Antagonist Enamel Wears More Than Ceramic Inlays

INTRODUCTION
The clinical performance of ceramic inlays has been well-documented (Quailtrough 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 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 paralleometer (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 μm, 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 scan were matched with the use of locally developed software (Match 3D, University of Munich, Germany). Finally, the datasets of the initial die scan were matched with the use of locally developed software (Match 3D, University of Munich, Germany).
and the follow-up dies were matched, and a dataset was generated by superpositioning and translation:

Baseline dataset: \( \{ r_n^f \} \), \( r_n^f = r_n^b(x_n^f, y_n^f), n = 1, ... , N \)

Follow-up dataset: \( \{ r_n^f \} \), \( r_n^f = r_n^b(x_n^f, y_n^f), n = 1, ... , N \)

\( r_n^f = (x_n^f, y_n^f, z_n^f) \) is a point on the surface of the baseline image, while \( r_n^f = (x_n^f, y_n^f, z_n^f) \) is the corresponding point on the follow-up image.

The two datasets can be superimposed with three rotations (\( \alpha, \beta, \gamma \)) and three translations (\( t_x, t_y, t_z \)). \( R = R(\alpha, \beta, \gamma) \cdot r + r' \) (\( R = 3 \times 3 \) rotation matrix of the three angles \( \alpha, \beta, \gamma \)).

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, Perthen, Göttingen, Germany) with a resolution of \( x/y/z = 25/25/0.5 \, \mu m \). 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).

RESULTS

Mean wear of the analyzed ceramic inlays was 78 \( \mu m \) after 4 yrs, 110 \( \mu m \) after 6 yrs, and 116 \( \mu m \) 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 \( \mu m \) after 4 yrs to 238 \( \mu m \) 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 wear 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; \( p > 0.05 \)).
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 μm. X/y-resolutions from 10 x 10 μm to 25 x 25 μm 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 ± 10% (Kunzelmann, 1996; Krämer and Frankenberger, 2000). The 3-D scanner was reported to have an accuracy of ± 2 μm (Krämer and Frankenberger, 2000). 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 ± 3.2 μm, 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 μm vs. 34 μm in our study). Fifteen inlays in bicuspids 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 μm 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 Quatrough, 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


