Enamel wear caused by monolithic zirconia crowns after 6 months of clinical use

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SUMMARY The purpose of this study was to evaluate enamel wear caused by monolithic zirconia crowns and to compare this with enamel wear caused by contralateral natural antagonists. Twenty monolithic zirconia crowns were placed in 20 patients requiring full molar crowns. For measurement of wear, impressions of both jaws were made at baseline after crown cementation and at 6-month follow-up. Mean and maximum wear of the occlusal contact areas of the crowns, of their natural antagonists and of the two contralateral natural antagonists were measured by the use of plaster replicas and 3D laser scanning methods. Wear differences were investigated by the use of two-sided paired Student’s t-tests and by linear regression analysis. Mean vertical loss (maximum vertical loss in parentheses) was 10 (43) μm for the zirconia crowns, 33 (112) μm for the opposing enamel, 10 (58) μm for the contralateral teeth and 10 (46) μm for the contralateral antagonists. Both mean and maximum enamel wear were significantly different between the antagonists of the zirconia crowns and the contralateral antagonists. Gender and activity of the masseter muscle at night (bruxism) were identified as possible confounders which significantly affected wear. Under clinical conditions, monolithic zirconia crowns seem to be associated with more wear of opposed enamel than are natural teeth. With regard to wear behaviour, clinical application of monolithic zirconia crowns is justifiable because the amount of antagonistic enamel wear after 6 months is comparable with, or even lower than, that caused by other ceramic materials in previous studies.

KEYWORDS: crowns, restoration occlusal wear, tooth wear, wear, zirconia, zirconium oxide

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Introduction

All-ceramic restorations have become increasingly popular in recent years, mainly because of their excellent biocompatibility and aesthetics (1). Today many different all-ceramic systems are available. They differ in their microstructure (predominantly glassy ceramics, particle-filled glasses, polycrystalline ceramics), manufacturing technique and clinical application (1, 2). The availability of computer-aided design and manufacture has enabled the construction of well-fitting frameworks for crowns and fixed partial dentures from high-strength polycrystalline ceramics, for example transformation-toughened zirconium dioxide (zirconia) (1–3).

The scientific literature shows that zirconia has proved to be a suitable substructure ceramic with a wide range of indications, among others, for large fixed partial dentures in stress-bearing regions (1–9). Clinical studies have indicated that zirconia-based fixed partial dentures may be regarded as viable restorations in the anterior and posterior dentition with excellent clinical short-term survival (5, 6, 8, 9). The opaque white colour of zirconia must be
veneered with glassy ceramic, however, and fracture or chipping of the ceramic veneer has been reported to be a major complication (2, 9–13).

Several proposals for overcoming the chipping problem have been published (14–16), and as a result of advances in CAD/CAM technology and the techniques used for zirconia materials, CAD/CAM fabricated non-veneered, monolithic zirconia restorations have become increasingly popular. One basic requirement for monolithic restorations was the introduction of zirconia with increased translucency; this was achieved by modifications of the fabrication process and the sintering procedures (17). Furthermore, to achieve acceptable aesthetics, pre-stained zirconia and shading liquids which match the natural tooth colour are available.

It is unclear how the mechanical properties and autocatalytic surface transformation (low-temperature degradation) of zirconia are affected by these modifications. One in vitro study revealed that monolithic, full-contour zirconia crowns have higher fracture toughness than veneered zirconia-based crowns (18). The first encouraging clinical reports of monolithic zirconia crowns are now available (19).

A question of special interest is the wear behaviour of monolithic zirconia restorations, in particular, wear of the enamel of natural antagonists opposed to the extremely hard zirconia material. Several in vitro studies have addressed this topic by the use of different wear simulation devices. The results of these studies indicate that zirconia has high wear resistance and, compared with other dental ceramics, causes similar or less wear of different antagonist materials (human enamel, steatite, synthetic hydroxyapatite, stainless steel) (18, 20–27). Results relating to techniques for finishing and polishing the zirconia surface are controversial. One study reported lower wear of the antagonist material with glazed zirconia (18), whereas other studies showed that well-polished surfaces without glaze can reduce wear of opposing materials (21, 24–26).

In vitro wear studies have shortcomings, however. For example, they evaluate wear behaviour by simulation of only one or two wear mechanisms under limited chewing simulation conditions. All wear methods lack evidence of clinical relevance (28). There is, therefore, a need to assess the clinical wear behaviour of zirconium dioxide restorations.

The objectives of this clinical study were:
1 to quantify enamel wear caused by antagonistic monolithic zirconia crowns and
2 to quantify the wear of the zirconia crowns by opposing natural dentition.

Two contralateral, not crowned, antagonists with occlusal enamel contacts served as controls. The null hypothesis was that monolithic zirconia crowns and natural teeth cause comparable wear of opposing enamel under clinical conditions.

Methods

Participants

The Ethics Committee of the University Hospital, Heidelberg, independently reviewed and approved the study (ethical approval: local university review board, no. 222/2010). Written consent was a precondition for participation. Thirty-three patients requiring full crowns on molars were screened, and 20 were included in the study. To meet the inclusion criteria, the patients needed a natural (not crowned) opposing antagonist and two natural (not crowned) contralateral antagonistic teeth. Teeth with fillings were allowed if at least one occlusal contact point was enamel. Subjects with clinical signs of bruxism (attrition score >2 according to Wigdorowicz-Makowera et al. (29), muscle pain), subjects who reported grinding and/or clenching and subjects who reported other medical or mental disorders and/or sleep disorders were excluded (30, 31). Subjects meeting the inclusion criteria were examined in a second step by the use of a disposable electromyographic device (BiteStrip, up2dent). Severe muscle activity at night (more than 100 episodes within 5 h) was observed for nine subjects who were therefore excluded from the clinical trial. Four other subjects had to be excluded because thorough examination revealed missing enamel occlusal contact points of contralateral antagonists. The age of the 20 participants ranged from 21 to 73 years (mean age 43, s.d. 14); 10 participants (50%) were male.

Clinical procedures and fabrication of the crowns

All clinical and technical procedures were performed in strict agreement with a clinical and technical instruction protocol. Before crown preparation, lost
tooth structure was replaced by core build-up with adhesively retained composite resin (Rebilda SC*). Teeth were prepared by the removal of 0.5–0.7 mm (circular) and 1.0–1.2 mm (occlusal) with a pronounced circumferential chamfer at the preparation margin. Our objective was to achieve a 4° convergence angle of the tooth preparation. Conventional impressions were obtained in polyether, by the use of a one-step, dual-viscosity technique (Impregum Penta Soft and Impregum Garant L Duosoft†), and sent to the participating laboratory where working casts of type IV gypsum (Sherahardrock‡) were subsequently made.

The crowns were made of translucent, pre-shaded, yttrium-stabilised zirconia (Zenostar Zr Translucent§) by the Zenostar method, that is, fabrication of non-veneered, monolithic crowns by the following:

1. 3D scanning of the working casts and working dies (D700 3D scanner¶)
2. Design of the dental restoration by the technician by the use of CAD/CAM software (3shape CAD Design Software§) and
3. Transfer of the digitally adjusted data to a milling machine (Zenotec 4030 M1§) which cuts the zirconia crown to the final form.

As needed, after the milling process, the crowns were thoroughly adapted and the occlusal surfaces were characterised with fine-grit diamond burs before sintering. The crowns were sintered at 1520 °C for 3 h in a high-temperature sinter furnace (Zenotec fire§). Subsequently, the crowns, particularly the occlusal surfaces, were polished with the polishing equipment recommended by the manufacturer (Zenostar Polishing Set§). After polishing, the crowns were cleaned with a steam jet and glazed with a glaze spray (Zenostar Magic Glaze Spray§). They were then stained and characterised by means of shading pastes (Zenostar Color Zr§) to match the natural tooth colour. Firing of the glaze at 850 °C for 2 min (Vitamat 2500**) completed the manufacturing process.

During the intra-oral try-ins, perfect fit, occlusion and aesthetics of the crowns were checked. Unavoidable occlusal adjustments were performed with fine-grit diamond burs; the surfaces were subsequently polished thoroughly with a set of diamond-impregnated polishers (Zenostar Polishing Set§). The crowns were luted non-adhesively to the abutment teeth by the use of glass-ionomer cement (Ketac Cem Aplicap†).

Follow-ups and wear evaluations
To evaluate wear, impressions were made at baseline (1–2 weeks after insertion) and after 6 months (24 ± 2 weeks after insertion). Two impressions (one each of the maxilla and the mandible) were taken with a vinylpolysiloxane impression material (Virtual putty and Virtual light††), by the use of the dual-viscosity technique. Replicas were made of type IV dental stone (GC Fujirock EP Pearl White‡‡; GC Europe N.V., Leuven, Belgium). The occlusal contact points of the zirconia crowns, of their antagonists, and of the two contralateral antagonistic teeth (control teeth) were intra-orally marked with 12-μm Hanel occlusion foil§§. The clinical status, particularly the marked occlusal contact points were photographed to determine the occlusal contact areas (OCA) for wear measurement and the reference areas for occlusal matching.

Occlusal wear was measured with a 3D laser scanner, by the method described by Mehl et al. (32). First, the occlusal surfaces of the replicas were digitised by the use of a three-dimensional optical profilometer (Laserscan 3D¶¶). The data sets obtained in this way were then checked for surface changes or wear by the use of surface analysis software (MATCH 3D, version 1.6¶¶). The extent of wear was calculated by superimposing the baseline data on those from the follow-up (occlusal matching). A matching method without reference points, as described by Mehl et al., (32) was used; this enables determination of surface changes with accuracy of 10 μm. To prevent surface changes as a result of wear or artefacts in the replicas (voids in the stone, etc.) from impairing the superim-

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position process, a threshold value of \(-30 \, \mu m\) was defined. This means that all areas of the recall replica which differed from the baseline replica by more than \(30 \, \mu m\) in the negative direction were not included in the matching process. Matching was accepted when the standard deviations between the image points of the two occlusal surfaces were \(<20 \, \mu m\). The results of this matching process were differential images showing surface changes (wear zones) in red, in a false-colour representation. These differential images enabled measurement of the wear both of the entire occlusal surface and of individual, interactively selectable areas (e.g. the OCA). For each zirconia crown and for the antagonists and contralateral control teeth, the mean vertical loss and maximum vertical loss of the OCA were evaluated by the use of the photographs with marked contact points. Figures 1 and 2 show examples of a zirconia crown and a natural antagonist tooth at initial placement and 6 months later, with their corresponding differential images.

**Statistical evaluation**

**SPPS for Windows, release 13*** was used for descriptive analysis of wear values. Further statistical analysis was performed with **SAS** version 9.2†††. Wear differences between zirconia crown antagonists and contralateral control teeth were investigated by the use of two-sided paired Student’s \(t\)-tests. To evaluate the effects of gender, age and muscle activity at night on the extent of wear, a linear regression model was fitted. The response variable was ‘wear difference between the antagonist of the zirconia crown and the contralateral antagonist’. The assumed type 1 error was fixed at 0.05.

**Results**

Because of three dropouts, results were obtained from 17 participants only. Reasons for dropout were renewal of fillings in the antagonistic tooth and/or control tooth for two patients and unmatchable casts for the other patient. After 6 months, mean vertical loss of OCA (standard deviations in parentheses) was 10 (5) \(\mu m\) for the zirconia crowns, 33 (32) \(\mu m\) for the opposing enamel, 10 (6) \(\mu m\) for the contralateral control teeth and 10 (7) \(\mu m\) for the antagonists of the contralateral control teeth (Fig. 3). The amount of maximum vertical loss was 43 (14) \(\mu m\) for the zirconia crowns, 112 (70) \(\mu m\) for the opposing enamel, 58 (35) \(\mu m\) for the contralateral control teeth and 46 (28) \(\mu m\) for the antagonists of the contralateral control teeth (Fig. 4). Both mean and maximum wear were significantly different between the antagonists of the zirconia crowns and the antagonists of the contralateral control teeth (mean wear: \(P = 0.02\), maximum wear: \(P = 0.004\); Table 1). The linear regression model revealed that

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†††SAS Institute, Cary, NC, USA.

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gender and activity of the masseter muscle at night significantly affected the differences between wear of antagonists of zirconia crowns and antagonists of contralateral control teeth. Wear differences were larger for females than for males ($P = 0.009$ for mean wear and $P = 0.03$ for maximum wear), whereas wear differences were smaller for participants with high muscle activity at night (mean wear: $P = 0.02$, maximum wear: $P = 0.02$; (Table 1).

**Discussion**

For veneered zirconia restorations, chipping is the major technical complication and even improvement of the veneering technique [e.g. modification of the firing procedure (15), CAD/CAM manufacture of the veneer (16), etc.] cannot guarantee success of the veneer. Thus, elimination of the veneer seems to be essential, because of the high incidence of technical complications for veneered zirconia restorations as a result of adhesive and/or cohesive failure of the veneer. In addition to these technical complications, however, wear of the restoration and its antagonistic teeth can limit clinical use of a dental material. Although wear of all types of dental material has been assessed in numerous *in vitro* studies (18, 20–27), the dental literature contains few reports on enamel wear *in vivo* (33, 34).
Furthermore, behaviour of different ceramic materials (e.g. feldspathic ceramic) has been assessed in very few clinical studies (35, 36). As far as the authors are aware, this clinical study is the first to assess antagonistic tooth wear of monolithic zirconia restorations.

This study showed that wear of enamel by opposing monolithic zirconia crowns is significantly higher than wear of enamel by antagonistic teeth. The working hypothesis must therefore be rejected. Mean antagonistic enamel wear caused by zirconia after 6 months was 33 μm (s.d. 32) with wide interindividual variation (between 8 and 142 μm). The maximum vertical loss of the antagonists (corresponding to the 1% quantile in MATCH 3D software) was 112 μm (s.d. 70), ranging between 49 and 222 μm. This large effect of the individual subject on the amount of wear, which leads to much variability of the results and reduced power of the statistical analysis, has been encountered in many previous studies of clinical wear, for example Heintze et al. (37). Enamel cracks on the surface of the antagonists, as observed by Stawarczyk et al. (27) in their laboratory trial, were not noticed, either during clinical inspection with a magnifying glass or by analysis of the photographs and replicas.

When these results are compared with the findings of other clinical studies (35, 36), it becomes obvious that the measured mean enamel wear caused by zirconia is equal to or less than that for other ceramics. Etman et al. (35) observed mean antagonistic wear at the occlusal contact points after 6 months ranging between 76 μm for veneered metal crowns and 131 μm for Procera Allceram crowns. These values are two to four times higher than those in our study. Esquivel-Upshaw et al. (36) reported mean enamel wear by different ceramics (d.SIGN glass-veneer, IPS Eris veneer, e.max Press core) after 1 year of approximately 60 μm. This value might be expected for tooth wear after 1 year in our study also.

As reported after several studies (18, 21, 22, 24–27), surface treatment of monolithic zirconia restorations has a significant effect on antagonistic tooth wear. Polished zirconia has been identified as causing the least antagonistic tooth wear, whereas glazed zirconia caused greater antagonistic wear, with the exception of one study which used stainless steel balls as antagonists (18). In our study, which was initiated in 2010, all zirconia crowns were polished and glazed during fabrication and assiduously polished with appropriate polishers after occlusal adjustment during try-ins. If polishing is omitted after adjusting the OCA during try-in of the restoration, wear can be expected to be significantly higher for this kind of restoration (21). This finding emphasises the need for precise polishing of the surface of the restoration after occlusal adjustment.

Wear of a contralateral natural tooth pair was also assessed in this study. The results showed that enamel wear by enamel of the antagonistic contralateral teeth was significantly less than wear of the teeth which were opposed to zirconia (means: 10 μm versus 33 μm, maximum: 46 μm versus 112 μm). This finding is not in accord with the results of Esquivel-Upshaw...


et al. (36); in their clinical study with different ceramics, they accepted the hypothesis that equivalent wear occurs between ceramic–enamel and enamel–enamel tooth pairs. This statement, however, is not based on the fact that the authors found lower enamel wear by ceramic, as in this study, rather that they measured greater enamel wear by enamel of the two contralateral antagonistic teeth (40–80 μm after 1 year). The enamel wear by enamel in our study is within the range of results presented in the previous studies (33, 34). In one study, mean enamel wear by enamel was calculated to be 29–38 μm per year for natural molars and 15–18 μm for natural premolars (33). According to another publication, mean wear of the occlusal surfaces of premolars and molars after 2 years was approximately 15–16 μm (34).

When comparing results from different studies of tooth wear, the methods used to determine wear must be taken into consideration. Results are, frequently, not directly comparable because the methods were not standardised. For example, the complete occlusal area [e.g. Esquivel-Upshaw et al. (36)] or occlusal contacts only [e.g. Etman et al. (35)] can be used to assess wear. Aggravating this situation, several analytical methods have been used for determination of clinical wear. Furthermore, our own yet unpublished results have shown that even measurements by the use of optical 3D laser scanning, currently regarded as the preferred method for clinical wear analysis, are indicative of moderate correlations in different study centres and cannot be directly compared or combined.

The mean occlusal wear of the zirconia crowns in this clinical trial was 10 μm (s.d. 5 μm) and was clearly less variable (range between 1 and 19 μm) than the enamel wear of the antagonists. Other clinical wear studies on zirconia with which this result could be compared are not yet available. However, several in vitro wear studies with zirconia have been conducted (18, 20–27). Some found no measurable wear of zirconia by steatite and/or enamel antagonists, which is not compatible with our clinical results for zirconia wear (22–24). This may be another indication that laboratory simulations (of wear and other material properties) often do not very closely match clinical conditions and most do not reflect clinical wear (28, 38, 39).

Another issue that should be kept in mind is the low-temperature degradation of zirconia. Yttrium-stabilised zirconia had lower flexural strength after ageing than before, whereas alumina-toughened zirconia was less sensitive to ageing (40). Alumina-toughened zirconia might therefore be useful for production of monolithic restorations to be placed in the hydrothermal environment of the oral cavity.

A strength of this study was the use of contralateral natural antagonists as control teeth, which may facilitate determination of the usually strong patient effect in clinical wear studies. Furthermore, an attempt was made to include a rather homogenous group of participants by excluding subjects with clinical signs of bruxism and severe muscle activity at night. Nevertheless, a distinct patient effect on the variability of wear was observed in the present study, which may be caused by diet, favourite chewing side, oral habits, etc.

The BiteStrip device used measures the electromyographic activity of the masseter muscle and its use has been reported to be a useful means of screening for bruxism (41, 42). The method for wear measurements with an objective non-contact, optical scanning device was characterised by good reproducibility and accuracy and is a current standard for analysis of clinical wear (43, 44).

Weaknesses of the study were the small sample size and the short observation time. Furthermore, it should be taken into account that some wear values were within the range of measurement accuracy of 10 μm according to Mehl et al. (32). In addition, it should be mentioned that the detail reproduction of vinylpolysiloxane and dental stone type IV generally do not exhibit accuracy in the region of 10 μm; it is less precise under clinical conditions (45, 46). For the above-mentioned reasons, the measured absolute wear values must be interpreted with caution, and the focus should be the comparisons of the differences in wear. The effects of ageing of zirconia (low-temperature degradation), especially, and their consequences on wear behaviour, are not well known. Further clinical evaluation of the wear of zirconia restorations over a longer time period must be conducted before a valid assessment can be made.

Conclusions

Monolithic zirconia crowns are associated with greater wear of opposed enamel than are natural teeth. Nevertheless, clinical use of monolithic zirconia crowns seems justifiable, because the amount of antagonistic
enamel wear after 6 months was comparable with, or even lower than, that caused by other ceramic materials in the previous studies.

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Conflict of interest

No conflict of interests declared.

References

26. Sabrah AH, Cook NB, Luangruangrong P, Hara AT, Bottino MC. Full-contour Y-TZP ceramic surface roughness effect on


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