A Clinical Report and Overview of Scientific Studies and Clinical Procedures Conducted on the 3M ESPE Lava™ All-Ceramic System

Andree Piwowarczyk, DMD;[1] Peter Ottl, DMD;[1] Hans-Christoph Lauer, DMD;[2] and Timo Kuretzky, DDS[3]

The Lava™ All-Ceramic System (3M ESPE Dental Products, St. Paul, MN) is a high-strength zirconia system, which can be utilized to create all-ceramic crowns and fixed partial dentures (FPDs) for use in the anterior and posterior regions of the oral cavity. The following study offers an overview of previously conducted scientific studies and clinical procedures that feature the Lava™ All-Ceramic System as well as a more general overview of zirconia ceramics. A clinical report demonstrates the use of the Lava™ All-Ceramic System with the restoration of 2 single crowns.

J Prosthodont 2005;14:39-45.

INDEX WORDS: All-ceramic restorations, zirconia, CAD/CAM technology

DURING THE past few years, partially stabilized zirconia has been integrated into restorative dentistry. First introduced as a hip-replacement material in the early 1990s, this material is stabilized with yttrium oxide and exists as yttria–tetragonal zirconia polycrystals (Y–TZP) at room temperature. Various studies have been performed on its biocompatibility and long-term effects.[1,2] In dentistry, zirconia ceramic has been clinically used to create orthodontic brackets,[3] stock dowel patterns,[4-7] implants,[8] abutments for implant prosthetics,[9] and hard framework cores for crowns and fixed partial dentures (FPDs).[10,11]

Besides offering a high flexural strength and an elastic modulus considered low for ceramic materials, Y–TZP is characterized by high fracture toughness.[12,13] When cracks appear due to wear on the ceramic, a physical effect, referred to as transformation toughening or martensitic-like transformation, serves to prevent the crack from spreading in the ceramic. The tensile stress acting on the crack tip induces a phase transformation from the partially stabilized tetragonal modification of zirconia into a monoclinic phase.[14] This phase transformation is connected to a volume expansion of approximately 3–4% and leads to local compressive tension in the material that counteracts the progress of the crack.[15]

Incorporating the aforementioned positive material properties, the Lava™ All-Ceramic System (3M ESPE Dental Products, St. Paul, MN) can be utilized to create all-ceramic crowns and FPDs for use in the anterior and posterior regions of the oral cavity. The following study offers an overview of previously conducted scientific studies and clinical procedures featuring the Lava™ All-Ceramic System as well as a more general overview of zirconia ceramics.

Materials and System Overview

The Lava™ All-Ceramic System utilizes CAD/CAM technology to produce a densely sintered and high-strength zirconia framework with a 3% mol partially yttria-stabilized zirconia polycrystal content. The polycrystals have a tetragonal crystal structure and an average grain size of 0.5 μm or smaller (Fig 1). The equipment used for the Lava™ All-Ceramic System in a

[1]*Associate Professor, Department of Prosthetic Dentistry, School of Dentistry, Johann Wolfgang Goethe University, Frankfurt, Germany.*

[2]*Professor and Chairman, Department of Prosthetic Dentistry, School of Dentistry, Johann Wolfgang Goethe University, Frankfurt, Germany.*

[3]*Analytical Chemist, 3M ESPE Dental AG, Seefeld, Germany.*

Accepted May 27, 2004.

Correspondence to: Andree Piwowarczyk, DMD, Associate Professor, Department of Prosthetic Dentistry, School of Dentistry, Johann Wolfgang Goethe University, Theodor-Stern-Kai 7, D-60590, Frankfurt, Germany. E-mail: piwowarczyk@t-online.de

1059-941X/05

doi: 10.1111/j.1532-849X.2005.00003.x

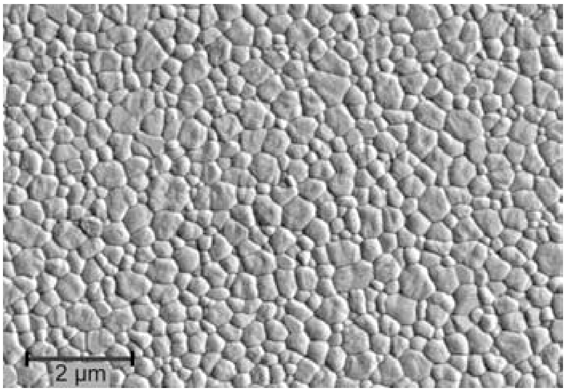

Figure 1. Microstructure of a densely sintered ZrO_2 blank (SEM photograph).

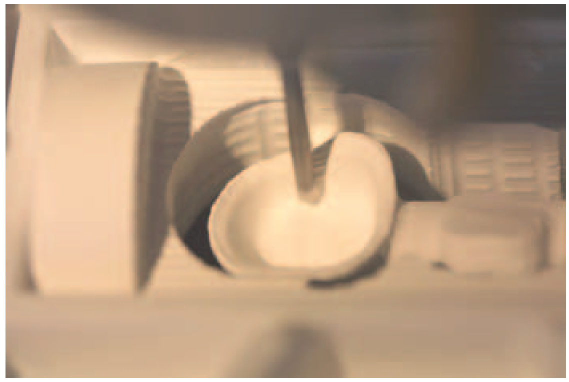

Figure 3. Milling a 3-unit bridge from a presintered ZrO_2 blank using carbide rotary instruments.

dental laboratory includes a special scanner (Lava Scan), a computerized milling machine (CAM) (Lava Form), and a sintering oven (Lava Therm) plus CAD/CAM software technology (Fig 2). Developing restorations with this system incorporates the following main steps:

1. After mounting a saw-cut working cast in the scanner, the configuration of the tooth preparations and any edentulous areas are scanned by a contact-free optical process that uses white light triangulation. The entire scanning process takes approximately 5 minutes for a crown preparation and 12 minutes for a 3-unit FPD.
2. In order to compensate for shrinkage during the sintering process (zirconia has a linear shrinkage of 20–25%), the CAM produces an enlarged framework structure. The average milling time for a crown coping is approximately 35 minutes for a crown preparation and 75 minutes for a 3-unit FPD substructure (Fig 3). After milling, the sprues holding the framework to the block of sintered zirconium are removed and reshaped by hand.
3. Sintering is accomplished using the Lava Therm, a special automated oven. The oven is preprogrammed to run for 8 hours, including the heating and the cooling phases (Fig 4). The sintered framework is then veneered with a ceramic material (Lava Ceram) specially adapted to the coefficient of thermal expansion (WAK 10 ppm) of zirconia.

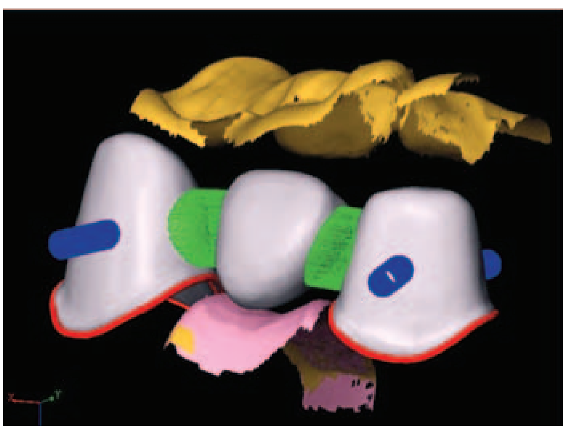

Figure 2. 3D CAD-generated bridge framework with pontic: scanning the alveolar ridge and the opposing dentition, individual connector design, and use of the "digital wax knife" to obtain ceramic veneer of uniform thickness.

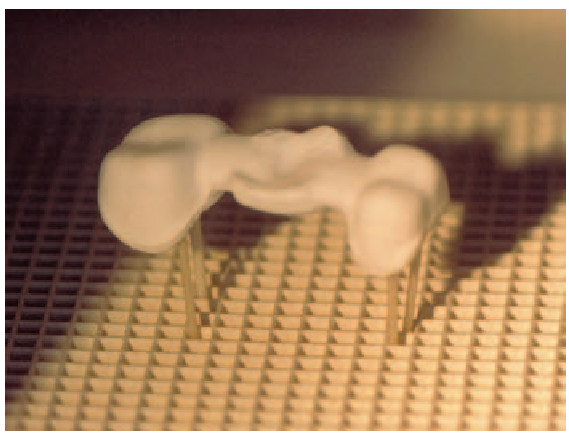

Figure 4. Moveable storage of the framework on the sintering mount of the Lava™ All-Ceramic System.

Results of Material Testing

Various *in vitro* and clinical studies, as well as studies based on animal experiments, have been conducted for the general scientific evaluation of zirconia ceramics, and for the Lava™ All-Ceramic System.

Takagi et al[16] investigated the properties of densely sintered zirconia with medium-sized grains of approximately 0.8 μm. The zirconia partially stabilized with 3.5 mol-percent Y_2O_3 exhibited a fracture toughness K_{IC} of 8.4 MPa $*$ $m^{1/2}$, an average elastic modulus of 200 GPa and flexural strength of 1,000 MPa, which is twice as high as pure Al_2O_3. Measured values for the flexural strength with a content of 5 mol-percent Y_2O_3 were lower than that of 3 mol-percent, since with an yttria content of more than 3-4%, the transformation toughening loses its effectiveness.

A study by Tinschert et al,[17] featuring different industry and laboratory-developed ceramic materials, demonstrated that zirconium TZP (Metoxit AG Thayngen, Switzerland) achieved the best results in the 4-point flexural strength with 913.0 ± 50.2 MPa. The industrial ceramics Zirconia and Cerec Mark II had the largest Weibull modulus at 18.4 and 23.6, respectively.

Christel et al[18] investigated a 5 mol-percent Y_2O_3 partially stabilized zirconia ceramic (Prozyr, Ceramiques Techniques Desmarquest, Trappes, France), which was either sintered in a depressurized manner or condensed by means of hot isostatic pressing (HIP). Fracture toughness K_{IC} was found to be 9–10 MPa $*$ $m^{1/2}$, the modulus of elasticity was 200 GPa, and flexural strength was 900 MPa (depressurized sintering) and 1,200 MPa (depressurized sintering and HIP).

The surface finish of the material has a decisive influence on the strength of ceramic materials. Kosmač et al[19] determined that the flexural strength and the Weibull modulus of different zirconia ceramics containing 3 mol-percent yttrium could be significantly reduced by dry or wet surface finish using diamond polishing instruments of 50 and 150 μm.

The static, flexural, and fatigue strength of high-performance zirconia TZP (Metoxit AG) and of the glass-infiltrated aluminum oxide ceramic In-Ceram (Vita Zahnfabrik, Bad Säckingen, Germany) were determined by Geis-Gerstorfer and Fäßler[20] in the 3-point bending test using specimens with 30 × 5 × 3 mm dimensions and rounded edges. A predefined microdefect was produced on the bottom of the specimen. The notches were created by using Knoop hardness indentations. The depths of the notches for zirconia and In-Ceram were 62 ± 0.6 and 75 ± 1.6 μm, respectively. Zirconia and In-Ceram exhibited values of 1,016 MPa and 426 MPa, respectively, in the static flexural strength of the notched specimens. After 10^6 cycles, zirconia and In-Ceram exhibited fatigue strength (DIN 50100) values of 480 and 130 MPa, respectively.

Jung et al[21] evaluated the decrease in strength of a feldspathic ceramic (Vita Mark II, Vita Zahnfabrik), a glass ceramic (MGC, Corning, Inc., Acton, MA), a glass-infiltrated aluminum oxide ceramic (Vita Celay In-Ceram, Vita Zahnfabrik), and a tetragonal zirconia ceramic stabilized with approximately 3 mol-percent yttrium (Y–TZP, Norton-St. Gobain, Raleigh, NC) with multicyclical loading using the Hertzian test.[22] To determine the "life expectancy" of the ceramic materials, the specimens (3 × 4 × 25 mm) were loaded from <40 ms to fracture in a 4-point bending test. The yttrium-stabilized zirconia yielded the best results in this study. No decrease in strength below a value of approximately 1,300 MPa was determined for a contact loading of 500 N and 10^6 cycles (Fig 5).

The change in mechanical properties of a zirconia partially stabilized with 2.5–3.0 mol-percent

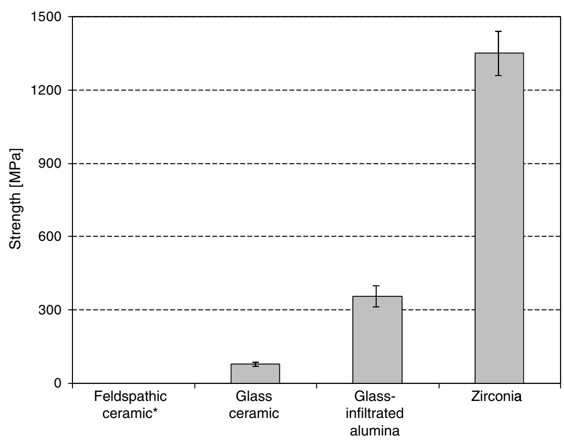

Figure 5. Strength (means and standard deviations) of different ceramic materials after 10^6 cycles and indentation with spheres (r = 3.18 mm) at a constant load (P = 500 N). *All feldspathic ceramic specimens showed no measurable results under the conditions outlined (Jung et al[21]).

Y_2O_3 (Kyocera Corp., Kyota, Japan) was investigated by Shimizu et al[23] *in vitro* and *in vivo*. Ceramic specimens measuring 10 × 3 × 1.5 mm were implanted in the shinbones of rabbits and tested for 3-point flexural strength. The initial strength was above 1,000 MPa *in vitro* and values of more than 700 MPa were determined for all probes after a period of 3 years *in vivo*.

In the 3-point bending test, Ichikawa et al[24] demonstrated measured values of approximately 1,300 MPa 12 months after implanting cylindrical zirconia ceramic specimens stabilized with 3 mol-percent yttrium (diameter: 2 mm, length: 10 mm) subcutaneously in rats. Fibrous tissue with a thickness of 46.9 ± 7.8 μm in the area of the implanted material also was determined after this time.

Rountree et al[25] investigated the tensile strength of Lava™ All-Ceramic System FPDs, which were subjected to 1.2×10^6 masticatory loadings with 50 N and 10,000 thermocycles (5°C/55°C) on movable abutments 24 hours after definitive cementing using KetacCem™ Cement (3M ESPE Dental Products). The results of the 3- and 4-unit bridges were 1,458 ± 407 N and 979 ± 245 N, respectively.

Rosentritt et al[26] determined the tensile strength of 3-unit bridges, whose intermediate units exhibited a length of 10 mm and were adhered to extracted teeth. After 6,000 thermocycles and mastication simulation (1.2×10^6) with 50 N, Lava™ All-Ceramic System bridge frameworks demonstrated significantly higher measured values (992 N) than Empress 2 (IvoclarVivadent) and InCeram frames (Vita) (387 and 334 N, respectively).

Tinschert et al[27] investigated the tensile strength of all-ceramic FPDs. An extended chamfer preparation on the abutment teeth demonstrated a cervical preparation depth of approximately 0.8 mm. To create the frames, the circular wall strength of the retainer crowns was determined at 0.6 mm, and the transverse sections of the connection places in the transitional area to the FPD units at 4 × 4 mm^2. Unveneered and veneered frames, which demonstrated strength of approximately 1.6–2.5 mm in the occlusal area, were loaded to fracture after fixing them on a metal model with zinc phosphate cement. Fracture values of 1,047 ± 153, 1,499 ± 155, and 1,937 ± 124 N, respectively, were determined for unveneered 3-unit FPD frames from IPS Empress 2 (IvoclarVivadent), InCeram Zirconia (Vita Zahnfabrik), and DC Zirkon (DCS Dental AG Zwijndrecht, Netherlands). Veneered FPDs demonstrated higher results of 1,332 ± 131 (IPS Empress 2), 1,692 ± 262 (InCeram Zirconia), and 2,289 ± 223 (DC Zirkon).

Hertlein et al[28] investigated the marginal fit of the Lava™ All-Ceramic System for anterior and posterior teeth with a chamfered preparation margin under a stereomicroscope. Corresponding to divisions made by Holmes et al[29] measured values of 38 ± 20 μm were determined for the marginal gap (MG) and 72 ± 36 μm for the absolute marginal discrepancy (AMD). Yeo et al[30] examined the marginal fit of anterior crowns from various all-ceramic systems under a microscope. Celay InCeram, conventional In-Ceram, and IPS Empress in layering technique exhibited values of 83 ± 33, 112 ± 55, and 46 ± 16 μm, respectively.

Clinical Report

The following clinical report shows the utilization of the Lava™ All-Ceramic System with 2 single crowns.

Figure 6 shows the preoperative clinical case with unacceptable crown margins on teeth #7 and #10. The existing crowns demonstrate a mismatch in color and shape compared to the adjacent and contralateral teeth. From a functional point of view, excursive movements were not possible without interference. The existing metal posts in the endodontically treated teeth #7 and #10 shone through in the root region and led to a discoloration of the gingival tissues.

After removing the crowns on teeth #7 and #10 and inserting all-ceramic posts and cores, the poorly contoured crown margins were reprepared and smoothed to form a chamfer for the Lava All-Ceramic System crowns. A consistent circumferential axial reduction of the core was achieved in the postpreparation along with marginal refinement. The fitting accuracy of the framework was tested in the patient's mouth before the ceramic veneer was applied (Figs 7 and 8).

Figure 9 details the crowns inserted on both of the posterior incisor teeth. Despite an unfavorable initial situation, an esthetically pleasing result was achieved in this case.

Summary and Recommendations

Using CAD/CAM technology, the Lava™ All-Ceramic System enables the manufacture of an

Figure 6. Baseline situation with insufficient crown margins on the maxillary lateral incisors.

Figure 8. Try-in of the Lava all-ceramic system frameworks.

individually created, high-strength, densely sintered framework from zirconia. The yttria-partially-stabilized zirconium oxide ceramic is processed in a softer, presintered condition, simultaneously shortening the processing time while reducing the wear of the milling machine.

Laboratory tests conducted by various authors[12,13,16-21,23-27] have shown that zirconia ceramic with a percentage of approximately 3% mol-yttria is significantly superior to other hard core ceramics with regard to mechanical properties and fatigue loading. Based on the test results available in the literature, the Lava™ All-Ceramic System is indicated for crowns and 3-unit FPD restorations in the anterior and posterior areas.

For the creation and processing of FPD constructions with 2 intermediate units, Körber and Ludwig[31] concluded that the patient should exhibit a median maximum masticatory strength of approximately 293 N.

With regard to the clinical use of all-ceramic FPDs in posterior areas, Tinschert et al[32] called for an initial strength of 1,000 N. This takes into consideration that the permanent strength of ceramics can be reduced by half the initial value because of the below-critical crack growth after longer-term stress. Even unveneered 3- and 4-unit zirconia hard core frameworks achieved the stated loading limit of 1,000 N. Veneered systems show a further increase in strength[27,32] and permit the assumption that, in the bonding process, a stable connection of the ceramic veneer mass to the zirconia framework is formed. The design of the connectors between crown and pontic is significant for FPD frameworks, as this area is especially in danger of fracture.[33]

Because of biomechanics and esthetics, a highly invasive process with a high loss of substance should be avoided. Accordingly, the high strength

Figure 7. Zirconia frameworks individually manufactured with the Lava all-ceramic system on the die before veneering.

Figure 9. Lava all-ceramic crowns *in situ* on teeth #7 and #10.

of the Lava™ All-Ceramic System provides for the manufacture of substructures with adequate coping strength and a thickness average of 0.5 mm. The possibility of performing a minimally invasive preparation reduces the risk that the vitality of the crowned tooth is lost.

Likewise, because of the clinically acceptable marginal fit, the manufacturing process of the framework is proven successful. The single-phase ceramic used for the veneer not only offers excellent esthetic properties (opalescence, translucence), but also a high degree of homogeneity and good surface properties. The latter characteristics promote noninflammatory apposition of the periodontal tissues.

The Lava all-ceramic system and the CAD/CAM technology used in manufacturing all-ceramic crowns and 3-unit FPDs for anterior and posterior regions meet high demands regarding esthetics and function. A clinical follow-up study of 21 3-unit zirconia posterior bridges bonded with an adhesive and processed according to DCM (Direct Ceramic Machining Process, ETH Zurich, Switzerland) showed that after an observation period of 385 days, none of the restorations showed fractures or splitting.[34,35]

In summary, extensive laboratory testing to date has confirmed the strength superiority of zirconia ceramic. Further long-term (5–10 year) clinical studies are needed to confirm that the utilization of the Lava All-Ceramic system meets demands concerning strength, fit, and esthetics.

References

1. Cales B: Zirconia as a sliding material: histologic, laboratory, and clinical data. Clin Orthop 2000;379:94-112.
2. Cales B, Stefani Y, Lilley E: Long-term in vivo and in vitro aging of a zirconia ceramic used in orthopaedy. J Biomed Mater Res 1994;28:619-624.
3. Keith O, Kusy RP, Whitley JQ: Zirconia brackets: an evaluation of morphology and coefficients of friction. Am J Orthod Dentofacial Orthop 1994;106:605-614.
4. Strub JR, Pontius O, Koutayas S: Survival rate and fracture strength of incisors restored with different post and core systems after exposure in the artificial mouth. J Oral Rehabil 2001;28:120-124.
5. Kern M, Simon MHP, Strub JR: Clinical evaluation of all-ceramic zirconia posts. A pilot study. J Dent Res 1997;76:293 (abstract 2234).
6. Meyenberg KH, Lüthy H, Schärer P: Zirconia posts: a new all-ceramic concept for nonvital abutment teeth. J Esthet Dent 1995;7:73-80.
7. Ottl P, Hahn L, Laurer HCH, et al: Fracture characteristics of carbon fibre, ceramic and non-palladium endodontic post system at monotonously increasing loads. J Oral Rehabil 2000;29:175-183.
8. Akagawa Y, Ichikawa Y, Nikai H, et al: Interface histology of unloaded and early loaded partially stabilized zirconia endosseous implant in initial bone healing. J Prosthet Dent 1993;69:599-604.
9. Prestipino V, Ingber A: Esthetic high-strength implant abutments. Part I. J Esthet Dent 1993;5:29-36.
10. Filser F, Eglin M, Lüthy H, et al: FEA study of DCM machined zirconia vs Vita-Celay In-ceram bridges. J Dent Res 1999;78:204 (abstract 792).
11. Lüthy H, Filser F, Gauckler L, et al: Reliability of DCM machined zirconia bridges: comparison for different interdental connector areas. J Dent Res 1999;78:205 (abstract 793).
12. Green DJ, Hannink RHJ, Swain MV: Transformation Toughening of Ceramics. Boca Raton, CRC Press, 1989, pp 137-144.
13. Rieger W: Medical applications of ceramics. In Kostorz G: High-Tech Ceramics. London, Academic Press, 1989, pp 191-228.
14. Yanagida H, Komoto K, Miyayama M: The Chemistry of Ceramics. Chichester, NY, Wiley, 1996, pp 247-249.
15. Marx R: Moderne keramische Werkstoffe für ästhetische Restaurationen—Verstärkung und Bruchzähigkeit [Modern ceramic materials for aesthetic restorations—strengthening and tensile strength.] Dtsch Zahnärztl Z 1993;48:229-236.
16. Takagi H, Nishioka K, Kawanami T, et al: The properties of a closely sintered zirconia. Ceram Forum Int 1985;62:195-198.
17. Tinschert J, Zwez D, Marx R, et al: Structural reliability of alumina-, feldspar-, leucite-, mica- and zirconia-based ceramics. J Dent 2000;28:529-535.
18. Christel P, Meunier A, Heller M, et al: Mechanical properties and short-term in-vivo evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res 1989;23:45-61.
19. Kosmač T, Oblak C, Jevnikar P, et al: Strength and reliability of surface treated Y-TZP dental ceramics. J Biomed Mater Res 2000;53:304-313.
20. Geis-Gerstorfer J, Fäßler P: Untersuchungen zum Ermüdungsverhalten der Dentalkeramiken Zirkondioxid-TZP und In-Ceram. [Fatigue tests of ZrO_2–TZP and In-Ceram.] Dtsch Zahnärztl Z 1999;54:692-694.
21. Jung YG, Peterson IM, Kim DK, et al: Lifetime-limiting strength degradation from contact fatigue in dental ceramics. J Dent Res 2000;79:722-731.
22. Guiberteau F, Padture NP, Cai H, et al: Indentation fatigue: a simple cyclic Hertzian test for measuring damage accumulation in polycrystalline ceramics. Phil Mag 1993;68:1003-1016.
23. Shimizu K, Oka M, Kumar P, et al: Time-dependent changes in the mechanical properties of zirconia ceramic. J Biomed Mater Res 1993;27:729-734.
24. Ichikawa Y, Akagawa Y, Nikai H, et al: Tissue compatibility and stability of a new zirconia ceramic in vivo. J Prosthet Dent 1992;68:322-326.
25. Rountree P, Nothdurft F, Pospiech P: In-vitro-investigations on the fracture strength of all-ceramic

posterior bridges of ZrO_2-ceramics. J Dent Res 2001;80:57 (abstract 173).
26. Rosentritt M, Behr M, Lang R, et al: Fracture strength of tooth colored posterior fixed partial dentures. J Dent Res 2001;80:57 (abstract 174).
27. Tinschert J, Natt G, Jorewitz A, et al: Belastbarkeit vollkeramischer Seitenzahnbrücken aus neuen Hartkernkeramiken. [Fracture strength of all-ceramic fixed partial dentures.] Dtsch Zahnärztl Z 2000;55:610-616.
28. Hertlein G, Höscheler S, Frank S, et al: Marginal Fit of CAD/CAM manufactured all ceramic zirconia prostheses. J Dent Res 2001;80:42 (abstract 049).
29. Holmes JR, Bayne SC, Holland GA, et al: Considerations in measurement of marginal fit. J Prosthet Dent 1989;62:405-408.
30. Yeo IS, Yang JH, Lee JB: In vitro marginal fit of three all-ceramic crown systems. J Prosthet Dent 2003;90:459-464.
31. Körber KH, Ludwig K: Maximale Kaukraft als Berechnungsfaktor zahntechnischer Konstruktionen. [Maximum mastication force as a calculatory factor in dental constructions.] Dent Lab 1983;83:55-60.
32. Tinschert J, Natt G, Doose B, et al: Seitenzahnbrücken aus hochfester Strukturkeramik. [High performance ceramic posterior bridges.] Dtsch Zahnärztl Z 1999;54:545-550.
33. Kelly JR, Tesk JA, Sorensen JA: Failure of all-ceramic fixed partial dentures in vitro and in vivo: analysis and modeling. J Dent Res 1995;74:1253-1258.
34. Sturzenegger B, Feher A, Lüthy H, et al: Klinische Studie von Zirkonoxidbrücken im Seitenzahnbereich mit dem DCM-System. [Clinical study of zirconia bridges in posterior areas using the DCM system] Acta Med Dent Helv 2000;5:131-139.
35. Filser F, Kocher P, Weibel F, et al: Reliability and strength of all-ceramic dental restorations fabricated by direct ceramic machining (DCM). Int J Comput Dent 2001;4:89-106.