Monolithic CAD/CAM Lithium Disilicate Versus Veneered Y-TZP Crowns: Comparison of Failure Modes and Reliability After Fatigue

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Purpose: The aim of this research was to evaluate the fatigue behavior and reliability of monolithic computer-aided design/computer-assisted manufacture (CAD/CAM) lithium disilicate and hand-layer–veneered zirconia all-ceramic crowns. ***Materials and Methods:*** A CAD-based mandibular molar crown preparation, fabricated using rapid prototyping, served as the master die. Fully anatomically shaped monolithic lithium disilicate crowns (IPS e.max CAD, n = 19) and hand-layer–veneered zirconia-based crowns (IPS e.max ZirCAD/Ceram, n = 21) were designed and milled using a CAD/CAM system. Crowns were cemented on aged dentinlike composite dies with resin cement. Crowns were exposed to mouth-motion fatigue by sliding a WC-indenter (r = 3.18 mm) 0.7 mm lingually down the distobuccal cusp using three different step-stress profiles until failure occurred. Failure was designated as a large chip or fracture through the crown. If no failures occurred at high loads (> 900 N), the test method was changed to staircase r ratio fatigue. Stress level probability curves and reliability were calculated. ***Results:*** Hand-layer–veneered zirconia crowns revealed veneer chipping and had a reliability of < 0.01 (0.03 to 0.00, two-sided 90% confidence bounds) for a mission of 100,000 cycles and a 200-N load. None of the fully anatomically shaped CAD/CAM-fabricated monolithic lithium disilicate crowns failed during step-stress mouth-motion fatigue (180,000 cycles, 900 N). CAD/CAM lithium disilicate crowns also survived r ratio fatigue (1,000,000 cycles, 100 to 1,000 N). There appears to be a threshold for damage/bulk fracture for the lithium disilicate ceramic in the range of 1,100 to 1,200 N. ***Conclusion:*** Based on present fatigue findings, the application of CAD/CAM lithium disilicate ceramic in a monolithic/fully anatomical configuration resulted in fatigue-resistant crowns, whereas hand-layer–veneered zirconia crowns revealed a high susceptibility to mouth-motion cyclic loading with early veneer failures. *Int J Prosthodont 2010;23:434–442.*

Full-coverage crowns constitute the most common fixed prosthodontic treatment.[1] According to a survey conducted by the American Dental Association, more than 45 million dental crowns, in which 37 million were porcelain-based, were placed in private dental offices in the United States in 1999.[2] To meet this abundant market and the increased demands of patients and dentists for highly esthetic, metal-free, and biocompatible restorations, several types of all-ceramic systems have been developed in the last few decades.

In a systematic review of clinical data covering observation periods of at least 3 years, all-ceramic crowns showed comparable survival rates with metal-ceramic crowns when used in the anterior dentition.[3] However, crown fracture within the all-ceramic material is still the most common cause for failure, strongly related to the

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location of the restoration. Molars showed a significantly higher fracture rate than premolars and anterior teeth (21%, 7%, and 3%, respectively).[3,4] Hence, great effort has been expended in the development of more reliable all-ceramic systems.

In the early 1990s, yttrium oxide partially stabilized tetragonal zirconia polycrystal (Y-TZP) was introduced to dentistry as a core material for all-ceramic restorations and has been made available through the computer-aided design/computer-assisted manufacture (CAD/CAM) technique. Compared to other all-ceramic systems, Y-TZP exhibits superior mechanical properties, owing to a transformation toughening mechanism.[5,6]

Long-term clinical data for zirconia-based all-ceramic restorations with observation periods exceeding 5-year time frames are not yet available. The high stability of the Y-TZP core ceramic observed in vitro has been confirmed in short-[7] and medium-term clinical studies.[8–12] Zirconia framework damage has not been reported in three-unit posterior fixed partial dentures (FPDs).[7,10–12] However, fractures within the veneering ceramic were described as the most frequent reason for failure. Chip-off fracture rates at 8% to 25% after 24 to 38 months[8–10,13] were observed for tooth-supported FPDs. One study on implant-supported zirconia all-ceramic FPDs revealed an even higher chip-off fracture rate of 53% after 12 months.[14] Hence, the long-term success of veneered zirconia FPDs seems to be limited predominately by the weak performance of the veneering ceramic.

Surprisingly, zirconia restorations most often described in the literature are FPDs rather than single crowns. Limited clinical data are available concerning the reliability of veneered zirconia crowns. Only a few short-term clinical reports have been published up to now. In a retrospective clinical study conducted in a private practice,[15] a promising survival rate (92.7% after 3 years) with no zirconia core fractures and few veneer fractures was recorded (2%) for 204 zirconia posterior crowns. However, only 11% of the crowns placed originally were examined clinically. Hence, results of this investigation relied predominately on patient records, limiting the significance of this study strongly. In the only controlled clinical trial on posterior zirconia-based crowns yet published,[16] relatively low complication rates were found over a 2-year period. One zirconia maxillary molar restoration of a patient with nocturnal bruxism fractured through the core 1 month after insertion, resulting in a 93.4% survival rate after 2 years. Fractured surfaces within the veneering ceramic have not been reported. However, the reduced number of crowns ($n = 15$) investigated in that study has to be considered as a major limitation. Promising results of the zirconia framework have also been described in a clinical report on posterior implant-supported zirconia-based crowns. No crown framework fractured, and all restorations were in function after an observation period of 2 years.[17] However, fractures of the veneering material not extending to the core-veneer interface were reported in 12.5% of patients. The rapidly growing use of zirconia in prosthetic and implant dentistry warrants more clinical research, especially long-term data on crowns fabricated using this material. In consideration of the reported veneer failure rates with zirconia-based restorations, glass-ceramic systems have regained consideration for posterior full-crown restorations.

In the early 1990s, the lost-wax press technique was introduced to dentistry as an innovative processing method for all-ceramic restorations. IPS Empress (Ivoclar Vivadent), a leucite-reinforced glass-ceramic, is one of the most representative materials among pressable ceramics. Further enhancements of this system led to the introduction of a lithium disilicate glass-ceramic system (IPS Empress II) with significantly increased strength. More recently, a consecutive pressable lithium disilicate glass-ceramic (IPS e.max Press) with improved physical properties and translucency through different firing processes was developed. The lithium disilicate glass-ceramic investigated in this study (IPS e.max CAD) was designed for CAD/CAM processing technology. Restorations can be produced with a core part and subsequent veneering with veneering ceramics. Due to the favorable translucency and shade variety of this glass-ceramic material, fully anatomical restorations can be fabricated (chair- or labside) with subsequent staining characterization. Because of its high strength, the material offers versatile applications and can be used for the fabrication of single crowns in the anterior and posterior regions, with application of conventional or self-adhesive cementation.

Since high survival rates (100% after 2 to 5 years) with no fracture failures have been reported for lithium disilicate IPS Empress 2 crowns,[18,19] the exploration of the monolithic CAD/CAM-fabricated lithium disilicate crown system IPS e.max CAD is expected to be promising.

Since no study has been published as of yet on the clinical performance of CAD/CAM-fabricated lithium disilicate crowns and only little information is available on Y-TZP-based crowns, a preclinical investigation of the in vitro longevity and microstructural fatigue is expected to be most enlightening for evaluation of the long-term behavior of the described all-ceramic systems.

Mouth-motion fatigue using a clinically relevant load application will be used to assess failure modes and reliability of two all-ceramic systems for posterior crown indication. Results of CAD/CAM-fabricated lithium disilicate full crowns (IPS e.max CAD) will be compared with hand-layer–veneered Y-TZP-based crowns (IPS e.max ZirCAD/Ceram).

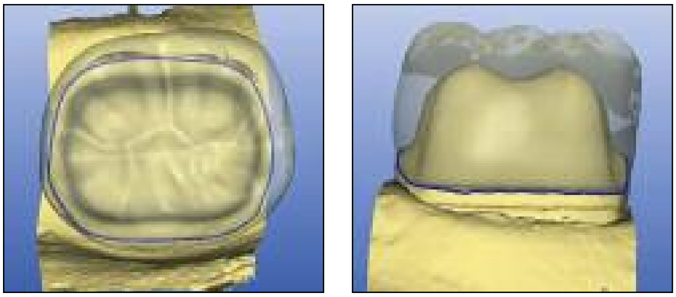

Fig 1 **(left)** Occlusal and **(right)** buccal views of the CAD/CAM crown configuration. IPS e.max CAD: fully anatomical design (occlusal reduction: 2 mm, axial: 1.5 mm); IPS e.max ZirCAD/Ceram: 0.5-mm Y-TZP core, 1- to 1.5-mm veneering ceramic layer.

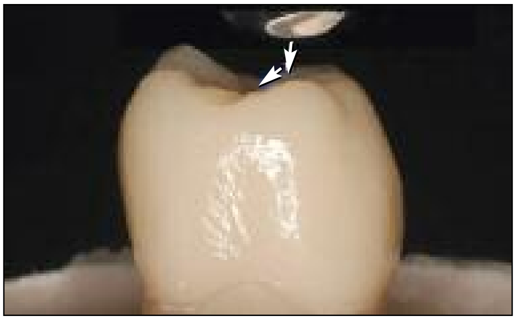

Fig 2 Mouth-motion fatigue with load application on the distobuccal cusp of the crown **(arrows)**.

Materials and Methods

An anatomically correct CAD-based three-dimensional model of a mandibular first molar full crown was generated.[20] Tooth preparation was modeled by reducing the proximal walls by 1.5 mm and the occlusal surface by 2.0 mm. Impressions of the prepared, adjacent, and opposing teeth were taken (Aquasil, Dentsply). Monolithic CAD/CAM lithium disilicate full crowns (IPS e.max CAD, Ivoclar Vivadent; n = 19) and hand-layer–veneered Y-TZP-based crowns (IPS e.max ZirCAD/Ceram, Ivoclar Vivadent; n = 21) were tested. All crown samples were provided by the manufacturer. Fully anatomically shaped IPS e.max CAD and IPS e.max ZirCAD cores (0.5-mm thick) were designed (Fig 1) and milled with a CAD/CAM system (Cerec InLAB, Sirona) from presintered blocks. After the milling procedure, final sintering of the IPS e.max CAD crowns and IPS e.max ZirCAD cores was performed following the manufacturer's guidelines. IPS e.max ZirCAD cores were veneered using the hand-layering technique (IPS e.max Ceram) according to the manufacturer's instructions. Glazing with a standard cooling procedure was applied as the final treatment.

All crowns were cemented to aged (stored in distilled water at 37°C for at least 30 days), resin-based composite dies (Tetric EvoCeram A2, Ivoclar Vivadent) with a self-curing resin-based dental luting material (Multilink Automix, Ivoclar Vivadent). Prior to cementation, a layer of metal primer (Metal/Zirconia Primer, Ivoclar Vivadent) was applied to the internal surface of the IPS e.max ZirCAD zirconia core (no sandblasting was employed). Lithium disilicate IPS e.max CAD crowns were etched with 5% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar Vivadent) for 20 seconds according to the instructions of the manufacturer. Specimens were stored in water for a minimum of 7 days prior to mechanical testing to allow hydration of the resin cement.[21,22]

To determine the step-stress profiles, three crowns per group (IPS e.max CAD and IPS e.max ZirCAD/Ceram) were subjected to single load–to-failure testing. Specimens were mounted in a universal testing machine (model 5566, Instron), and load-to-fracture was applied through a WC indenter ($r = 3.18$ mm) on the distobuccal cusp at a rate of 1 mm/min. Samples from each group (IPS e.max CAD, n = 6; IPS e.max ZirCAD/Ceram, n = 18) were subsequently exposed to mouth-motion step-stress fatigue. Mechanical testing was performed by sliding a WC indenter 0.7 mm lingually down the distobuccal cusp (Fig 2), beginning 0.5 mm lingual to the cusp tip, simulating aspects of natural occlusion, at 2 Hz using an electrodynamic fatigue testing machine (EL-3300, Enduratec, Bose). Crown specimens were immersed in water during fatigue testing. Three step-stress profiles (mild, moderate, and aggressive) were designed for fatigue testing. At the end of each load cycle, all specimens were inspected under polarized light stereomicroscopy (50× MZ Apo stereomicroscope, Carl Zeiss) for cracks and damage.

Eighteen ZirCAD specimens were distributed across the three profiles in the ratio of 3:2:1, mild to aggressive, respectively. The mild profile started at 50 N and went to 750 N at 180,000 cycles; the moderate profile started at 100 N and went to 750 N at 170,000 cycles; the aggressive profile started at 200 N and went to 750 N at 140,000 cycles. The step-stress profiles for IPS e.max CAD started with a 500-N load based on the load-to-fracture experiments and ended at a maximum of 900 N and 180,000 cycles for the mild profile, 900 N and 110,000 cycles for the moderate, and 900 N and 60,000 cycles for the aggressive profile. IPS e.max CAD crown samples (n = 6) were distributed across the three profiles in a 3:2:1 distribution. Bulk fractures of the monolithic lithium disilicate IPS e.max CAD crowns and chip-off fractures of the veneering ceramic for veneered IPS e.max ZirCAD/Ceram crowns, as well as

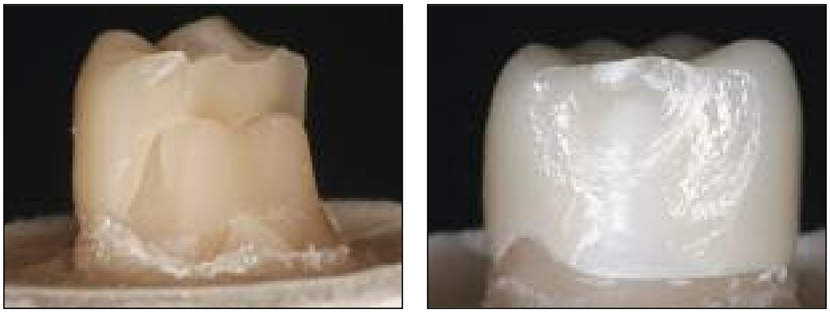

Fig 3 Single load–to-failure results and fracture modes (note the different failure modes). **(left)** IPS e.max CAD crown (2,576 ± 206 N); **(right)** IPS e.max ZirCAD/Ceram crown (1,195 ± 221 N).

Table 1 Step-Stress Fatigue Results of IPS e.max CAD Crowns Revealing Step-Stress Profiles, Number of Cycles, and Resulting Failure Mode

Step-stress profile	Step-stress fatigue: Total cycles	Load (N)	Failure mode and damage extension
1	180,000	900	No failure
1	180,000	900	No failure
1	180,000	900	No failure
2	110,000	900	No failure
2	110,000	900	No failure
3	60,000	900	No failure

IPS e.max ZirCAD core fractures, were considered as failures. A master Weibull curve and reliability for completion of a mission of 100,000 cycles at a 200-N load were calculated (ALTA 7 PRO, Reliasoft).[23]

If there were no failures during exposure to step-stress fatigue, it was deemed reasonable, based on the high loads involved, to change the test method. The remaining samples (IPS e.max CAD, n = 10) were then used to determine the load at which 50% of the samples could be expected to survive 1,000,000 cycles with a loading frequency of 5 Hz via the staircase fatigue method.[24] An *r* ratio (1:10) fatigue strategy (load range: 90 to 900 N, 95 to 950 N, 100 to 1,000 N, 110 to 1,100 N) was employed and failure was designated as a large chip or bulk fracture through the crown.

Results

During single load–to-failure testing, IPS e.max CAD crowns showed bulk fractures exposing the resin preparation at a high load level (2,576 ± 206 N, Fig 3). IPS e.max ZirCAD/Ceram crowns revealed fractures limited to the veneering ceramic (1,195 ± 221 N, Fig 3).

None of the IPS e.max CAD crowns revealed failures in the form of chip or bulk fractures during mouth-motion step-stress fatigue up to a load level of 900 N and 180,000 cycles (Table 1). Only superficial surface damage was observed (Fig 4). Survival of all IPS e.max CAD mouth-motion step-stress fatigue specimens (n = 6) in the first 3:2:1 distribution grouping resulted in moving staircase fatigue testing to 1,000,000 cycles. At loads in the range of 900 to 1,000 N, no failures were observed at 1,000,000 cycles (Fig 5). Based on the results of these *r* ratio fatigued samples (n = 10), it appeared that fatigue damage had only a minimal effect on the IPS e.max CAD ceramic (Table 2). At loads above 1,100 N, IPS e.max CAD crowns failed by bulk fracture (Fig 6).

Hand-layered Y-TZP-based crowns (n = 18) exhibited a different failure mode during step-stress mouth-motion fatigue compared to monolithic lithium disilicate crowns. Forty-nine percent of IPS e.max ZirCAD/Ceram crowns revealed crack initiation and propagation before chip-off fractures within the veneering ceramic occurred (Fig 7). Delamination of the hand-layer veneering ceramic (IPS e.max Ceram) with exposure of the IPS e.max ZirCAD core ceramic could not be observed. None of the IPS e.max ZirCAD/Ceram crown specimens exhibited fractures in the IPS e.max ZirCAD core ceramic (Fig 7). The maximum load applied before failure was 500 N, although the profiles extended to 750 N.

Fig 4 **(left)** Occlusal view and **(center)** cross section of an IPS e.max CAD crown at a load of 900 N exhibiting only minor occlusal damage **(right)** at 180,000 cycles after mouth-motion fatigue.

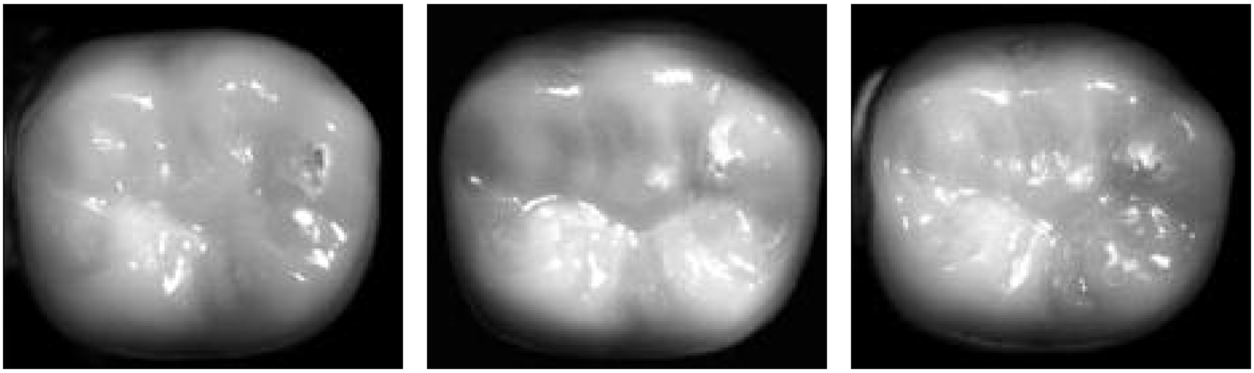

Fig 5 IPS e.max CAD crowns after *r* ratio fatigue and 1,000,000 cycles (90 to 1,000 N). No bulk fractures were observed. **(left)** 90 to 900 N; **(center)** 95 to 950 N; **(right)** 100 to 1,000 N.

Table 2 Staircase *r* Ratio Fatigue Results of IPS e.max CAD Crowns Revealing Number of Cycles, Load Range, and Resulting Failure Modes

Staircase *r* ratio fatigue: Total cycles	Load (N)	Failure mode and damage extension
1,000,000	90–900	No failure
1,000,000	95–950	No failure
1,000,000	100–1,000	No failure
1,000,000	100–1,000	No failure
1,000,000	100–1,000	No failure
1,000,000	110–1,100	Minor chip fracture
900,000	110–1,100	Bulk fracture
723	110–1,100	Bulk facture
287	110–1,100	Large chip fracture
800,000	120–1,200	Bulk fracture

Fig 6 IPS e.max CAD crown exhibiting bulk fracture at 800,000 cycles and *r* ratio fatigue range of 120 to 1,200 N (arrow = area of load application).

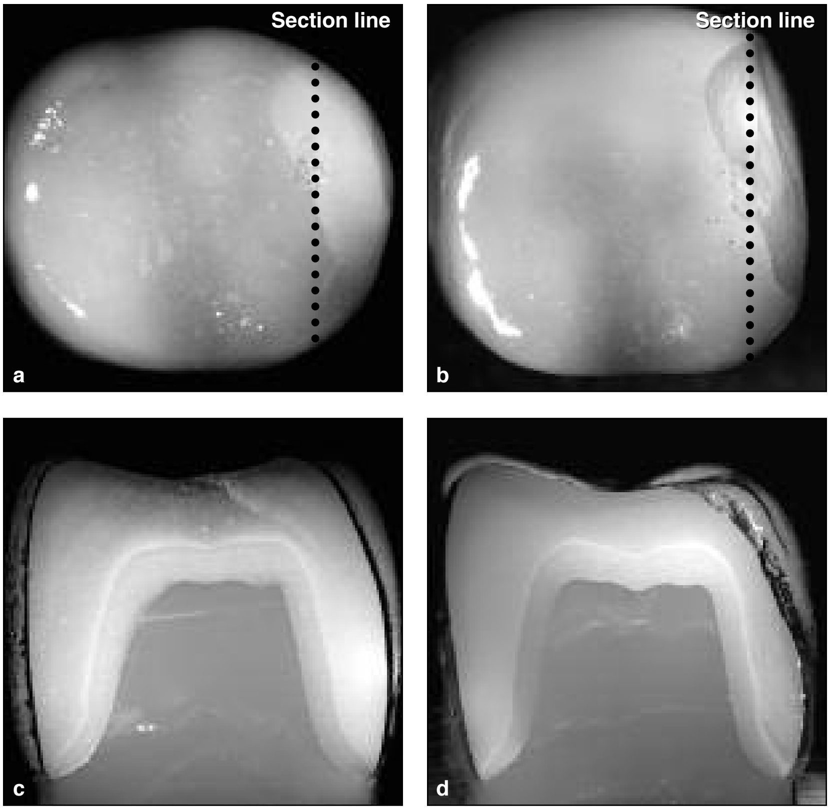

Fig 7 **(a and b)** Occlusal view and **(c and d)** section of IPS e.max ZirCAD/Ceram crowns exhibiting **(a and c)** crack formation (failure at 300 N and 60,000 cycles) and **(b and d)** chip fracture (failure at 200 N and 60,000 cycles) after mouth-motion step-stress fatigue.

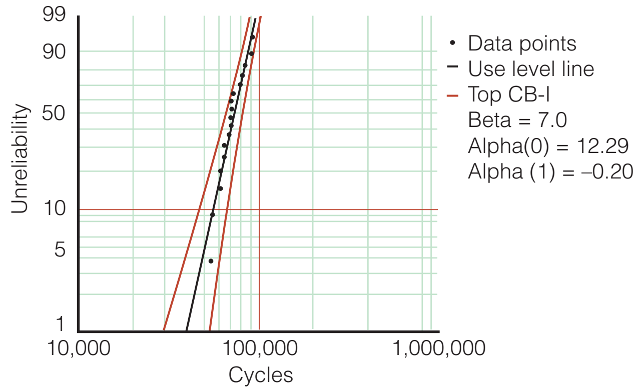

Fig 8 IPS e.max ZirCAD/Ceram unreliability (Weibull distribution) versus time (cycles) at a 200-N load (90% two-sided confidence bounds).

Using a power law cumulative damage model, the two-parameter Weibull beta value for the ZirCAD specimens was 7.0 (4.5 to 10.2, two-sided 90% confidence bounds). This indicates a threshold for damage accumulation in these specimens. The calculated reliability for hand-layer–veneered ZirCAD core crowns for a mission of 100,000 cycles and 200 N was < 0.01 (0.03 to 0.00, two-sided 90% confidence bounds), while for 200 N and 50,000 cycles, the reliability was 0.95 (0.99 to 0.80). The hand-layering technique on ZirCAD resulted in limited reliability, where at 200 N, more than 90% of specimens failed by 100,000 cycles (Fig 8).

Discussion

Clinically, all-ceramic restorations commonly fail through stress corrosion and slow crack growth resulting from fatigue caused by repetitive occlusal contact.[25] This complex mechanical scenario of damage initiation and accumulation was reproduced in the present study design[26,27] by using mouth-motion fatigue loading of anatomically correct all-ceramic single crowns cemented onto a standardized mandibular molar model. Given that cyclic loading under wet conditions may reduce the initial strength of ceramics by 50%, fatigue is a significant factor limiting the lifespan of all-ceramic restorations.[28,29]

The presently investigated CAD/CAM lithium disilicate crowns appeared to be resistant to mouth-motion step-stress (900 N/180,000 cycles) and also to staircase fatigue (1,000 N/1,000,000 cycles), and showed no failures up to load levels exceeding posterior physiologic chewing forces (range: 250 N to 800 N).[30] A threshold for damage and bulk fracture could be detected in the range of 1,100 to 1,200 N.

By contrast, hand-layer–veneered zirconia-based crowns resulted in a very limited reliability; approximately 90% of specimens failed from veneer chip-off fracture by 100,000 cycles at 200 N. These results are similar to previous findings for other veneered zirconia systems (LAVA, Cercon) tested using this methodology.[27] Hence, the observed fatigue behavior of zirconia-based crowns does not seem to be material- or system-dependent for the limited number of systems tested.

Given the known highly accelerated failure from surface cracks with mouth-motion sliding contacts in water, 100% failure within the veneers can be anticipated.[31] Fatigue properties of all-ceramic systems can be related to flaw population (size number and distribution) inherent in the material from various fabrication processes, as well as residual stress. The sintering process for layering veneering ceramics is described as technique-sensitive and subject to variability due to the individual building and multiple firing steps. But attempts to improve the microstructure and mechanical properties of veneering ceramics with the development of glass-ceramic ingots for pressing veneering ceramics onto zirconia frameworks did not result in increased reliability.[32,33]

Since the veneering ceramic material (flexural strength: approximately 90 MPa) is weak compared to the high-strength core material (900 MPa), the veneering ceramic is prone to fail at low loads during the evolution of complex tensile fields in function. Thus, all tested hand-layer–veneered Y-TZP crowns failed from cohesive fractures within the veneering ceramic, where a thin layer of veneering ceramic still remained on the zirconia coping. This type of failure mode has been reported clinically[10,17] and indicates a sufficient interfacial bond between the core and the veneer material. The cracks observed in 49% of crowns before chip-fracture occurred originated from the occlusal surface where the load was applied and propagated evenly along the crown's long axis, involving most of the axial walls and the margins (Fig 7). The large chips observed for the Y-TZP veneer (Fig 7) without exposure of the core-veneer interface strongly suggest high residual stresses within the veneer layer. This may be related to the very low thermal diffusivity of Y-TZP (approximately 3 Wm/K),[34] which will affect the cooling rate of the veneering porcelain. This cooling rate difference may lead to different stress states in the two systems.[35] Clinically, additional residual stresses may also result from place to place variation in thermal properties, owing to irregular veneering ceramic thickness and the relative core veneer layer thickness ratio.[36] If these tensile stresses are not considered in the design of the restoration, failure can occur at unexpected low stresses.[37]

Catastrophic failure of the Y-TZP ceramic in terms of core cementation surface radial cracking was not evident in any of the veneered Y-TZP crowns and is consistent with most clinical observations.[7,10,15,17] The high crystalline content, flexural strength, and fracture toughness of the Y-TZP-based core material can be considered as reasons for the superior ability to resist subcritical crack propagation and stress corrosion in an aqueous environment.[32]

While zirconia provides strength in vivo[15,17] and in vitro,[26,27,32] failure modes of veneered zirconia crowns suggest that future development should focus on veneering ceramics. Further investigations on framework design modifications [38] and refinement of the cooling parameters of veneering ceramics[35] for Y-TZP core materials are necessary for clinical long-term success.

The CAD/CAM lithium disilicate group showed fracture loads and reliability results greater than most available literature,[27] even after exposure to extensive fatigue exceeded maximum chewing forces by a substantial margin.

Loading a ceramic monolayer until fracture causes contact damage at the loading surface forming Hertzian cone cracks, which extend to the deeper areas followed by a zone of microdeformation of the ceramic further down (ie, fracture is caused by surface damage).[39,40] Apart from cone cracks at the loading site, radial cracks can form at the cementation interface. The substrate deforms under the load causing tension stress at the lower surface.[41] Fractographic analysis of clinically failed all-ceramic crowns has proven that fracture originated mostly with the formation of radial cracks at the cementation interface.[42–44]

Two main reasons might be responsible for the greater fatigue reliability of the CAD/CAM lithium disilicate ceramic in this study. First, due to the fully anatomical design and the monolithic application of the CAD/CAM lithium disilicate ceramic, the material revealed a thickness of 2 mm in the occlusal area where the load was applied. The load to cause bulk fracture from radial cracks in layered ceramics increases as the square of the thickness increases.[45] Hence, the load to cause bulk fracture in the CAD/CAM lithium disilicate can be expected to diminish rapidly as the thickness is lowered, so caution is advised if adequate crown reduction is not provided. Unexpected in the current findings is the lack of surface fatigue damage in this material, even at high loads. Secondly, the CAD/CAM process uses industrial-produced homogenous blanks with minimal inherent flaws compared to the manual procedures of hand-layer veneering. A significantly increased Weibull modulus and increased reliability of oxide ceramic restorations have been reported when using the same ceramic material in the form of industrial prefabricated blocks and when applying the milling technique.[6] Promising results for CAD/CAM-generated all-ceramic molar crowns with a survival rate of 94.6% up to 7 years have also been reported in a clinical application.[46] A pressure casting procedure is used to manufacture the presently investigated CAD/CAM lithium disilicate blocks. Optimized processing parameters prevent the formation of microstructural defects. Due to partial crystallization, blocks are processed in an intermediate phase, which enables fast machining with CAD/CAM systems. The partial crystallization process leads to formation of lithium metasilicate crystals, resulting in high strength and good edge stability. Following the milling procedure, the material is tempered and thus reaches the final state. The CAD/CAM-fabricated IPS e.max CAD system combines strength (flexural strength: 360 MPa, according to the manufacturer) with favorable esthetic properties, such as tooth shade translucency and brightness, resulting from its microstructure containing fine-grain lithium disilicate crystals embedded in a glassy matrix.

From an economic point of view, all-ceramic crowns can be considered competitive with metal-ceramics due to the escalating cost for precious metals.[47] However, the esthetic and functional completion of all-ceramic crowns and FPD frameworks involving traditional veneering methods, such as the powder layering technique, appears to be inefficient. One possibility for increasing the cost effectiveness involves the industrial fabrication of glass-ceramic monoblocks and machining of the entire restoration by means of CAD/CAM technologies.[48] CAD/CAM lithium disilicate crowns can be fabricated in 1 to 2 hours, which leads to a significant reduction in the fabrication time.[49] Clinical data for reference on this all-ceramic system is not yet available.

Conclusion

This investigation was designed to evaluate clinically relevant fatigue behavior of a CAD/CAM lithium disilicate and a veneered zirconia all-ceramic crown system. According to the results of this in vitro study, hand-layer–veneered zirconia-based crowns were highly susceptible to mouth-motion fatigue veneer chipping. CAD/CAM fabrication of the lithium disilicate ceramic resulted in fatigue-resistant crowns with increased mechanical stability, and only bulk fracture could be observed at high load levels. There was little evidence of fatigue damage in the lithium disilicate system at any loads other than those that caused bulk fracture. Enhanced clinical reliability is to be expected given the adequate reduction of the prepared tooth to provide sufficient thickness of the ceramic. Application of this all-ceramic system for tooth- and implant-supported prosthetic dentistry seems very promising. Additionally, this technique leads to cost-effective fabrication of esthetic all-ceramic crowns using the CAD/CAM technique. Long-term in vivo studies are necessary to confirm the presented results.

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