and adjacent teeth had to be unchanged over the whole period, and (2) the contact area of the ceramic inlay had to be exclusively in enamel. One-year assessments were defined as baseline, with four-, six-, and eight-year dies serving as follow-up. Impressions of the restored teeth and their antagonists were poured with Fuji-Rock white (GC, Tokyo, Japan), and dies were mounted in standard fixing devices in a parallelometer (Willytec, Munich, Germany). Casts were scanned with the use of the Munich-type triangulation sensor, Laserscan 3D Pro (Willytec). The dies were fixed on a plane to facilitate a rectangular scan, supported by locally developed software (University of Munich). To minimize false-positive results, we scanned the surfaces from 2 different directions, with a triangulation angle of 22°, so the resolution of the selected test device was $z/x/y = 5/25/2 \mu\text{m}$, with a depth range of 20 mm. The 2 scans were matched with the use of locally developed software (Match 3D, University of Munich, Germany). Finally, the datasets of the initial die

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Figure 1. To determine ceramic wear, we applied the region-of-interest mask to the left lower second premolar (region-of-interest mask in Match 3D: left side). The borderlines of the inlay were controlled by visual inspection of the clinical photograph (here, eight-year recall).

Figure 2. Matching 3D software difference image of the upper left second premolar (antagonist of Fig. 1, **left image** after 6 yrs, **right image** after 8 yrs). Wear is visible as greyish areas (here at the palatal cusp as occlusal contact area).

and the follow-up dies were matched, and a dataset was generated by superpositioning and translation:

Baseline dataset: $\{\vec{r}_n\}$, $\vec{r}_n = \vec{r}_n(x_n, y_n)$, $n = 1, \dots, N$

Follow-up dataset: $\{\vec{r}_n^t\}$, $\vec{r}_n^t = \vec{r}_n^t(x_n^t, y_n^t)$, $n = 1, \dots, N$

$\vec{r}_n = (x_n, y_n, z_n)$ is a point on the surface of the baseline image, while $\vec{r}_n^t = (x_n^t, y_n^t, z_n^t)$ is the corresponding point on the follow-up image.

The two datasets can be superimposed with three rotations (α , β , γ) and three translations (t_x , t_y , t_z). $\vec{r}^t = R(\alpha, \beta, \gamma) \cdot \vec{r} + \vec{t}$ ($R = 3 \times 3$ rotation matrix of the three angles α , β , γ).

After superimposition, an image showing the difference was generated (Figs. 1, 2). In initial images, different levels of depth are represented as shades of grey. In follow-up images, the negative changes are displayed as shades of red, whereas positive changes are visible as shades of grey. To determine an assessable area, we determined a so-called "region of interest" for each restored tooth and antagonist (Figs. 1, 2). The region of interest was the complete occlusal area of inlays and occlusal contact areas for the antagonists, with clinical photographs as controls. To reduce data scatter, we computed the evaluation using 2%-quantiles, allowing for the inclusion of 98% of the values (Mehl *et al.*, 1997).

Statistical analyses were performed with SPSS software. Data concerning the comparison of ceramic vs. antagonist wear were normally distributed (by the Kolmogorov-Smirnov test) and were therefore analyzed with paired *t* tests. Significant changes in wear behavior were computed by Friedman two-way ANOVA (level of significance = 0.05).

From 16 study participants (12 females, four males; mean age, 35.1 yrs), we selected 36 Class II inlays (14 premolars, 22 molars, 13 maxillary, 23 mandibular) with cusp inclinations below 45°. Twenty inlays had been luted with the light-cured hybrid-type restorative resin composite Tetric (filler content, 82wt%), and 16 inlays with the dual-cured luting composite Variolink Low (filler 72wt%; both Ivoclar Vivadent, identical fillers).

We carried out three-dimensional scanning of luting gaps using a profilometer (Perthometer S3P, Perth, Göttingen, Germany) with a resolution of $x/y/z = 25/25/0.5 \mu\text{m}$. The computer-based analysis of the profilometrically collected data was carried out with locally developed software (Xpert for Windows XP, University of Erlangen; Krämer and Frankenberger, 2000). Occlusal contact areas

were excluded from the measurement. To obtain a value independent of the luting gap width, we introduced the relative depth of the luting gap in relation to the completely abraded area:

relative depth = $(l_{\text{wf}} \times w_{\text{wf}} \times d_{\text{max}}) / (l_{\text{tot}} \times w_{\text{tot}})$ where

l_{wf} = length of the worn furrow,

w_{wf} = average width of the worn furrow;

d_{max} = average maximum depths of particular steps evaluated with XPert,

l_{tot} = total length of the furrow within the occlusal surface,

and

w_{tot} = average width of the furrow.

Statistical analysis was performed with SPSS for Windows XP V11.0 (SPSS Inc., Chicago, IL, USA). The statistical unit was 1 ceramic restoration. Differences between groups were evaluated pair-wise with the Mann-Whitney U-test (level of significance, 0.05). Differences over the investigation period were calculated by the Friedman test (two-way ANOVA for dependent samples). We used linear regression analysis to assess correlation between width and depth of the luting gap (correlation coefficient, r^2).

RESULTS

Mean wear of the analyzed ceramic inlays was 78 μm after 4 yrs, 110 μm after 6 yrs, and 116 μm after 8 yrs (Fig. 3), and the difference between 4 and 8 yrs was statistically significant (Friedman two-way ANOVA; $p < 0.05$). Mean wear of antagonistic enamel significantly increased from 120 μm after 4 yrs to 238 μm after 8 yrs (Friedman two-way ANOVA, $p < 0.05$; Fig. 3). Compared with ceramic inlays, antagonistic enamel suffered significantly more wear after 8 yrs of clinical service (paired *t* test, $p < 0.05$; Fig. 3). Location of inlays and antagonists in the oral cavity had no influence on wear results (paired *t* test; $p > 0.05$).

Luting gap analysis revealed 60% ditching after 8 yrs (Table). Luting gap wear increased significantly over time (Friedman test, $p < 0.05$). A correlation between substance loss and particular location of the inlays in the oral cavity was not found (mandibular/maxillary or premolar/molar; Mann-Whitney U-test; $p > 0.05$). Substance loss was independent of luting cements (Mann-Whitney U-test; $p > 0.05$).

Figure 3. Boxplot chart of wear rates [μm] for ceramic inlays and corresponding antagonists after 4, 6, and 8 yrs of clinical service ($n = 17$). Differences are relative to the baseline investigation. Horizontal bars in boxes are medians; 50% of all values are within the boxes. The bars represent the complete range of values measured.

DISCUSSION

Despite a large number of clinical reports dealing with ceramic inlays, few quantitative *in vivo* data are available on the wear of ceramics, enamel, or luting composites (Hayashi *et al.*, 2003). Fundamental requirements for valuable data acquisition are low failure rates and few drop-outs. In the present study, 8% failures occurred in 59% of the restorations after 8 yrs (Krämer and Frankenberger, 2005). Until now, routine clinical aspects have been examined, such as post-operative hypersensitivity or bulk fractures (El-Mowafy and Brochu, 2002; Sjögren *et al.*, 2004). Data on wear have been based predominantly on estimations or on chewing simulations *in vitro* (Krejci *et al.*, 1993; Yip *et al.*, 2004).

Two different methodologies were used in the present study for the non-destructive analysis of surfaces. In general, profilometric and opto-electric investigations (Kawai *et al.*, 1994; Krejci *et al.*, 1994b) are possible for three-dimensional data acquisition. Due to enhanced computer technology, PC-navigated mechanical profilometry systems were developed, revealing vertical ranges $< 1 \mu\text{m}$. X/y-resolutions from $10 \times 10 \mu\text{m}$ to $25 \times 25 \mu\text{m}$ have been shown to be reliable. The scanning of steep areas or deep and narrow luting gaps is limited by the scanning needle's geometry; however, volumes may be measured with an accuracy of $\pm 10\%$ (Kunzelmann, 1996; Krämer and Frankenberger, 2000). The 3-D scanner was reported to have an accuracy of $x/y/z = 25/2/5 \mu\text{m}$ (Mehl *et al.*, 1997), so the low vertical resolution is a disadvantage compared with mechanical profilometry. Therefore, we used the laser triangulation method in the present study to measure abrasion characteristics of ceramic inlays and their antagonists (Figs. 1, 2).

Due to its high vertical resolution, mechanical profilometry has been described as the most accurate system for recording surface changes (Krejci *et al.*, 1994b). However, its precision is limited by cuspal inclinations of more than 45° , so only slopes of less than 45° were selected, to avoid bending of the scanning needle (Krämer and Frankenberger, 2000). The geometry of the scanning needle is critical for scanning narrow luting areas. The tip

Table. Substance Loss of Luting Composites Tested, Width, Total Length of Luting Gap, and Percentage of Negative Sections of the Luting Gap ($n = 36$), with Results of Regression Analysis (corrected r^2 , variance-analysis ANOVA, regression coefficient)

Time (mos after placement)	100 (2.1)
Total length of luting gap [mm] (SD)	13.2 (6)
Width of luting gap [μm] (SD)	198 (49)
Negative luting gap relative to total length	60% (24)
Relative depth of luting gap, Variolink Low [μm] (SD)	27.5 (17)
Relative depth of luting gap, Tetric [μm] (SD)	18.9 (15)
Relative depth of luting gap [μm] (SD)	23 (16)
Width of luting gap [μm] (SD)	198 (49)
r^2	0.76
ANOVA (p)	< 0.000
Regression coefficient (SD)	0.13 (0.012)

of the diamond needle has a radius of $5 \mu\text{m}$, with an equilateral triangular shape, so only a furrow depth with less than 50% of its width is reliably detectable (Krämer and Frankenberger, 2000). Analysis of the present data showed widths in the range of 80 to $460 \mu\text{m}$ and depths of 4 to $75 \mu\text{m}$, combined with an evident linear correlation of width and depth allowing for a profilometric accuracy of $\pm 2 \mu\text{m}$ (Krejci *et al.*, 1994b; Kunzelmann, 1996).

In the present study, we also evaluated the influence of different filler contents and of variables such as width of the luting gap, location of the restored tooth, and contact area on luting gap abrasion. For the evaluation of luting gap wear, only changes between adjacent structures (enamel and ceramic) were assessed, so enamel and ceramic were taken as the reference for abrasion (Kunzelmann, 1996; Mehl *et al.*, 1997). The Xpert software required the division of volume loss by abraded area, resulting in the term "relative depth" (Krämer and Frankenberger, 2000).

Hayashi *et al.* (2004) reported clinical eight-year wear data of a dual-cured luting composite between enamel and feldspathic ceramic. They used a charge-coupled device laser with an accuracy of $4.3 \pm 3.2 \mu\text{m}$, and the software-assisted superimposition of the profiles did not allow for the assessment of low abrasion areas. This may be the reason for differences in mean wear rates ($70 \mu\text{m}$ vs. $34 \mu\text{m}$ in our study). Fifteen inlays in bicuspid were scanned only after 8 yrs, with no baseline or intermediate recalls. In the present study, all 36 teeth were prospectively evaluated from baseline.

Compared with data from the six-year investigation, analysis of the present data revealed no statistically significant influence of the location of the restoration within the mouth. This may be attributed to the evaluated wear of contact-free areas. The correlation between depth and width of the luting gap was clearly evident. Compared with data from other studies reporting wear of luting composites, analysis of the present data indicated the most intensive abrasion within the first year of clinical service (Isenberg *et al.*, 1992). The influence of food abrasion on the results was evident, with a relative depth of $23 \mu\text{m}$ in contact-free areas. The present profilometric study quantitatively analyzed luting gap abrasion, resulting in no correlation between filler content of luting composites and wear resistance, although the introduction of the ultrasonic insertion technique elicited the hope of more wear resistance by the use of higher filled ($> 80\%$ wt) composites. Thus,

the first part of the null hypothesis was confirmed.

Until now, the wear complex of ceramic inlay vs. opposing enamel has not been sufficiently addressed. Since the introduction of ceramics as an inlay material, wear resistance has been estimated to be substantial (Burke and Qualtrough, 1994). However, some authors claimed an abrasion behavior similar to that for enamel (Krejci *et al.*, 1994a). Prospective clinical long-term data are lacking. Recent reviews referred to qualitative or semi-quantitative evaluations of casts (Yip *et al.*, 2004). Moreover, digital data acquisition is now possible, since the introduction of non-contact optical scanning methodologies (Mehl *et al.*, 1997). The design of a quantitative study has to meet several requirements; therefore, the present study was restricted to participants who received no further restoration over the entire observation period (Lambrechts *et al.*, 1989). An additional food consumption assessment was not carried out, because such an assessment is not realistic over an observation period constituting approximately 10% of an individual's life. Rotary instrument adjustment and/or polishing was strictly forbidden after the baseline investigation.

Taking these factors into consideration may explain why only 20% of the clinically evaluated restorations remained for quantitative examination (Hayashi *et al.*, 2004). In contrast, the strict requirements made it possible for us to obtain reliable data. Another important factor was the definition of baselines for ceramic/enamel wear analysis. Overhangs falsify early results, so it made no sense to include data before 6 mos of clinical service, when overhangs tend to interfere with valuable measurements (Krämer and Frankenberger, 2000).

The main part of the two-fold null hypothesis (similar wear of enamel and ceramic) was rejected. This phenomenon of higher enamel wear was confirmed by positive step formations of ceramic inlays to adjacent enamel, which may cause complications in dynamic occlusion over time. This may be the reason that bulk, partial, and marginal fractures have been reported for all IPS Empress *in vivo* studies over time (El-Mowafy and Brochu, 2002). Also, *in vitro*-based conclusions, that IPS Empress may provide wear characteristics similar to those for enamel, were rejected (Ratledge *et al.*, 1994; Ramp *et al.*, 1997).

Opposing enamel cusps suffered significantly more abrasion than glass-ceramic inlays, with no influence of tooth location. Beyond 6 yrs of clinical service, a significant increase in luting gap wear was detectable. The filler content of luting composites showed no influence on wear.

Further studies should address the different ceramics used in the oral environment, as well as the correlation between *in vitro* and *in vivo* results.

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REFERENCES

- Åberg CH, van Dijken JW, Olofsson AL (1994). Three-year comparison of fired ceramic inlays cemented with composite resin or glass ionomer cement. *Acta Odontol Scand* 52:140-149.
- Burke EJ, Qualtrough AJ (1994). Aesthetic inlays: composite or ceramic? *Br Dent J* 176:53-60.
- Clelland NL, Agarwala V, Knobloch LA, Seghi RR (2001). Wear of enamel opposing low-fusing and conventional ceramic restorative materials. *J Prosthodont* 10:8-15.
- El-Mowafy O, Brochu JF (2002). Longevity and clinical performance of IPS-Empress ceramic restorations—a literature review. *J Can Dent Assoc* 68:233-237.
- Fradeani M, Aquilano A, Bassein L (1997). Longitudinal study of pressed glass-ceramic inlays for four and a half years. *J Prosthet Dent* 78:346-353.
- Fuzzi M, Rappelli G (1999). Ceramic inlays: clinical assessment and survival rate. *J Adhes Dent* 1:71-79.
- Gladys S, Van Meerbeek B, Inokoshi S, Willems G, Braem M, Lambrechts P, *et al.* (1995). Clinical and semiquantitative marginal analysis of four tooth-colored inlay systems at 3 years. *J Dent* 23:329-338.
- Hayashi M, Tsuchitani Y, Miura M, Takeshige F, Ebisu S (1998). 6-year clinical evaluation of fired ceramic inlays. *Oper Dent* 23:318-326.
- Hayashi M, Wilson NH, Yeung CA, Worthington HV (2003). Systematic review of ceramic inlays. *Clin Oral Investig* 7:8-19.
- Hayashi M, Tsubakimoto Y, Takeshige F, Ebisu S (2004). Quantitative measurement of marginal disintegration of ceramic inlays. *Oper Dent* 29:3-8.
- Heymann HO, Bayne SC, Sturdevant JR, Wilder AD Jr, Roberson TM (1996). The clinical performance of CAD-CAM-generated ceramic inlays: a four-year study. *J Am Dent Assoc* 127:1171-1181.
- Isenberg BP, Essig ME, Leinfelder KF (1992). Three-year clinical evaluation of CAD/CAM restorations. *J Esthet Dent* 4:173-176.
- Kawai K, Isenberg BP, Leinfelder KF (1994). Effect of gap dimension on composite resin cement wear. *Quintessence Int* 25:53-58.
- Krämer N, Frankenberger R (2000). Leucite-reinforced glass ceramic inlays after six years: wear of luting composites. *Oper Dent* 25:466-472.
- Krämer N, Frankenberger R (2005). Clinical performance of bonded leucite-reinforced glass ceramic inlays and onlays after eight years. *Dent Mater* 21:262-271.
- Krejci I, Lutz F, Reimer M, Heinzmann JL (1993). Wear of ceramic inlays, their enamel antagonists and luting cements. *J Prosthet Dent* 69:425-430.
- Krejci I, Lutz F, Reimer M (1994a). Wear of CAD/CAM ceramic inlays: restorations, opposing cusps, and luting cements. *Quintessence Int* 25:199-207.
- Krejci I, Reich T, Bucher W, Lutz F (1994b). [A new method for 3-dimensional wear measurement.] *Schweiz Monatsschr Zahnmed* 104:160-169 [article in German].
- Kunzelmann K-H (1996). Wear analysis and quantification of restorative materials *in vitro* and *in vivo* (PhD thesis). Munich, Germany: University of Munich.
- Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G (1989). Quantitative *in vivo* wear of human enamel. *J Dent Res* 68:1752-1754.
- Mehl A, Gloger W, Kunzelmann KH, Hickel R (1997). A new optical 3-D device for the detection of wear. *J Dent Res* 76:1799-1807.
- Molin MK, Karlsson SL (2000). A randomized 5-year clinical evaluation of 3 ceramic inlay systems. *Int J Prosthodont* 13:194-200.
- Oh WS, DeLong R, Anusavice KJ (2002). Factors affecting enamel and ceramic wear: a literature review. *J Prosthet Dent* 87:451-459.
- Qualtrough AJ, Wilson NHF (1996). A 3-year clinical evaluation of a porcelain inlay system. *J Dent* 24:317-323.
- Ramp MH, Suzuki S, Cox CF, Lacefield WR, Koth DL (1997). Evaluation of wear: enamel opposing three ceramic materials and a gold alloy. *J Prosthet Dent* 77:523-530.
- Ratledge DK, Smith BG, Wilson RF (1994). The effect of restorative materials on the wear of human enamel. *J Prosthet Dent* 72:194-203.
- Sjögren G, Molin M, van Dijken JW (2004). A 10-year prospective evaluation of CAD/CAM-manufactured (Cerec) ceramic inlays cemented with a chemically cured or dual-cured resin composite. *Int J Prosthodont* 17:241-246.
- Yip KH, Smales RJ, Kaidonis JA (2004). Differential wear of teeth and restorative materials: clinical implications. *Int J Prosthodont* 17:350-356.