CAD/CAM applications for implant-supported prosthesis

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Abstract

Introduction: The integration of CAD/CAM technology with high-strength ceramics enables the creation of all-ceramic restorations, even in posterior regions. These restorations are typically composed entirely of ceramic material. Alternatively, a high-strength ceramic substructure can be utilized, necessitating ceramic veneering and glazing. CAD/CAM milling techniques, along with the advent of new zirconia ceramics, facilitate the production of full-zirconia restorations featuring occlusal design, without the need for veneering.

Aim of the Study: The aim of the study is to assess the abrasion of zirconia restorations in comparison to ceramic ones, and also to evaluate the abrasion of the opposing teeth to these restorations.

Material and Methods: The specimens, totaling 16 in number with a diameter of 5mm and a thickness of 2mm, were crafted from various ceramic materials. The zirconia specimen underwent glazing immediately after polishing. Ceramic veneers were chosen to be applied onto the zirconia substructures. Human enamel and Vita Omega 900 ceramic, typically utilized in metal-ceramic restorations, served as reference materials. The ceramic veneers were glazed using the appropriate glazing material. The specimens were then smoothed using abrasive paper while being cooled with cold water. Surface roughness was assessed before conducting the abrasion tests using a profilometer. Standard abrasion simulation was achieved using steatite spheres as antagonists.

Results and Discussions: Zirconia demonstrates greater resistance to abrasion compared to ceramic materials. Interestingly, in the subsequent analysis, the hypothesis suggesting that the reduced abrasion observed for zirconia would coincide with increased abrasion of antagonists was disproved. Although enamel antagonists were not quantitatively assessed, comparison of SEM micrographs revealed similar wear patterns for both steatite and enamel. The materials tested represent typical zirconia ceramics commonly employed in the fabrication of all-ceramic substructures.

Conclusions: The abrasion tests conducted with steatite or enamel antagonists did not reveal any noticeable abrasion on the surface of zirconium oxide. Ceramic exhibited comparable or even lower rates of abrasion compared to enamel. The abrasion experienced by antagonists against zirconia was found to be similar or even lower when compared to the results observed with ceramic.

Keywords: CAD/CAM tehnology, high-strengh ceramic, ceramic veneer, zirconia ceramics, enamel

INTRODUCTION

The combined CAD/CAM technology with high-strength ceramics allows for the fabrication of all-ceramic restorations, even in posterior areas. All-ceramic restorations are typically entirely made of ceramic. Alternatively, a high-strength ceramic substructure can be used, requiring ceramic veneering and glazing. CAD/CAM milling methods and the introduction of new zirconia ceramics allow for the fabrication of full-zirconia restorations with an occlusal design, but without veneering. These zirconia-based restorations have good aesthetic outcomes even without veneering. Partial zirconia substructures exhibit higher hardness, increased fracture resistance, and structural accuracy with less variation in strength compared to ceramic. Because the properties of ceramic substructures differ significantly from ceramic veneering, a different abrasion behavior is expected. Specific mechanical properties, such as hardness, friction resistance, and fracture resistance, should greatly influence abrasion resistance. [1][2][3]

Abrasion is a complex process influenced by enamel thickness and hardness, mastication combined with parafunctional habits and neuromuscular forces, as well as the abrasive influence of food and antagonists. Occlusal antagonistic contact is a significant reason for abrasion and gradual removal of dental material. Abrasion is caused by the grinding of hard ridges, transforming the surface into a flatter one. Different aspects of abrasion include grinding, wear, and corrosion: grinding occurs during chewing, with food being the third element involved, wear is the result of antagonistic contact during chewing, swallowing, and occlusal movements, and corrosion is the result of chemical reactions. [4][5]

Chewing, clenching, and wetting can cause abrasion of ceramic surfaces, which are reasons for the breaking and chipping of dental surfaces, especially ceramic veneers. Dental materials experience similar abrasion to natural tooth enamel. These considerations lead to the conclusion that natural antagonistic teeth should not be affected by materials used in dental restorations. However, antagonist enamel abrasion has been shown to have greater resistance than dental restoration materials. Antagonistic enamel withstands clinical conditions (Fig 1.). [6][7][8]

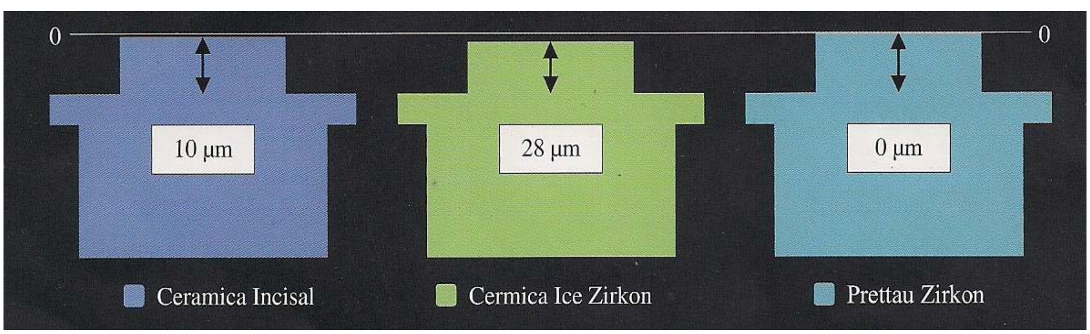

Figure 1. Schematic representation of wear effects on various test specimens after 3.024 million contact cycles on the friction body

However, morphological and structural differences in enamel complicate standard abrasion testing. Previous attempts to standardize enamel cusp resistance through grinding have not reduced the variability of abrasion results compared to non-standardized antagonist enamel. For this reason, only the application of identical morphological forms of antagonists, such as steatite spheres, allows for standardization of antagonist conditions and thus valid quantification of abrasion results. [9][10][11]

While steatite spheres cannot be considered an ideal substitute for human enamel due to mechanical and tribological properties, their suitability as antagonist material for in vitro abrasion resistance studies has been documented. Clinical trials are essential for characterizing the complex situation of oral abrasion. However, these in vivo evaluations are expensive and time-consuming, and certain variables, such as individual chewing forces or ambient conditions, cannot be sufficiently controlled. [12][13]

On the other hand, laboratory tests allow for the investigation of singular parameters of abrasion processes, but the considerable variability even in vitro abrasion simulations must be taken into account. Abrasion tests show only a weak correlation with clinical data but provide an assessment of different materials under standard conditions. The purpose of this in vitro study was to investigate the abrasion resistance of various types of ceramics compared to steatites and human antagonist enamel. The hypothesis of this study was that zirconia has higher abrasion resistance than ceramic and also than antagonist enamel. [14][15]

Aim of the study

The aim of the study is to measure the abrasion of zirconia restorations compared to ceramic ones, as well as the abrasion of the antagonist teeth of these restorations.

MATERIAL AND METHODS

The specimens (totaling 16, diameter of 5mm, thickness of 2mm) were fabricated from various types of ceramics. To secure them during testing, the specimens were placed in the center of a round aluminum tube using a light-cured dental composite. Zirconia materials were represented by either pre-sintered systems or isostatically pressed ones. The Zeno Zr Bridge system for zirconia was used for veneer-free fabrication. The zirconia specimen was glazed, with glazing performed immediately after polishing. Ceramic veneers were selected for application on the zirconia substructures. Human enamel and Vita Omega 900 ceramic, used for metal-ceramic restorations, were used as references. Ceramic veneers were glazed with the corresponding glazing material. The specimens were smoothed with abrasive paper under cold water. Surface roughness was determined before abrasion testing using a profilometer. To simulate standard abrasion, steatite spheres were used as antagonists. A cusp height of 1.5 mm was used for these tests because individual human cusps range from 0.6 mm to 2-4 mm. Human enamel served as a reference antagonist to simulate a typical clinical situation. To prepare the antagonist enamel, human molars were separated into individual cusps. Human cusps and steatite spheres were randomly selected and placed in the center of round aluminum tubes using a light-cured dental composite. Untreated antagonists were mounted in the chewing simulator. During abrasion simulation, the specimens were subjected to 600 thermal cycles in distilled water at temperatures of 5°C and 55°C for 2 minutes each cycle.

Following the abrasion test, vertical substance loss on various ceramic types was determined using a 3D profilometer. A standard abrasion area on steatite antagonists was quantified to evaluate antagonist abrasion. Individual morphological and structural differences in human enamel have complicated standard abrasion testing and may cause large variations in abrasion data. Therefore, we refrained from determining abrasion areas on antagonist enamel. Instead, for qualitative characterization of abrasion patterns, all specimens and antagonists underwent microscopic scanning after abrasion simulation. Damages to antagonist enamel caused by the abrasion test were described. Calculations and statistical analysis were performed using SPSS 17.0 for Windows. Mean and standard deviations were calculated and analyzed using analysis of variance (ANOVA). The significance level was set at $\alpha = 0.05$.

RESULTS

Roughness surface: The Ra roughness surface of zirconia was 0.1 ± 0.1 µm, with only one system showing slightly higher values at 0.2 ± 0.1 µm (Lava). Ceramics ranged from 0.1 ± 0.1 µm (Vita Omega 900) to 0.2 ± 0.1 µm (Lava Ceram, Creation Zi-F, Cercon Ceram Kiss). No significant difference was found between individual materials (p = 1.000). Enamel (0.9 ± 0.2 µm) exhibited significantly higher roughness values than any ceramic test. Steatite spheres showed an average roughness of 1.7 ± 0.2 µm.

Abrasion on zirconia: None of the zirconia tests showed any abrasion after simulation tests with either steatite or enamel. When steatite was used as antagonists, the two glazing systems exhibited a vertical substance loss of 82.0 ± 19.6 µm (polished veneer) and 85.9 ± 18.1 µm (sandblasted veneer). When enamel was used as antagonists, the abrasion values were 62.0 ± 33.4 µm (polished veneer) and 76.2 ± 16.9 µm (sandblasted veneer). No significant differences (p>0.288) were observed between different substructures. SEM images of zirconia specimens after abrasion testing showed a smooth surface. However, differences were noted in glazed specimens. SEM revealed that the glazing was completely flawed, leading to exposure of the zirconia framework, with rough surfaces showing deep abrasion marks found on the glaze interferences in the sliding direction.

Abrasion on ceramics: In abrasion tests with steatite antagonists, the predicted abrasion rates ranged from 186.1 ± 33.2 µm (Vita Omega 900) to 233.9 ± 66.9 µm (Cercon Ceram Kiss), with no significant differences observed (p > 0.05). The enamel reference did not exhibit a significantly different abrasion rate (p > 0.323) but showed a large variation (233.9 ± 66.9 µm). Abrasion tests with enamel antagonists showed less distinct wear patterns, with rates ranging from 90.6 ± 3.5 µm (Lava Ceram) to 123.9 ± 50.7 µm (Creation Zi-F). For enamel specimens, the abrasion rate was 123.3 ± 131.0 µm. Differences between results were not significant (p > 0.188). SEM images of ceramics after abrasion testing showed rough surfaces and wear marks in the sliding direction. Circular defects were found in most ceramic specimens.

Antagonist abrasion: For zirconia, abrasion rates with steatite antagonists ranged from 0.714 ± 0.281 mm2 (Ceramill Zi-T YTZP) to 1.360 ± 0.321 mm2 (Cercon Base). No significant difference (p = 1.000) was found between individual results. Glazed zirconia specimens showed antagonist abrasion of 1.747 ± 0.316 mm2 (polished) and 1.439 ± 0.410 mm2 (sandblasted) but with no significant difference (p = 1.000) for unglazed materials. Antagonist abrasion on ceramics was higher than that on zirconia specimens. Results ranged from 1.708 ± 0.275 mm2 (Lava Ceram) to 2.568 ± 0.827 mm2 (Cercon Ceram Kiss). No Cercon Ceram Kiss ceramic showed any significant difference (p > 0.190) in abrasion rate compared to enamel (1.147 ± 1.203 mm2). Antagonist enamel abrasion areas were not determined because the validity of these wear data would be insufficient due to the individual morphology and different structure of enamel.

After abrasion testing, surface flattening of the antagonists (steatite, enamel) was found for each material. Antagonists opposed by zirconia showed a smooth surface. Glazed zirconia and ceramics caused scratches on the antagonists in the sliding direction. Evaluation of antagonist enamel with SEM revealed chipping, fissures, smoothing, rough surfaces, or scratches on the worn surfaces. Some differences were found between the results of materials in individual material groups.

DISCUSSIONS

The first part of the hypothesis suggests that zirconia exhibits higher abrasion resistance than ceramic materials. Surprisingly, in the second part, the hypothesis that the low abrasion for zirconia coincides with the increased abrasion of antagonists was rejected because the low abrasion for zirconia was correlated with the low abrasion for steatite antagonists. Although enamel antagonists were not quantitatively evaluated, comparison of SEM micrographs showed comparable wear areas for steatite and enamel. The tested materials represent typical zirconia ceramics, which are commonly used for fabricating all-ceramic substructures. A system for zirconia (Zeno Zr Bridge) is available for manufacturing full-zirconia fixed partial dentures without veneering. Three different masses of ceramic are used for veneering zirconia frameworks, while Vita Omega 900 serves as a reference for veneering metal-based frameworks. To simulate a clinical situation, glazed ceramics were investigated, as well as zirconia after polishing or sandblasting. Unglazed materials were used for direct comparison. Before testing, a clinically relevant rough surface was simulated by polishing ceramic surfaces with a standard intraoral grinding set. For the wear test, specimens were polished under standardized conditions to achieve comparable roughness.

Various forces such as sliding, roughness, as well as environmental conditions (e.g., water, food) cause differences in abrasion strength. As a consequence, different abrasion tests to investigate abrasion behavior in various dental materials may yield different results. Most abrasion tests offer only limited correspondence, if any, with clinical data, although they allow for comparative evaluation and classification of different materials under standardized conditions. Therefore, testing under conditions closely resembling the clinical situation is preferable. A masticatory force of 50 N applied at a frequency of approximately 1–1.6 Hz represents the average chewing load and is commonly used for in vitro simulation in the oral cavity. Continuous rinsing with thermal water to remove wear debris from the specimen surface, keeping specimens wet throughout the test, resulted in specimen aging. Clearly, tests for enamel antagonists need to be conducted under clinical conditions. For example, in clinical conditions, enamel exhibits higher abrasion than ceramics. Since the geometric structure of enamel is far from standardized, it can only be used for abrasion evaluation. In this regard, only applying antagonists with identical shape, such as steatite spheres, allows for standardization of antagonist conditions and thus quantification of abrasion results. However, even antagonist abrasion is dependent on testing conditions with ceramic materials.

No zirconia ceramic, regardless of manufacturing type or application, showed signs of wear, neither against steatite nor against enamel. As expected, zirconia was not damaged by steatite or enamel. For glazed zirconia, the glaze was removed, resulting in exposure of the zirconia. Surprisingly, no differences were found between wear rates after different treatments—polishing or sandblasting—although surface sandblasting should have led to additional abrasion. Glaze can fill and smooth the rough surface of zirconia, thus, glaze layers would have been protected by bonding to zirconia. Glazing of zirconia may be necessary for aesthetic aspects. In clinical conditions, glazed layers were found to be worn off after six months, which may require polishing of zirconia surfaces before glazing. Ceramic showed significant abrasion values (compared to steatite) compared to zirconia, but results were lower or equal to reference values for enamel. There were no significant differences in abrasion between individual ceramics, although they were applied for veneering different infrastructures (alloy and zirconia).

As expected, results obtained with non-standardized natural cusps show extremely varied outcomes. These variations stem from the heterogeneity of the antagonists: the hard tissue of human teeth can have varying enamel geometry and thickness and can become brittle. Nonetheless, the results provide an impression of the types of abrasion on ceramic and enamel antagonists. Tests with steatite antagonists allow for quantitative interpretation of abrasion rates because these antagonists are available in standardized sizes and qualities. Although steatite antagonists cannot be considered an ideal substitute for human enamel due to its mechanical and tribological properties, its capacity for in vitro wear testing has been demonstrated. Abrasion rates were higher on steatite antagonists than on enamel. The reasons could be the higher hardness or initial roughness of steatite or the changing contact areas during the wear process: assuming greater wear on enamel—combined with subsequent increased contact area—may lead to lower overall abrasion. SEM did not show significant differences between steatite and enamel, but the images only reflect the situation after the abrasion process. Further tests should be conducted on this subject.

SEM images of the ceramic worn surfaces revealed combined fractures, cracks, smooth, and rough surfaces. SEM images on ceramic samples revealed circular defects, presumed to be cone cracks. These cone cracks are described as defects that occur on the ceramic surface when in direct contact with antagonist contact points. No traces of abrasion could be detected on the zirconia surfaces. Only minor differences in abrasion were found between steatite and enamel.

Contrary to expectations that zirconia produces antagonist abrasion, current results show that zirconia oxide causes less abrasion on steatite antagonists than on ceramic ones. SEM images demonstrated that overall, enamel abrasion and deterioration occurred regardless of whether zirconia or ceramic was the antagonist. Enamel defects include abrasions, cracks, fractures, even chipping. Smooth areas are visible on both enamel and steatite opposed to zirconia. These findings coincide with clinical observations, where ceramic wear is indicated to be lower than enamel wear. This deterioration is influenced by material properties such as hardness, fracture resistance, or composition.

Sliding of antagonists on zirconia caused only flattening of the antagonist surface. These results lead to the assumption that zirconia can be used for the fabrication of fixed partial prostheses without faceting. However, verification of occlusal contact data is essential because abrasion in these cases is limited to the antagonist surface. Nevertheless, other aspects of using zirconia oxide without faceting, as well as how zirconia abrasions ceramic or tooth enamel, need further investigation under clinical conditions.

CONCLUSIONS

Esthetic restoration receives increased attention, and zirconia has also begun to occupy a larger share of restoration materials. Despite the limitations of this in vitro study, zirconia has shown favorable mechanical properties.

The abrasion test results with steatite or enamel antagonists did not indicate measurable abrasion on the surface of zirconium oxide. Ceramic showed comparable or even lower rates of abrasion than enamel. The abrasion of antagonists against zirconia was found to be comparable, or even lower, compared to the results for ceramic.

Utilizing CAD/CAM technology for zirconia can help reduce errors in laboratory procedures such as impression, wax-up, casting, etc. Additionally, the technique for full-zirconia crowns can decrease the turnaround time for restoration or occlusal adjustment. Overall, full-zirconia crowns can save time for both the restoration process and the patient's teeth.

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