In vitro performance of full-contour zirconia single crowns

Florian Beuer a,*, Michael Stimmelmayr b, Jan-Frederik Gueth a, Daniel Edelhoff a, Michael Naumann c

a Department of Prosthodontics, Munich Dental School, Goethestr. 70, 80336 Munich, Germany
b Josef-Heilingbrunner-Str. 2, 93413 Cham, Germany
c Department of Prosthodontics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany

ARTICLE INFO

Article history:
Received 10 January 2011
Received in revised form 24 October 2011
Accepted 29 November 2011

Keywords:
Zirconia
CAD/CAM
Veneering porcelain
Full-contour
Single crown

ABSTRACT

Objectives. Zirconia based restorations exhibited high failure rates due to veneering-porcelain fractures. Milling to full-contour might be an alternative approach for zirconia restorations. The aim of this study was to evaluate full-contour zirconia crowns in terms of light-transmission, contact wear (restoration and antagonist) and load-bearing capacity. Powder build-up veneered zirconia substructures and CAD/CAM-veneered zirconia substructures served as controls.

Methods. Four different kinds of crowns were fabricated on 12 metal dies: zirconia substructure with powder build-up porcelain (veneering technique), zirconia substructure with CAD/CAM generated veneering (sintering technique), full-contour zirconia glazed (glazed full-contour) and full-contour zirconia polished (polished full-contour). All crowns had the same dimensions. After light-transmission was measured the crowns were cemented on the corresponding metal dies. The specimens were loaded according to a special wear method in the chewing simulator (120,000 mechanical cycles, 5 kg load, 0.7 mm sliding movement, 320 thermocycles). Wear of the restoration and the antagonist were measured. All specimens were loaded until failure. One-way ANOVA and a LSD post-hoc test were used to compare data at a level of 5%.

Results. Polished full-contour showed significantly higher light transmission than the other groups (p = 0.003; ANOVA). Polished full-contour exhibited significantly less contact wear at the restoration (p = 0.01; ANOVA) and higher contact wear at the antagonist (p = 0.016; ANOVA) compared to the other groups. Glazed full-contour zirconia showed similar contact wear at the antagonist compared to veneering technique (p = 0.513, post-hoc LSD). Crowns with conventional veneering showed significantly lower load-bearing capacity (p < 0.001; ANOVA).

Significance. Milling zirconia to full-contour with glazed surface might be an alternative to traditionally veneered restorations.

© 2011 Academy of Dental Materials. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Metal-free, all-ceramic restorations have become more widely distributed due to their high esthetic potential and their excellent biocompatibility [1,2]. Today, many framework structures for prosthetic restorations are fabricated in computer aided design (CAD)/computer aided manufacturing (CAM) procedures, which means that a major part in the working sequence is carried out by industrial machines [3-6]. On the
one hand, frameworks can be fabricated more efficiently. On the other hand, it is possible to achieve industrial quality standards, which are particularly important for ceramic materials. Every pore and imperfection is a potential starting point for cracks and thus for clinical failure of ceramic restorations. The veneering material, however, has been layered according to the well-known fabrication process of the metal-ceramic technique to date. Failure rates between 0 and 25% have been reported for fixed dental prostheses (FDPs) after 3 years of clinical service [7–9]. The typical failure pattern of a veneering material in the daily clinical practice is known as ceramic chipping [5,10,11]. This fracture pattern is associated with a thin layer of glass ceramic that remains on the zirconia framework [1,9,11,12].

From the economical point of view, the esthetic and functional completion of crown and FDP frameworks involving traditional methods, such as the powder layering technique, appears to be inefficient. Applying veneering porcelain by brush in several bakes is time consuming and costly. Sintering a CAD/CAM fabricated veneer cap made from lithium-disilicate to zirconia was reported to offer high mechanical stability in vitro [5]. Another possibility for increasing the cost-effectiveness involves the industrial fabrication of monoblocks and machine the entire restoration by means of CAD/CAM technology [13,14]. These mono-block restorations, however, are fabricated from glass ceramics, which are less stable in comparison to zirconia-based restorations. Therefore, the indication range is clearly limited to single crowns and small FDPs [13–17]. Fabricating mono-block restorations from pure zirconia could increase the mechanical stability and expand the range of indications. However, zirconia is known as a whitish, opaque core material and its wear behavior has not been understood completely [18,19]. Prior to clinical application, full-contour zirconia restorations have to proof their suitability in vitro.

The aim of this study was to evaluate full-contour zirconia single crowns to established veneered zirconia substructures with identical dimensions in terms of esthetics, wear and load-bearing capacity. The working hypothesis is that full-contour zirconia crowns will show superior load-bearing capacity and less light-translucency compared to traditional zirconia-based crowns.

2. Materials and methods

A 1.2 mm, 360° chamfer preparation was made on a mandibular right first molar (Frasaco, Tettnang, Germany) and the occlusal surface was reduced by 1.5 mm. To control volumetric reduction, a silicon impression (Optosil, Heraeus Kulzer, Hanau, Germany) was made prior to tooth preparation and used as a guideline for preparation. Additionally, the provisional crown (Protemp Garant, 3M ESPE, Seefeld, Germany) was used to verify the thickness, thus the circumferential and occlusal reductions could be quantified (Dial Caliper, Kori Seiki, Tokyo, Japan). The preparation was completed with a surveyor (F1, DeguDent) using a carbide bur (Komet H 356 RGE 103.031, Gebr. Brasseler, Lemgo, Germany) to ensure that the preparation had an 8° tapered angle. Twelve specimens were tested in each group (n = 12). Therefore twelve silicone impressions were made (Adisol blau, Siladent Dr. Boehrme und Schoeps GmbH, Goslar, Germany) with a custom impression tray (U3 # 141163 Oribilok, Orbis Dental, Munster, Germany) in order to duplicate the prepared tooth into metal-dies. The impressions were filled with wax (Nawax compact, Yeti Dental Products, Engen, Germany). After cooling the wax patterns were removed and invested (rema dynamic S, Dentaurum, Ispringen, Germany). The wax was burnt out and metal-alloy (Remanium 2000, Dentaurum) was casted into the mold. The metal dies were finished and capped into polymethylmetacrylat-resin (Paladur, Heraeus Kulzer). To ensure the correct preparation angle all 12 master casts were finished with the surveyor using a carbide bur. These 12 master casts functioned as testing models. From each testing model an impression (Impregum, 3M ESPE, Seefeld, Germany) was taken using a plastic impression tray (Inlay, Heko, Berlin, Germany). After 24 h a resin modified die material (Resin Rock, Whipmix, Dortmund, Germany) was poured into the impressions. Each master die was scanned (Everest Scan, KaVo, Biberach, Germany) and two zirconia copings were manufactured by a CAD/CAM-system (Zenio 4820 Premium, I.M.E.S, Eiterfeld, Germany) using pre-sintered zirconia (ZirLuna, ACF, Amberg, Germany). A wall thickness of 0.5 mm and a virtual spacer layer of 10 μm had been chosen. After the milling procedure the enlarged copings were removed from the CAM-machine and sintered (ZirLuna Fire, ACF).

The frameworks were examined for deformation and debris, adapted if necessary and cleaned with steam. Each framework was seated on a definitive die. The frameworks were evaluated on the dies by visual inspection under a microscope (magnification ∞, Stemi DV 4, Zeiss) for marginal discrepancy. The inspection was performed by three previously calibrated evaluators (two dental technicians and one dentist) [20,21]. Therefore two copings for each of the 12 testing models were available after framework fabrication.

2.1. Veneering technique (VT)

One coping was randomly chosen from each testing model and veneered using the powder build-up technique. The fabrication of specimens from group VT was reported [5].

2.2. Sintering technique (ST)

One major goal of the study was to fabricate exact duplicates of the veneered crowns using alternative fabrication techniques. The objective to received an exact copy of the veneered restorations from group VT by CAD/CAM-technologies was easily reached. The outer surfaces of crowns from group VT were dimmed by applying a contrast spray (Dentaco, Bad Homburg, Germany) and scanned by a white-light-scanner (Everest Scan, KaVo, Biberach, Germany). The used CAD/CAM-system (Everest, KaVo) provides the function of a double scan. So the outer and the inner shape with the seated coping can be scanned, matched together and the CAD/CAM-system allows manufacturing the space between both scans from a material of choice.
The fabrication process was performed as described in an earlier publication [5].

Twenty-four full-contour crowns were manufactured using the same presintered zirconia and CAD/CAM-system (Zeno 4820 Premium, IMES, Elterfeld, Germany) according to the outer surface of group VT. The restorations were sintered to full density at a temperature of 1450 °C for 4 h (Zirluna Fire, ACF). After sintering all crowns were cleaned and adapted as described above. As the result of this manufacturing process two full-contour crowns for each of the 12 testing models were available.

2.3. **Glazed full-contour (GF)**

One full-contour crown was randomly chosen from each testing model for group GF. After the sintering process the outer surface of each crown of group GF was covered with glaze and stain liquid (IPS e.max Ceram Glaze and Stain allround, Ivoclar Vivadent) and fired at 725 °C.

2.4. **Polished full-contour (PF)**

Specimens from group PF were polished with a special polishing kit for all-ceramic restorations available for dental laboratories (Polishing Kit for Ceramic Materials, Nr. 4326A.104, Komet, Gebr. Brasseler). A diamond polishing paste (Grain size D3, Nr. 54000140, Borden, Senden, Germany) with a brush was used for finalizing the surfaces. Polishing was carried out by a master ceramist (20 years of experience fabricating ceramic restorations) under the stereomicroscope. The surface quality was evaluated by two calibrated investigators (one dentist and one dental technician) to be clinically acceptable.

2.5. **Light translucency**

The translucency was determined by direct transmission in an industrial spectrophotometer (LabScan XE, Hunterlab, Murnau, Germany). Light generated by a xenon flash served as source. The edges of the crowns were sealed by black modeling clay to exclude penetration of any light other than through the ceramic material. Light translucency through the buccal surface of the crown was determined. The sensor of the digital spectrophotometer with a spectrum of 400–700 nm detected the quantity of light transmitted through the crowns. The spectrophotometer illuminated the specimens in a 0° angle while detection was performed in a 45° angle. Reflected light was collected and averaged by a fiber-optic ring. A sample illumination size of 5 mm was chosen. First a negative control test was performed using a metal crown with identical dimensions pressed to the modeling clay and the instrument was evaluated for zero light reading. Next, three crowns (n = 3) were randomly chosen from each group and measurements were performed. The results were expressed in translucency related to the control group. Measurement was repeated three times for each specimen and the mean was calculated.

Fig. 1 – (a): Three-dimensional surface scan of a crown veneered with veneering porcelain before chewing simulation. (b): Three-dimensional surface scan of a crown veneered with veneering porcelain after chewing simulation. (c): Visualization of matched datasets before and after chewing simulation of a crown veneered with veneering porcelain. Loss of volume is highlighted in red color (for interpretation of the references to color in this figure legend, the reader is referred to the web version of the article).
2.6. Three-dimensional measurement of the occlusal surface and the antagonist

To simulate wear in the artificial mouth a stainless steel antagonist with a diameter of 6 mm was used according to earlier publications [22,23]. All surfaces of the crowns and the antagonists were digitized before and after contact wear testing. Scan powder (Met-L-Chek Developer D 70, Helling, Heidgraben, Germany) was applied on the surfaces to make them scanable. The surfaces were scanned with a triangulation sensor (Laserscan 3D Pro, Willytec, Graefelfing, Germany). To minimize false-positive results the surfaces were scanned from two different directions as described in earlier publications [24,25]. The matched dataset of each surface before wear testing served as baseline.

2.7. Aging

The abutments and crowns were mounted in the chewing simulator (Willytec, Graefelfing, Germany) in a resin mold with cold setting denture material (PalaXpress, HeraeusKulzer). The stainless steel antagonists were positioned on the molar crowns to achieve contact to both buccal cusps and one lingual cusp. The contact points were checked with 12-μm occlusion foil (Hanel, Coltene/Whaledent, Langenau, Germany). The chewing simulator with integrated thermocycling performed a special program that had proven its suitability for evaluating wear of ceramic surfaces [26,27]. For this method the weight was set at 5 kg and the sliding movement at 0.7 mm [28]. Sliding was guided by the inner surfaces of the buccal cusps. A total of 120,000 cycles of unidirectional antagonist movements
with a frequency of 1.6 Hz were carried out. Thermocycling with a frequency of 320/120,000 cycles and a temperature difference between 5 °C and 55 °C was included in the wear testing process.

After the aging process the occlusal surfaces of all crowns and the antagonists were scanned again. The surfaces were prepared and scanned as described above. Finally the baseline datasets and the datasets after contact wear were superimposed and images showing the differences were generated. The negative changes were displayed as shades of red, whereas positive changes were visible in gray shades (Fig. 1a–c and Fig. 2a–c). Data were evaluated and scattered as described in previous studies [24,25]. Then the loss of height of each crown and antagonist was imported for analysis in a statistical program (SPSS 16.0, SPSS Software, Munich, Germany).

2.8. Load-bearing capacity

All specimens were loaded until failure in a universal testing machine (Zwick, Ulm Germany) at a crosshead-speed of 0.5 mm min⁻¹. The force was transferred to the central fossa of the occlusal surface via a tungsten ball (10.0 mm diameter) on an interposed polyethylene foil (1.0 mm thickness) [5]. A sudden decrease in force of more than 15 N was regarded as an indication of failure, and the maximum force up to this point was recorded as force at fracture. Using visual examination, crack location and fragmentation of core and veneering material were assessed.

2.9. Statistical analysis

The data of light translucency, data of wear (restoration and antagonist) and force at fracture data were imported into a statistical program (SPSS 16.0). To compare the results of the different groups, a one-way analysis of variance (ANOVA) and a post-hoc test (LSD-test) were performed. The level of significance was set at 5%.

3. Results

3.1. Translucency

Polished full-contour zirconia crowns showed significantly higher light translucency than the three other groups (p = 0.003; ANOVA)(Fig. 3). There were no differences detected in light translucency between groups VT and ST (p = 0.963, LSD post-hoc-test), groups VT and GF (p = 0.343, LSD post-hoc-test) and groups ST and GF (p = 0.366; LSD post-hoc test).

3.2. Contact wear restoration

The ANOVA showed significant differences in contact wear of the restorations (p = 0.01)(Fig. 4). Polished full-contour zirconia crowns showed significantly less contact wear than crowns from group ST (p = 0.01; LSD post-hoc-test) and VT (p = 0.004; LSD post-hoc-test), while there were no differences between groups PF and GF (p = 0.396; LSD post-hoc-test).

3.3. Contact wear antagonist

Polished full-contour zirconia crowns showed significantly more contact wear (p = 0.016; ANOVA) than groups ST (p = 0.009; LSD post-hoc-test), VT (p = 0.021; LSD post-hoc-test) and GF (p = 0.004; LSD post-hoc-test) at the antagonist (Fig. 4). However, no differences in contact wear of the antagonist were found between groups GF and ST (p = 0.758, LSD post-hoc-test), GF and VT (p = 0.513; LSD post-hoc-test) and ST and VT (0.728; LSD post-hoc-test).

3.4. Load capability

All restorations survived the artificial aging in the chewing simulator. The highest force, which can be applied by the universal testing machine, is 10,500 N. However, 9 specimens from
group ST, 11 specimens from GF and 11 specimens from PF did not fail at this load. The failure pattern observed in group VT showed cohesive fractures without substructure failure. The fractured specimens from group ST exhibited catastrophic failures including the zirconia coping (Fig. 5).

Veneered zirconia substructures (VT) showed significantly less load-bearing capacity compared to all other groups (p < 0.001; ANOVA/p < 0.001 for comparisons VT and FF, VT and GF, VT and ST; LSD post-hoc-test). Groups PF and GF did not exhibit statistical differences in load bearing capacities (p = 0.963; LSD post-hoc-test) while ST showed significantly lower load capability than FF (p = 0.027; LSD post-hoc-test) and GF (p = 0.024; LSD post-hoc-test).

4. Discussion

Different approaches to fabricate zirconia single crowns showed significantly different results in this study so the working hypothesis could be accepted. Translucency of all-ceramic restorations was described as major advantage of those materials [29,30].

In previous studies, translucency of all-ceramic materials was evaluated using flat specimens of standardized thickness by applying the contrast ratio method [31]. Discs may be the more accurate way to measure light translucency as important factors like seize and surface quality can be standardized. However, in this study, translucency was determined with the direct transmission method and translucency related to an opaque control was measured, allowing the use of crowns instead of discs. Polished full-contour zirconia crowns showed significantly higher translucency than the other tested groups. As only one interface (air–zirconia) refracting the light is present, less reflection compared to the other groups, can be assumed. All other tested groups exhibited two or more interfaces: glazed full-contour zirconia (air–glaze; glaze–zirconia), veneering technique (air–glaze; glaze–veneering porcelain, veneering porcelain–zirconia), sintering technique (air–glaze; glaze–veneering cap; veneering cap–sintering porcelain; sintering porcelain–zirconia). There are several factors as thickness, surface quality, and background influencing the measurement of the light translucency. However, these parameters were similar in this study and the experimental groups can be compared.

Until now, the wear complex of ceramic surfaces vs. opposing restorations has not been sufficiently addressed. Since the introduction of ceramics, wear resistance has been estimated as substantial [32,33]. The wear rate of ceramics should be preferably match that of posterior enamel, which is in the range of 20–40 μm per year [34]. The wear behavior of restorative materials and the antagonists is dependent on the type of material, the microstructure, surface roughness and strength [28]. As clinical evaluation of wear is complicated, time-consuming and expensive chewing simulators have been developed in an attempt to simulate the oral environment and produce contact wear in test specimens [28]. Heinze et al. emphasized the need of a standardized form of antagonist for comparison [28]. Different materials were suggested for fabricating antagonists for chewing simulators [35]. Stainless steel balls with a diameter of 6 mm simulating the cusp of a premolar were used as antagonists in this study according to previous investigations [22,23].

Due to enhanced computer technology, PC navigated mechanical profilometry systems can be used for measuring wear. The 3-D scanner used in this study was reported to have an accuracy of x/y/z = 25/25/5 μm [25], so the low vertical resolution is a disadvantage compared to mechanical profilometry. Therefore, scans from two different directions were used in this study to measure contact wear characteristics of single crowns and their antagonists.

Polished ceramic surfaces have been reported to be equal or surpass the smoothness accomplished with surface glazing [36]. Glazed full-contour zirconia crowns showed similar wear as the control group in this study. The glazed layer, which has a thickness of between 30 and 50 μm, was worn after the aging procedure [28]. The antagonist hitting the rough surface might lead to increased contact wear if a longer simulation program would have been chosen. The simulation program corresponds to a clinical wear of 6 months [37]. Results might have been different if longer simulation programs were applied. Polished full-contour zirconia exhibited significantly less wear compared to the control group and the sintering group. Under clinical conditions it might be possible that these restorations show less wear, too. After several years of clinical service they might stick out of the occlusal plane and act as a barrier in static and dynamic occlusion. However, polished full-contour zirconia crowns failed to exhibit differences in contact wear compared to glazed full-contour zirconia crowns. The hardness of the different materials might be a possible explanation for similar contact wear of the veneering group and the sintering group. The veneering porcelain exhibited hardness according to Vickers of 5400 MPa (unpublished data, information IvoclarVivadent) while lithium-disilicate showed 5800 MPa (unpublished data, information IvoclarVivadent). If the glazed layer is removed by contact wear both surface materials behave similar. In contrast if the glazed layer is removed from full-contour zirconia a different contact wear is observed. As the hardness of...
zirconia according to Vickers is 13000 MPa (unpublished data, information IvoclarVivadent) different contact wear behavior of full-contour zirconia restorations and veneered/sintered restorations can be expected. The differences between glazed full-contour zirconia and polished full-contour zirconia might be caused by the glazed layer, which is worn faster than pure zirconia.

Polished full-contour zirconia showed significantly more contact wear at the antagonist compared to the other groups. Metal–ceramics and feldspathic ceramics are known to cause considerable antagonist wear [38]. The surface finish of ceramic restorations was reported to have an effect on abrasion of the antagonist. Surface glazing produces hygienic surfaces and increases the strength of the ceramic restoration. It was reported that surface glazing also reduced the wear of the opposing teeth [39]. However, the glazed layer is easily removed by chairside occlusal adjustments or after a short period in clinical function. Several studies were performed to identify finishing and polishing techniques that would create surfaces as smooth or smoother than glazed porcelain [36,40–43]. Results might be different if other polishing techniques would have been applied on the zirconia surface.

The load-bearing capacity of groups ST, PF and GF was significantly higher compared to the control group. Two main reasons might be responsible for this result. First the failure pattern of the control group was predominantly a fracture of the veneering porcelain, while the failures documented in groups ST, PF and GF were catastrophic failures including the substructure (group ST). Secondly the CAD/CAM-process uses high quality material with a minimum of flaws compared to the manual veneering process. Catastrophic failure as a result of contact loading has made it difficult to identify whether cone cracking or subsurface damage was responsible. All groups evaluated showed higher fracture loads than most available literature and exceeded the maximum chewing forces. The abutment material has a significant influence on the fracture load and increased them in this study. Similar loads have been described with titanium and chrome–cobalt abutments [5]. The diameter of the loading piston influences the fracture load [44]. This study used a larger diameter than most comparable studies to ensure the three-point contact of the piston to the occlusal surface of the specimen. This might be one explanation of the higher load-bearing capacity compared to similar studies. However, the experimental groups of this study can be increased.

The fabrication techniques described in groups ST, PF and GF will lead to a significant reduction in the fabrication time compared to the standard technique (group VT). The increase in mechanical strength of the CAD/CAM-fabricated restorations may result in greater clinical reliability of those restorations. A major drawback of full-contour zirconia restorations might be the aging of the material. Further research has to be carried out whether these effects limit the clinical suitability.

5. Conclusion

According to the results of this study glazed full-contour zirconia crowns showed similar translucency, contact wear of the restoration and contact wear at antagonist as veneered zirconia crowns. However, glazed full-contour zirconia crowns showed higher fracture loads than veneered zirconia crowns, although different fracture patterns could be observed. Polished full-contour zirconia crowns exhibited less wear at the restoration but more wear at the antagonist compared to the other groups. The results of this study justify a clinical study with glazed full-contour zirconia crowns.

Conflict of interest

The authors declare they have no conflict of interest.

Acknowledgements

The authors would like to thank ACF and Ivoclar Vivadent for supporting this study with material. The authors are grateful for Dr. Kurt Erdelt’s assistance with the chewing simulator.

References


