Wear of Glass-ceramic-veneered Zirconia Posterior FPDS After 10 Years

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Research article

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Abstract

Background

The abrasion behavior of various ceramics is rarely investigated, though it is relevant for the clinical success of such restorations. The aim of this in vivo study was to evaluate the wear of glass-ceramic-veneered zirconium oxide frameworks over a period of 10 years.

Methods

The abrasive behavior of the restorations was examined in a total of 15 patients after a period of 3, 5, and 10 years using plaster models, which were then subjected to a scanning process on the Atos II industrial scanner and digitized for three-dimensional evaluation of the abrasion by the corresponding software (ATOS Professional 7.6). The individual post-examination models were compared to the baseline model and deviations calculated in the sense of the largest, punctual loss of material in millimeters ("minimal distance"), the average abrasion in millimeters ("mean distance"), and the volume decrease in cubic millimeters ("integrated distance"). Statistical analyses were performed using the Wilcoxon sign rank test or mixed regression models. Multiple testing was considered by Benjamini-Hochberg correction. The significance level was set at 0.05.

Results

We found steadily increasing wear of the ceramic. The average volume decrease was significant ($P < 0.001$) at 3 years and 10 years (-3.25 mm^3 and − 8.11 mm^3, respectively).

Conclusions

Despite the increasing wear of the glass-ceramic-veneered zirconium oxide frameworks in this study, the use of this class of materials can be regarded as clinically acceptable.

This study is registered in DRKS - German Clinical Trials Register

with the Register number 00021743

Background

Loss of hard tooth substance of the human dentition represents a natural wear phenomenon that increases in severity with increasing age [1]. Accordingly, special attention should be paid to the abrasive behavior of a dental material with the aim of finding an optimum between its own resistance to wear and low abrasiveness to the antagonist, and a wear comparable to that of natural teeth, which is a major challenge for current research [2]. Wear is generally considered to be the result of occlusal interactions, and the decision on supposedly suitable dental material has a direct effect on the antagonist. Both the restorative material and the antagonist can be severely abraded. In addition, chewing function may be impaired, resulting in a reduced quality of life and possible deterioration of systemic health [3, 4]. Finally, the susceptibility of the materials to wear could also affect the durability of the corresponding dental prosthesis [5].

Due to permanent improvements in the material properties and high aesthetic demands of patients, all-ceramics has become indispensable in everyday clinical practice as a material for restorations [6]. In light of the growing demand for highly aesthetic restorations, it is the dentist's task to both keep up to date with the latest scientific research and to develop scientific evidence to support the clinical application of materials [7, 8]. Special attention has been paid to zirconium dioxide as a dental material due to its superior mechanical properties, high biocompatibility, and natural appearance [9–11]. Because of its good mechanical strength, zirconium dioxide can be used as a framework material for all-ceramic fixed dentures [12–14]. However, with regard to aesthetic requirements, the manufactured frameworks need a suitable veneering ceramic, which is the weakest link in the entire construction [15–17]. In contrast, more recent developments, as another step in CAD/CAM technology, present monolithic zirconia as a restorative material, which is intended to be used for the fully anatomical reconstruction of dentures without a veneer. Currently, clinical studies and scientific knowledge of the properties, prognosis, and long-term survival of this material are rare [18].

The overarching discipline for studying the phenomenon of wear represents the tribology, which encompasses the entire field of friction, wear, and lubrication, as a science and technology of interacting surfaces [5], and making use of various methods. With the aid of profilometry, the surfaces of dental ceramics can be visualized and the surface roughness due to mechanical action illustrated. This involves a surface scan of the test specimen and the generation of a roughness profile [19, 20]. To visualize and demonstrate structural changes in the ceramic surface, a scanning electron microscope can be used [19], which can reveal even microstructural changes in the individual crystal phases of ceramics [21]. Fractography, which deals with the analysis of fracture surfaces, also benefits from this technique [22]. Lohbauer et al. made use of both optical profilometry as an analytical technique and scanning electron microscopy to determine the degree of wear of antagonistic tooth surfaces in the presence of monolithic zirconium oxide crowns on molars or premolars after a clinical functional period of 2 years. They showed that the monolithic restorations were not affected by antagonistic wear processes during the first 24 months in situ, and that the wear rates of the antagonists were within the acceptable range, regardless of whether they corresponded to natural tooth enamel or to ceramics as a restorative material [23].

Another method is X-ray diffraction, with which the various crystal phases can be investigated and graphically illustrated depending on temperature or mechanical impact [20, 21]. Further perspective on the detailed reproduction of surfaces is provided by light-optical, contact-free precision scanning methods with which, after scanning an object surface, digital and three-dimensional (3D) information can be obtained using special computer software [24–26].

This study presents a method for visualizing abrasion behavior on the basis of three- and four-unit all-ceramic bridges in the posterior region made of glass-ceramic-veneered Lava™ Frame zirconium dioxide frameworks (Lava™ system, 3M) in clinical use for 10 years at the time of investigation.

Methods

As part of the clinical study, which was approved in advance by the ethics committee of the University of Erlangen (Reference number: 2832), the abrasive behavior of all-ceramic zirconium dioxide bridges veneered with glass-ceramic was investigated at Dental Clinic 2 - Department of Dental Prosthetics of Friedrich-Alexander-University Erlangen-Nuremberg, Erlangen, Germany, after an observation period of 10 years using a light-optical scanning procedure with a 3D industrial scanner.

The optical 3D measurements and evaluations were based on conventional silicone impressions (AFFINIS heavy body + AFFINIS light body, Coltène/Whaledent GmbH & Co KG, Altstätten, Switzerland) taken of a total of 15 subjects at the beginning of the study period and after 36, 60, and 120 months, and the subsequent hard gypsum models (Fujijock, Multident Dental, Oldenburg, Germany), which were digitized using a 3D white light scanner (ATOS II) and the corresponding evaluation software (ATOS Professional 7.6) in order to compare the abrasive behavior.

For this purpose, the plaster models were equipped with prefabricated GOM reference points (diameter: 0.8 mm) in preparation for digitization. These reference points served as support points for the scanning software to transform the individual images into a complete 3D model. The clear constellation of the GOM glue points ensured the correct position of the scanned surfaces in the coordinate system and guaranteed the accuracy of this process. Subsequently, STL files were generated from the single measurement data necessary for an optimal representation of an object, resulting in digital representation of the four plaster models made from the impressions obtained during the follow-up examination for each test person.

In the next step, the individual post-examination models (36 months, 60 months, 120 months) were "matched" with the corresponding baseline model as a reference in order to compare the occlusal material loss, which indicated the abrasion of the ceramic over time, to the bridges after 3, 5, and 10 years of wear. A manual 3-point alignment of the models was performed to obtain the initially required rough pre-alignment. The tools used to implement this measure were striking points on both objects, such as prominent features on anterior or canine teeth, which were manually marked as precisely as possible on both the baseline and the corresponding virtual model.

Possible inaccuracies in the plaster were to be avoided during the analysis of abrasion; therefore, the area to be measured, which corresponded to the all-ceramic restoration on the baseline models, was selected over the surface, guaranteeing continuous constancy of the area to be measured with regard to the individual evaluations of the different years. At this point, a distinction must be made between complete selection of the occlusal surface of the bridges in the first test set-up and a separate selection of the individual bridge anchors and pontics (premolars and molars, respectively). In the last step of the "matching" process, the "local best-fit" option was used to achieve the final alignment by optimally aligning the selected sections with each other on the models using the best-fit function enabled by the software. Thus, on the basis of the selected surfaces, possible deviations in the restorations between the baseline model and the reference of the corresponding year could be investigated.

The associated evaluation software (GOM Professional 7.6) calculated the volume difference between the respective models and enabled the presentation of changes in the measuring objects to be compared based on a color gradient located on the occlusal surface of the digitalized model. The false-color image illustrated both a decrease in volume resulting from wear processes (negative deviations marked by blue areas) and an increase in the existing volume (positive differences marked by red areas), which could be explained by potential sources of error within the impressions or the plaster models created from them. A constant volume of both models in terms of relative agreement were marked as green areas.

The values calculated using the ATOS II industrial scanner and the corresponding software for the analysis of the abrasion behavior of the ceramic restorations included the largest punctual material loss in millimeters ("minimum distance"), the average removal of the surface in millimeters ("mean distance"), and the volume reduction of the all-ceramic restoration in cubic millimeters ("integrated distance").

The statistical programming language R V 3.6.3 (R Core Team (2020), R Foundation for Statistical Computing, Vienna, Austria) was used for all statistical analyses. In the first test setup described above, Wilcoxon sign rank tests were conducted. In the second experimental set-up, the pre-molar/molar comparisons were performed using mixed regression models. To account for multiple testing, P values were corrected using the Benjamini-Hochberg method. The level of significance was set to 0.05.

Results

Based on the 3D measurements of the entire occlusal surface of the restorations using industrial scanning technology in the first experimental set-up, the average minimum distance after 3 years was − 0.21 mm and after 120 months was − 0.64 mm. The tabular compilation of the calculated P-values in relation to minimum distance were compared in relation to the period of the follow-up examinations (36, 60, and 120 months), and each of the P-values was significant.

In relation to the minimum distance of the select pontics, after 3 years, -0.132 mm was the largest occlusal loss of ceramic with regard to the premolars, whereas a significantly higher − 0.251 mm was measured for the molars. At the time of the last follow-up examination, -0.278 mm was documented for the premolars and − 0.435 mm for the molars. The results illustrate a different abrasive behavior of the premolar and molar components of dental bridges, with continuously higher values of calculated material loss recorded for the molars.

In addition, the mean distance of the complete occlusal surface of the bridges was determined to be a mean loss of -0.048 mm after 36 months. An ongoing increase in material wear was indicated by the greatest average wear of the ceramic being measured at 120 months, with a significant − 0.131 mm.

For the mean distance for the selection of the individual bridge segments, an average ceramic removal of -0.038 mm was recorded after 36 months for the premolars and − 0.046 mm for the molars. The average abrasion of the restorations after 10 years was − 0.079 mm with regard to the premolars and − 0.117 mm with regard to the molar areas of the bridges, which ultimately showed remarkably greater material wear of the molars at that follow-up.

The integrated distance, as a representative of the average volume decrease, was − 3.25 mm^3 after 36 months. The significant measurement of -8.11 mm^3 after 120 months demonstrated increasing loss of volume over time.

In contrast to selection of the complete occlusal surfaces of the glass-ceramic-veneered all-ceramic bridges, in the second test set-up, each individual bridge pontic was selected separately via the surface. Thus, the integrated distance of the selected individual bridge components was determined in the second test set-up; after 3 years of wear, the average reduction in the volume of the premolars and molars was − 0.539 mm^3 and − 1.269 mm^3, respectively. Starting from the time the restorations were placed, after 120 months an average decrease in volume of -2.282 mm^3 for the premolars, and finally − 3.253 mm^3 for the molars, was recorded. Thus, the wear of the ceramic material, which steadily increased over time, was remarkable.

The results of the numerical evaluation of the abrasive behavior of the restorative material are graphically presented using box-plot diagrams in Figs. 1–3. A color-coded illustrative presentation of the results is shown in Fig. 4.

Discussion

Selection of the correct restorative material is fundamental to ensure both normal function and occlusal harmony [27]. A natural phenomenon is represented by the gradual abrasion in the dentition, and this process can be disturbed by the use of restorative materials to replace natural tooth structure [28]. Ultimately, the non-uniform structures and physical aspects between natural teeth and restorative materials result in different degrees of wear [3]. A number of studies have evaluated the long-term clinical behavior of ceramics [29–31], but studies on the loss of the vertical dimension are limited [32].

For this reason, we carried out the 3D light-optical examination of all-ceramic bridges using the Atos II scanning unit. The abrasive behavior was analyzed on the basis of various parameters using digitized virtual models corresponding to the condition of the dental restorations at the time of insertion and after 3, 5, and 10 years. Notably, both a decrease in volume due to wear processes over time and an increase in volume in some places was noted. This phenomenon could be caused by errors that occurred when taking the impression, such as insufficient adhesion of the impression to the impression tray or the localization of relevant areas outside its boundary [33], which were then carried over to the plaster models. Accordingly, to avoid falsification of the measurement results, the value range within the evaluations was adjusted, and the regions with an erroneous increase in volume were excluded.

Alternatively, instead of a conventional impression, the use of innovative technology, such as an intraoral scanner, can be considered to take a digital impression. Current studies have reported that digital acquisition of intraoral information is at least comparable to the conventional method, and could even be more precise [34, 35]. However, digital impressions also entail technical limitations and system-specific deviations [35, 36].

Overall, an increasing and significant loss of material was characteristic of the all-ceramic bridge constructions throughout the period under investigation. In addition, the results indicate that the premolar and molar bridge pontics did not react congruently to wear processes. In the case of the molars, higher individual values were recorded at each follow-up examination.

This was also observed in another in vivo study from 2008, in which crowns made of lithium disilicate were examined regarding their abrasion behavior by means of laser scanning the corresponding plaster models. After 1 year, the mean reduction in the occlusal volume of the crowns was 0.19 ± 0.06 mm^3 for premolar restorations and 0.34 ± 0.08 mm^3 for molar restorations [37]. The reason for this could be the occlusal surface, which increases in size with the molar region, resulting in a more pronounced chewing force in the distal part of the jaw [38]. In addition, the occlusion has a significant effect on the process of wear [27].

The fact that abrasion in general is a progressive phenomenon [27] has also been confirmed by other studies that have dealt with the wear behavior of teeth and restorative materials. An example of this is the study by Mundhe et al., in which a comparable study design was used to investigate the wear of the natural, antagonistic tooth enamel in response to definitively cemented crowns in the opposing jaw on a ceramic and metal-ceramic basis in order to investigate the effects of a restoration material used in the oral cavity on the natural tooth enamel. The maximum linear wear was determined by means of plaster models obtained from impressions, which were subsequently digitized using a 3D white-light scanner. The results confirmed that significant wear occurred over time, though the investigation period was only 1 year [39]. Furthermore, a current in vivo study by Esquivel-Upshaw et al. used a 3D laser scanner to illustrate occlusal loss of material not only on monolithic zirconium and metal-ceramic crowns, but also on natural teeth. After 1 year, no significant differences were observed in the wear behavior of the different materials and the natural enamel [40]. In addition, a number of in vitro studies have evaluated the wear potential of various materials. For example, Zurek et al. recording the volume loss of zirconium and lithium disilicate ceramics after a chewing simulation using white-light interferometry as a non-contact, optical method of measurement and a scanning electron microscope. A significantly higher loss of material was recorded for the lithium disilicate samples, with a low abrasiveness of zirconium oxide [32]. D'Arcangelo et al. also carried out an in vitro investigation of the wear resistance of various ceramics under masticatory simulation against a test body made of zirconium oxide. The loss of vertical dimension and the volume decrease were recorded with a 3D scanner [41].

Basically, abrasion in the oral cavity usually results from tooth-to-tooth or tooth-to-restoration contact, and this process is generally accelerated by a dental prosthesis. Despite constant technical innovations in the context of current research, no valid in vivo method has been established to objectively assess abrasion behavior [42]. However, the procedure used in this study, the generation of virtual 3D models using the Atos II industrial scanner, proved to be a very practical method for neutrally investigating and displaying the wear behavior of all-ceramic restorations. Thus, our method could be regarded as a unified investigation method to create better comparability within different studies dealing with wear behavior. In addition, the results of the present study confirm that all-ceramic and glass-ceramic-veneered zirconium oxide frameworks for bridge restorations generally have a basic suitability for use as a prosthetic treatment option in the posterior region, as described in similar studies [30, 43].

Notably, the number of subjects undergoing in vivo diagnostics over a longer period of time is currently small [30, 43]. In our study, the abrasive behavior of a total of 15 restorations was evaluated after a study period of 10 years. Long-term reports are required to obtain meaningful information about the clinical performance of a dental material [30].

Conclusions

The results of our study indicate that the rate of volume loss in glass-ceramic-veneered zirconium oxide frameworks increases significantly over time. The largest, punctual loss of material in molars is subject to a stronger decrease after 10 years. In addition, the frequency of the parameters used to examine the abrasion was higher in the last 5 years than in the first 5 years of the study period.

Despite the increasing wear of the glass-ceramic-veneered zirconium oxide frameworks used for bridge construction in the posterior region, as determined in this study, this class of materials has considerable advantages for use in dental restorations.

Declarations

Ethics approval and consent to participate:

This prospective clinical study, which was approved by the ethical committee of the University of Erlangen (Reference number: 2832), was conducted at Dental Clinic 2 - Department of Dental Prosthetics of Friedrich-Alexander-University Erlangen-Nuremberg, Erlangen, Germany.

Participation in the study was voluntary. At the beginning of the study, all subjects received and signed an information form in which each patient gave his or her consent for voluntary participation in the study. In the following investigations, the evaluation was carried out in a recall program within our clinic.

Authors' contributions:

All authors have contributed to the submitted manuscript and co-authored it.

R.E.M, projekt director and the developer of the three-dimensional examination method, wrote part of the manuscript and also helped to interpret the three-dimensional results. He also made constant corrections to the manuscript.

E.L, andC.M, conducted the clinical investigations and participated in the design of the manuscript and the interpretation of the results.

1. S, conducted the documentation of the clinical examination after 10 years. For this purpose he made 45 plaster models. In the next step he edited and scanned them and then carried out the three-dimensional analysis on the computer. In addition, he wrote a part of the materials and methods.

W.A,   is our statistician. He performed all statistical tests and wrote the part of the statistics for the results.

M.W, is the head of the prosthetic department in Erlangen. He supervised the study over the ten years and was present at the first examination appointments. His experience and knowledge in the field of prosthetics and science as well as the constant corrections helped the authors in the design of the manuscript.

1. B, conducted the clinical examinations and contributed significantly to the preparation of the manuscript as well as to the literature research. She compared the results from the current literature with the results obtained in our study.

Interest of conflict:

The authors declare that there was no conflict of interest

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Availability of data and materials:

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Figures

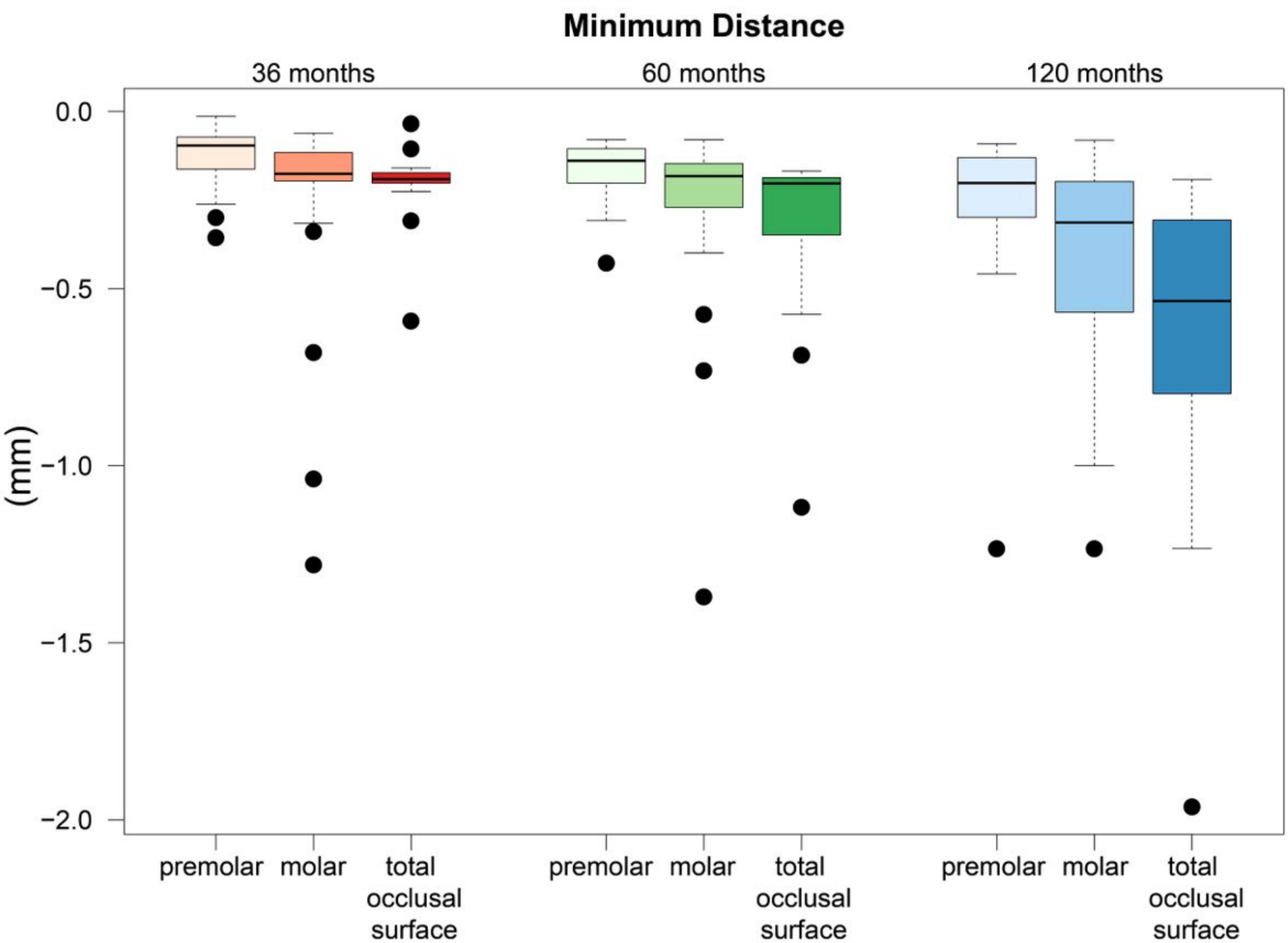

Figure 1

Punctual material loss after 3, 5, and 10 years.

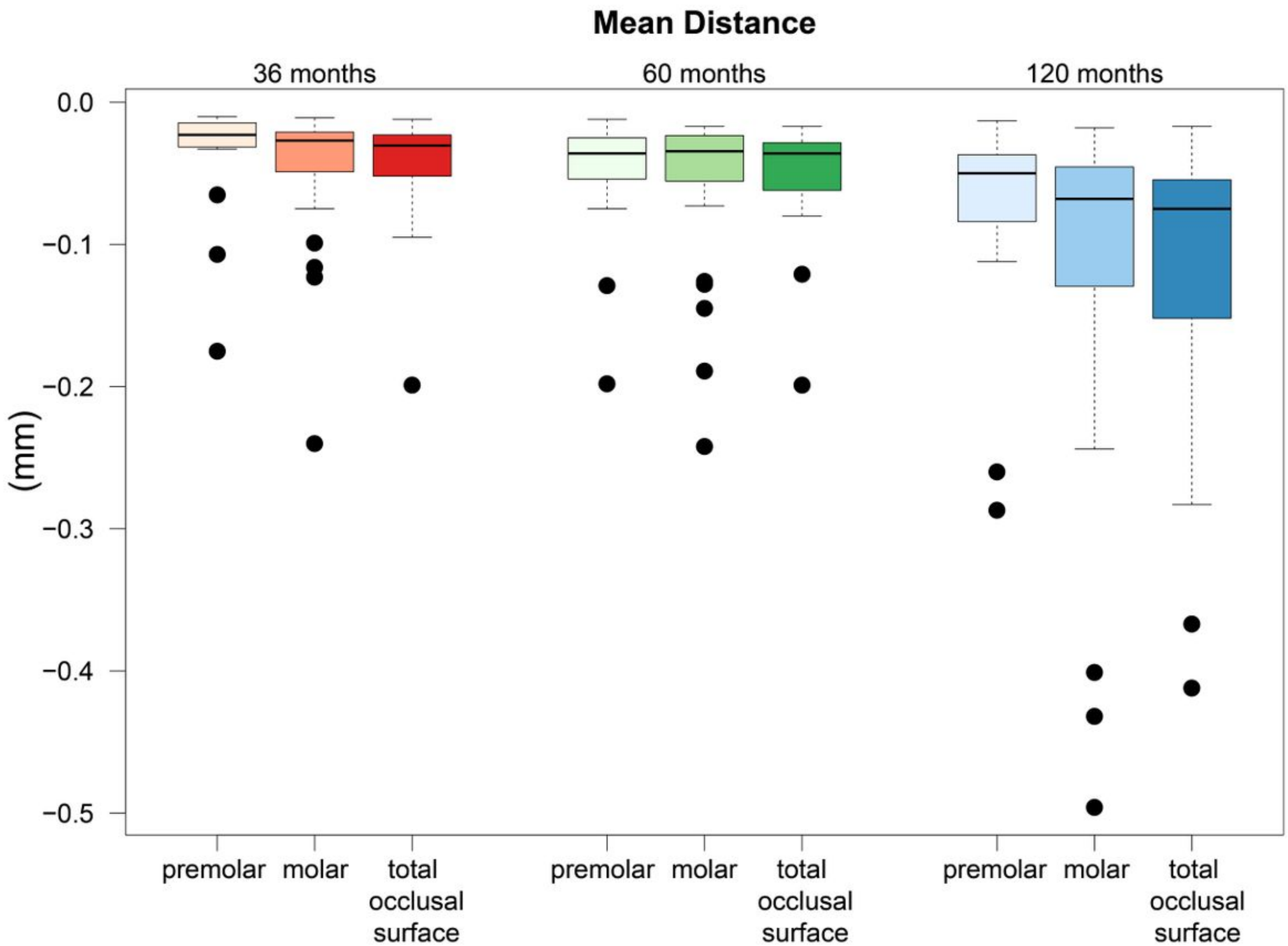

Figure 2

Average removal of the surface to assess the abrasive behavior.

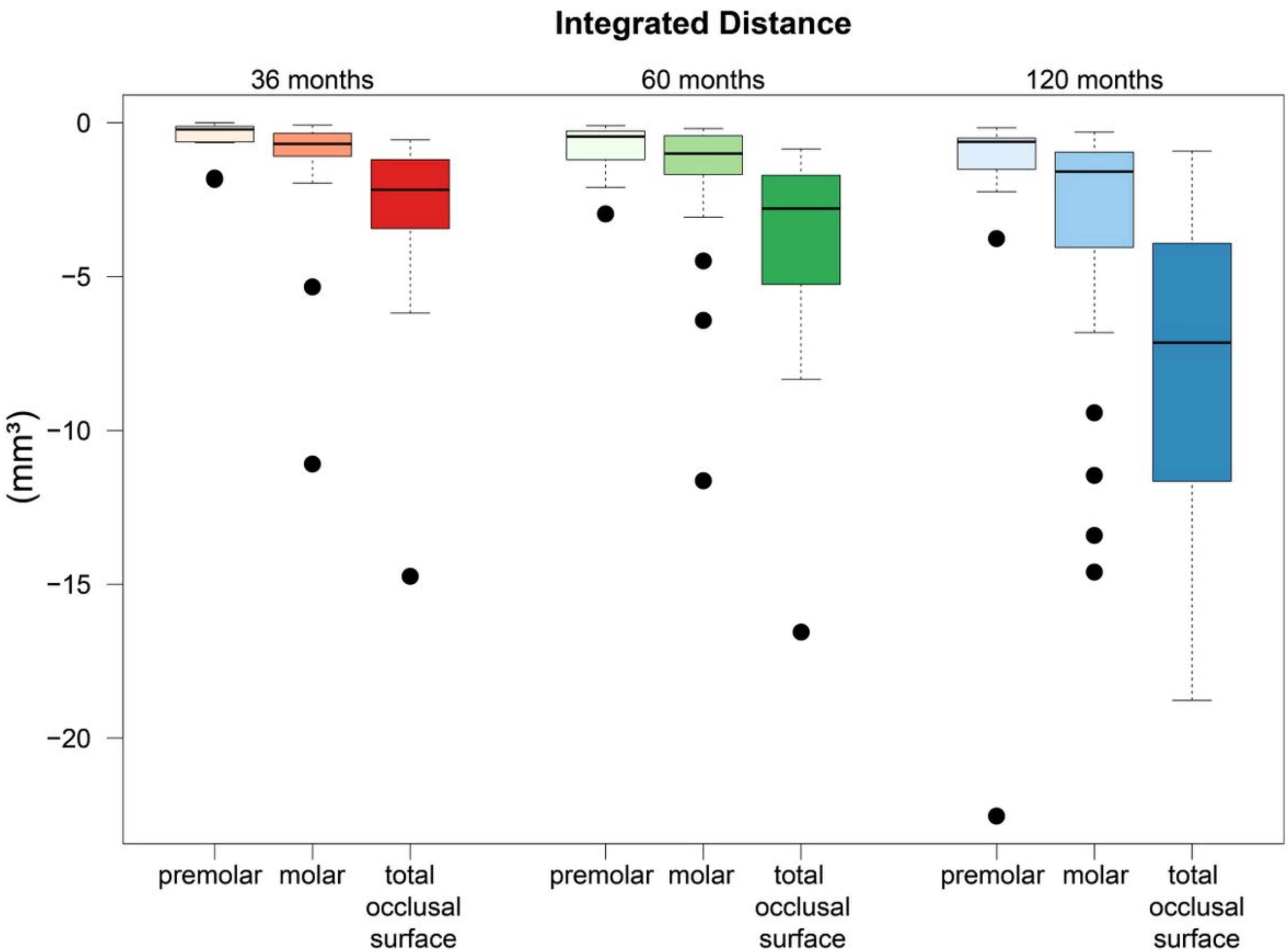

Figure 3

Volume reduction over 10 years.

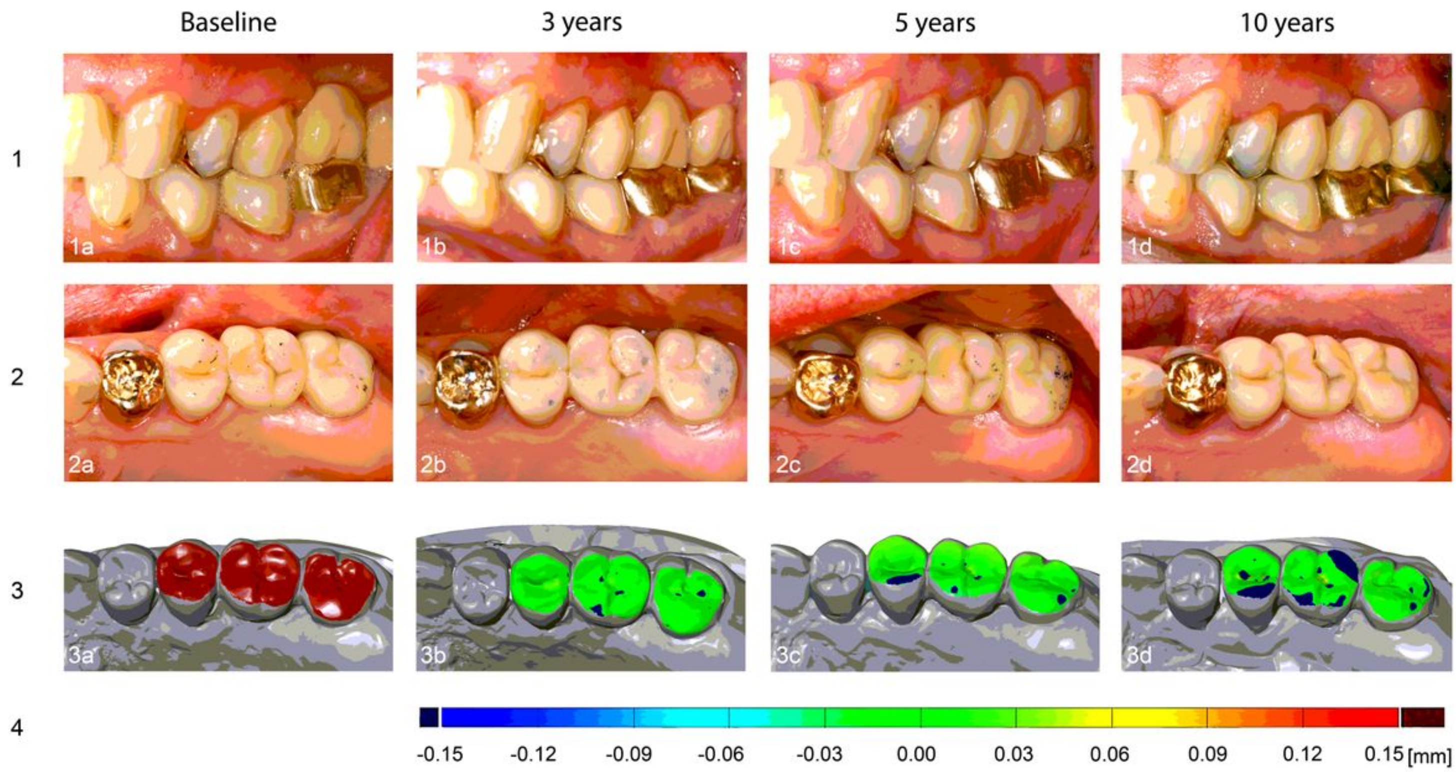

Figure 4

Clinical and virtual 3D representation of the wear of a restoration.Series 1: Vestibular view.Series 2: Occlusal view.Series 3:3D view after digitization of the plaster models.a, selected area; b-d, false color display in which the abrasive areas are marked in blue. Green areas have had no or almost no abrasive process.Series 4: false color scale.