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A Clinical Comparison of Zirconia, Metal and Alumina Fixed-Prosthesis Frameworks Veneered With Layered or Pressed Ceramic: A Three-Year Report

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A clinical comparison of zirconia, metal and alumina fixed-prosthesis frameworks veneered with layered or pressed ceramic

A three-year report

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ABSTRACT

Background. The authors conducted a randomized controlled clinical trial to determine whether performance differed between metal, zirconia and alumina fixed partial denture (FPD) frameworks veneered with pressed or layered ceramics designed for each framework type.

Methods. Posterior three-unit FPDs (N = 293) of 10 different framework/veneer ceramic combinations were placed by 115 dentists in 259 patients from their practices according to a masked protocol. Yearly, the clinicians graded the prostheses and the opposing dentition in vivo according to 17 criteria, and two independent scientists graded them in vitro by using gold-sputtered dies, scanning electron micrographs and clinical photographs.

Results. Three metal and five zirconia frameworks tested were not statistically different, with zero and two fractures, respectively. Alumina frameworks were statistically worse, with 11 fractures. The veneer ceramics CZR Press (Noritake Dental, Aichi, Japan) and Pulse interface (Jensen Dental, North Haven, Conn.) performed best with zirconia and metal frameworks, respectively. Four nonleucite-containing veneer ceramics used with zirconia frameworks had substantially more fractures.

Conclusions. Five zirconia framework brands performed equally well and were statistically comparable with metal frameworks at three years. Two leucite-containing veneer ceramics applied by means of pressing techniques had the statistically lowest number of fractures.

Clinical Implications. Dentists can use metal or zirconia frameworks successfully if they are designed properly, but to avoid veneer ceramic surface crumbling and minimize chipping, use of leucite-containing pressed ceramics is indicated.

Key Words. Restorative dentistry; fixed prosthodontics; dental materials; CAD/CAM; clinical protocols.

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In the past decade, significant changes have occurred in materials and methods used to fabricate fixed partial dentures (FPDs). Machining of zirconia, electrophoretic deposition of alumina and pressing of veneer ceramics are just a few changes challenging the 50-year supremacy of cast metal hand veneered with ceramic. It has yet to be determined clinically if the innovations have resulted in improvements. Direct clinical comparisons of zirconia-ceramic, alumina-ceramic and metal-ceramic restorations are needed to optimize patient care.

Desire for esthetics and biocompatibility brought all-ceramic restorations into dentistry well over 100 years ago.[1-4] Although some all-ceramic restorative materials have served well in single-unit and anterior multiunit restorations, all-ceramic restorations have shown less durability in posterior multiunit applications.[1-3,5-11] Today, yttria-reinforced zirconium oxide—zirconia—shows promise as a robust and durable material for use throughout the oral cavity, including in posterior multiunit restorations.[12] It has the highest flexural strength and fracture toughness available in dental ceramics.[13-16] In the continuing search for durable, highly esthetic dental materials, zirconia now is the center of attention. Proposed applications for zirconia in the oral cavity beyond FPDs include implant

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abutments, posts and orthodontic brackets.[17-20]

Several aspects of zirconia dental restorations require investigation in randomized controlled clinical trials. These include possible differences in performance between zirconia from different sources and performance of the veneering ceramics formulated specifically for use with zirconia. These veneering ceramics do not have in their formulations the leucite that traditionally is present in ceramics used with metals. This exclusion compensates for differences in coefficients of thermal expansion between metals and zirconias. The clinical performance of the new ceramics for zirconia has been questioned[5,12,21-27] but not yet fully investigated in controlled clinical trials that included different types of metal-ceramic restorations for direct comparisons. Pressing versus hand layering is another aspect of the new veneering ceramics that lacks validation in controlled clinical trials. Only a few researchers have reported about the pressing of ceramics.[28-31]

The goal of our randomized controlled clinical trial was to compare the performance of different framework materials and different veneering ceramics by using a practice-based research protocol to simulate real-world conditions.

MATERIALS, PARTICIPANTS AND METHODS

Selection of materials. Table 1 lists the materials, their sources and the fabrication methods we selected for the study. The zirconias we selected were from three sources, fully sintered or presintered and fabricated by means of computer-aided design/computer-aided manufacturing (CAD-CAM) and by using direct ceramic machining or digital imaging. The alumina we selected used electrophoretic deposition, and the metals we selected used cast or hand-adapted technologies. We sought hand-layered and pressed veneer ceramics for the three framework categories. The two ceramics pressed to zirconia (CZR Press [Noritake Dental, Aichi, Japan] and IPS e.max ZirPress [Ivoclar Vivadent, Amherst, N.Y.]) entered the study one year later because they were unavailable initially. We planned for the study to involve 32 three-unit posterior prostheses composed of each of the 10 framework-veneer ceramic combinations.

Selection of participants. ***Dentists.*** Criteria for the dentists we selected to participate in the study were as follows:

- known clinical ability from past associations with the Technologies in Restorative and Caries Research Foundation, Provo, Utah;
- experience with an all-ceramic system;
- active participation in clinical practice;
- willingness to participate in a long-term clinical trial;
- a personal profile that contributed diversity typical of dentists in general.

The group consisted of 106 general dentists and nine prosthodontists, of whom 108 were male and seven were female. They had a mean practice experience of 24 years (range, 1-54 years), and they had practices in 28 states in the United States and in two other countries.

Patients. We drew the patient participants from the patient pool of the participating dentists' practices. Inclusion criteria were as follows:

- need for a three-unit posterior prosthesis;
- presence of dentition opposing and adjacent to the test prosthesis;
- good overall health;
- no untreated occlusal problems;
- no active periodontal disease;
- no known sensitivity to study materials;
- desire to participate in a clinical evaluation;
- geographical stability.

The 259 patients consisted of 96 men and 163 women, and their mean age was 50 years (range, 16-89 years).

The study protocol was reviewed and approved by the internal review board of our research institute (Clinicians Report Foundation, Provo, Utah). All participants received oral and written information regarding the study purposes, and all of them provided written informed consent.

Selection of laboratories, technicians and fabrication techniques. We asked the manufacturers of the products selected for study to choose two commercial laboratories within the United States to fabricate 16 prostheses each. In-house laboratories were not permitted. In each case, the manufacturer or laboratory administrator selected the framework technician and ceramist to perform the work. Table 2 (page 1320) lists the two laboratories that fabricated each framework/veneer ceramic combination. The laboratory technicians knew they were participating in a clinical comparative study and could identify the specific study cases because their laboratory pre-

ABBREVIATION KEY. CAD/CAM: Computer-aided design/computer-aided manufacturing. **FPD:** Fixed partial denture. **SEM:** Scanning electron microscope.

TABLE 1

Materials, sources and fabrication methods used in this study.

FRAMEWORK TYPE	FRAMEWORK		VENEER CERAMIC		FRAMEWORK/VENEER CERAMIC HANDLING METHODS
	Brand	Manufacturer	Brand	Manufacturer	
Zirconia	Cercon Zirconia (presintered)	DeguDent, Hanau, Germany, and Dentsply, York, Pa.	Ceramco PFZ	Dentsply	Direct ceramic machining/hand layering
	Everest Fully Sintered	Metoxit, Thayngen, Switzerland, and KaVo Dental, Charlotte, N.C.	Initial ZR	GC, Tokyo	CAD-CAM*/hand layering
	Everest Presintered	Metoxit and KaVo	CZR Press†‡	Noritake Dental, Aichi, Japan	CAD-CAM/pressing
	IPS e.Max ZirCAD (presintered)	Metoxit and Ivoclar Vivadent, Amherst, N.Y.	IPS e.max ZirPress†‡	Ivoclar Vivadent	CAD-CAM/pressing
	Lava Zirconia (presintered)	3M ESPE, St. Paul, Minn.	Lava Ceram	3M ESPE	CAD-CAM/hand layering
Alumina	Wol-Ceram	Wol-Dent, Bad Soberheim, Germany	Cerabien Layered	Noritake Dental	Electrophoretic deposition/hand layering
	Wol-Ceram	Wol-Dent	Cerabien Experimental Pressed‡	Noritake Dental and Glidewell Laboratories, Newport Beach, Calif.	Electrophoretic deposition/pressing
Metal	Argedent 65SF (high noble, silver-free alloy)	Argen, San Diego	Pulse interface‡	Jensen Dental, North Haven, Conn.	Casting/pressing
	Captek (gold, platinum, palladium)	Precious Chemicals, Altamonte Springs, Fla.	Creation	Jensen Dental	Hand adaptation/ hand layering
	Ceramco Ultra Crown SF (high noble, silver-free alloy)	Dentsply	Ceramco Soft-Wear Enamels	Dentsply	Casting/hand layering

* CAD/CAM: Computer-aided design/computer-aided manufacturing.
† Not available when study initiated; entered one year later.
‡ Pressed veneer ceramic.

scription form omitted names of the laboratory, dentist and patient for masking purposes.

Clinical procedures. We standardized clinical procedures with detailed written instructions. Periapical radiographs and clinical images were obtained before treatment. Tooth preparations were specified as 1.5 to 2.0 millimeters of occlusal reduction and 1.5 mm of axial reduction with a 1.2-mm heavy chamfer at the margins. We received the following items from the dentists and forwarded them to the respective laboratories: full-arch impression with preparations, opposing cast, interocclusal record and masked laboratory prescription. Materials and laboratories were assigned to cases by means of a computerized randomization table prepared by the statistician. The dentists were masked as to material and laboratory names. Before cementation, the dentists evaluated the prostheses for fit, then cemented them with resin-modified glass ionomer cement (RelyX Luting Plus Cement, 3M ESPE, St. Paul, Minn.).

Evaluation methods. The clinicians performed the following procedures after cementation and annually: obtaining close-up intraoral images of the prosthesis and opposing dentition; making polyvinyl silicone impressions of the prosthesis and opposing dentition; and performing standardized clinical grading according to the 17 criteria listed in Table 3 (page 1321).

Two scientists at the Technologies in Restorative and Caries Research Foundation, who were required to reach consensus, used standardized forms to reconfirm clinical grades for five variables that were difficult to see clinically (fractures, surface smoothness, wear on the prosthesis, wear on opposing dentition, occlusal adjustment). To accomplish this, they used color clinical photographic prints, prints of images made on a scanning electron microscope (SEM) (Quantum 600, FEI Company, Hillsboro, Ore.) and gold-sputtered polyurethane replicas of the prostheses.

Statistical analyses. Descriptive statistics (number and percentage) were used to report

TABLE 2

Laboratories selected to fabricate the prostheses,* according to framework type.

FRAMEWORK TYPE	FRAMEWORK BRAND†	VENEER CERAMIC BRAND†	LABORATORY
Zirconia	Cercon Zirconia	Ceramco PFZ	Arrowhead Dental Laboratory, Sandy, Utah Fort Washington Dental Laboratory, Fort Washington, Pa.
	Everest Fully Sintered	Initial ZR	Blue West Dental Laboratory, El Dorado Hills, Calif. Jason Kim Dental Laboratory, Great Neck, N.Y.
	Everest Presintered	CZR Press‡	Esthetic Dental Arts, Albuquerque, N.M. Jason Kim Dental Laboratory
	IPS e.max ZirCAD	IPS e.max ZirPress‡	Mosaic Studios, Bradenton, Fla. Smile Designs by Rego, Santa Fe Springs, Calif.
	Lava Zirconia	Lava Ceram	Dental Crafters, Marshfield, Wis. Stanley Okon Dental Laboratory, Laguna Woods, Calif.
Alumina	Wol-Ceram	Cerabien Layered	Glidewell Laboratories, All-Ceramic Section, Newport Beach, Calif.
	Wol-Ceram	Cerabien Experimental Pressed‡	Glidewell Laboratories, Pressing Section
Metal	Argedent 65SF	Pulse interface‡	Esthetic Dental Arts Dental South, Gainesville, Ga.
	Captek	Creation	Bay View Dental Laboratory, Chesapeake, Va. Da Vinci Dental Studios, West Hills, Calif.
	Ceramco Ultra Crown SF	Ceramco SoftWear Enamels	Lord's Dental Studio, De Pere, Wis. Nakanishi Dental Laboratory, Bellevue, Wash.

* Manufacturers of the framework-veneer ceramic combination listed were asked to select two commercial laboratories anywhere within the United States to fabricate 16 prostheses each. Use of manufacturers' in-house laboratories was not permitted.
† Manufacturers are listed in Table 1.
‡ Pressed veneer ceramic.

status of the materials at each year. Statisticians used χ^2 and exact χ^2 to analyze graded criteria and number of prostheses with the different types of fractures shown in Figures 1 and 2 (page 1322). They analyzed the number of fractures per prosthesis by using analysis of variance and controlling for span length. We report survival rates and time to prosthesis replacement according to the Kaplan-Meier method.

RESULTS

Descriptive statistics. One hundred fifteen dentists placed 293 posterior prostheses (almost all of them three-unit FPDs) in 259 patients: 109 in the maxilla and 184 in the mandible. Ten prostheses replaced second molars, 260 replaced first molars and 23 replaced second premolars. Table 4 (page 1323) records the status of the prostheses overall and for each system at one, two and three years. As shown in Table 4, eight systems were at their three-year recall and two were at their two-year recall because veneer ceramics pressed to zirconia were not available initially. Recall rates were 99.7 percent, 98 percent and 97 percent at one, two and three years, respectively. Fewer than the 32 prostheses were planned for each of two systems (Wol-Ceram [Wol-Dent, Bad Soberheim, Germany]/Cerabien Layered [Noritake Dental] and Wol-Ceram/Cerabien Experimental Pressed [Noritake Dental and Glidewell Laboratories, Newport Beach, Calif.]) because of concern about framework fractures shortly after placement.

Nonstatistically different variables. All 10 systems performed at an overall A to B level (as defined in Table 3), whether graded clinically or in vitro in 16 of the 17 characteristics. Only fractures showed statistical differences. From this point forward, we will report framework and veneer ceramic fractures separately. Overall, endodontic therapy was 4 percent, dental caries 1 percent and patient satisfaction 95 percent graded as excellent.

Framework fractures. As Table 5 (page 1324) shows, 11 of 13 framework fractures (85 percent) involved Wol-Ceram alumina electrophoretic deposition technology. Two zirconia frameworks broke, one at 36 months (Everest Fully Sintered [Metoxit, Thayngen, Switzerland, and KaVo Dental, Charlotte, N.C.]/Initial ZR [GC, Tokyo]) and one at 40 months (Cercon Zirconia

TABLE 3

Criteria used to grade the condition of the prostheses clinically and in vitro.*

CRITERION	DEFINITION			
	A	B	C	D
1. Overall Esthetics	Matches adjacent tooth color and translucency	Slight mismatch	Obvious mismatch	NA†
2. Surface Smoothness*	Entire surface of prosthesis resembles enamel	Up to one-quarter of surface has porosity, rough texture or both	Up to one-half of surface has porosity, rough texture or both	More than one-half of surface has porosity, rough texture or both
3. Wear on Prosthesis*	No observable wear	One to three small wear facets ≤ 0.25 square millimeters	Four to six moderate wear facets ≤ 0.50 mm^2	Any number of wear facets > 0.50 mm^2
4. Wear of Opposing Teeth*	No observable wear	One to three small wear facets ≤ 0.25 mm^2	Four to six moderate wear facets ≤ 0.50 mm^2	Any number of wear facets > 0.50 mm^2
5. Retention	Abutment crown secure	NA	NA	Abutment crown loose
6. Margin Fit Using ×2 Magnification	No opening visible	Slight opening barely perceptible	Opening ≤ 0.25 mm	Opening > 0.25 mm
7. Gingival Health of Abutment Teeth	Normal color and texture, no swelling	Redness and swelling at gingival margin, bleeding on gentle probing	Redness and swelling beyond gingival margin, bleeding on probing, increase in probing depth	Redness, swelling, bleeding on probing, radiographically visible bone loss
8. Interproximal Contact	Tight contact: floss passage similar to natural tooth contacts	Light contact: floss passes through easily	NA	No contact
9. Fracture*	No cracks or small pieces of ceramic missing	Small crack or piece of ceramic missing, but does not compromise periodontal health or occlusion	NA	Large crack or piece of ceramic missing, which compromises periodontal health or occlusion
10. Postoperative Sensitivity	Tooth is not sensitive	NA	Tooth is sensitive to air, tactile stimulus or both, but prosthesis replacement not requested	Extreme sensitivity; patient requested replacement; date replaced _____
11. Duration of Sensitivity (If Present)	No sensitivity	Sensitivity present for three weeks or less, but replacement not requested	Sensitivity present for longer than three weeks, but replacement not requested	NA
12. Endodontics	Not required	NA	NA	Required; date performed _____
13. Occlusal Adjustment*	None	A few small areas ≤ 10 percent of surface	11 to 30 percent of surface	> 30 percent of surface
14. Plaque Accumulation on Prosthesis	None	≤ 25 percent of surface	26 to 50 percent of surface	> 50 percent of surface
15. Caries	None	NA	NA	Carious
16. Patient's Rating of Prosthesis "Feel"	Prosthesis feels like natural teeth elsewhere in the oral cavity	Prosthesis feels good, but the following characteristics are different from natural teeth (circle = smoothness, bite, taste, list any other points _____)	Prosthesis "feel" is objectionable, but replacement not requested	Prosthesis "feel" is objectionable and replacement is requested; date replaced _____
17. Patient's Rating of Esthetics	Prosthesis looks like natural teeth elsewhere in the oral cavity	Prosthesis differs slightly in appearance from natural teeth elsewhere in the oral cavity	Prosthesis appearance does not resemble that of natural teeth elsewhere in the oral cavity, but replacement not requested	Prosthesis appearance does not resemble that of natural teeth elsewhere in the oral cavity and replacement is requested; date replaced _____

* Grades reconfirmed by means of scanning electron micrographic prints, gold-sputtered dies and clinical photographic prints.
† NA: Not applicable.

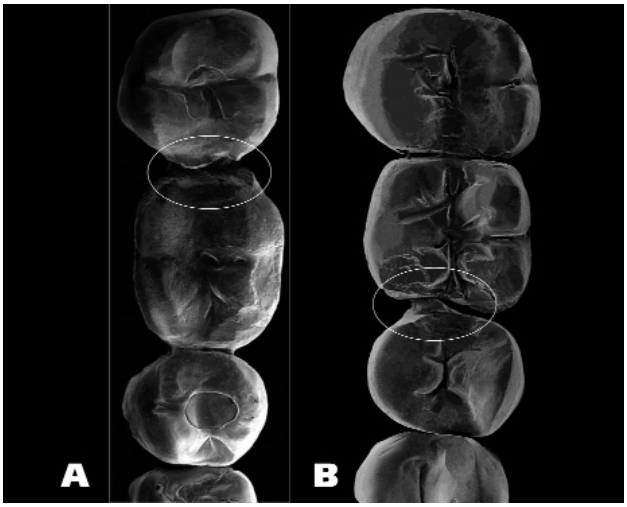

Figure 1. Scanning electron microscopic image of the two zirconia prostheses with framework fractures. Endodontic treatment, occlusal adjustment and possible fabrication error may have contributed to these fractures. **A.** Everest Fully Sintered (Metoxit, Thayngen, Switzerland, and KaVo Dental, Charlotte, N.C.)/Initial ZR (GC, Tokyo) prosthesis (pontic span length, 14.9 millimeters), which broke at 36 months. **B.** Cercon Zirconia (DeguDent, Hanau, Germany, and Dentsply, York, Pa.)/Ceramco PFZ (Dentsply) prosthesis (pontic span length, 12.8 mm), which broke at 40 months.

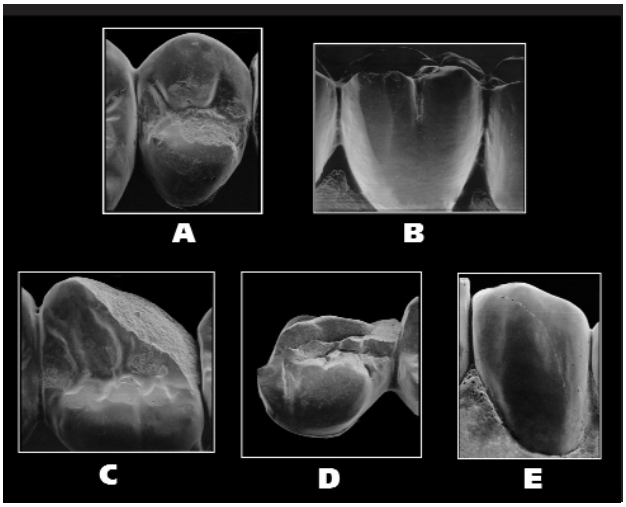

Figure 2. Scanning electron microscopic images defining five types of veneer ceramic fractures identified in this study. **A.** Surface crumbling. **B.** Chip. **C.** Large fracture. **D.** Delamination. **E.** Crack.

[DeguDent, Hanau, Germany, and Dentsply, York, Pa.]/Ceramco PFZ [Dentsply]). Figure 1 shows the SEM appearance of the two zirconia framework fractures. No metal frameworks broke. χ^2 analyses showed that framework fractures were statistically more numerous for alumina than for metal or zirconia ($P < .001$). No difference between metal and zirconia frameworks was apparent. Performances of the five zirconia brands tested, which came from three manufacturing sources (3M ESPE, DeguDent, Metoxit), were not statistically different.

Because of high fracture rate of their alumina frameworks, we removed Wol-Ceram prostheses from the study for replacement. Therefore, in the following section on veneer ceramic fractures, we report only on zirconia-based and metal-based restorations.

Veneer ceramic fractures. Veneer ceramic fractures were the most prevalent problem in this clinical trial. However, they did not necessitate prosthesis replacement unless their size or location compromised periodontal health or occlusion. We identified five types of fractures: surface crumbling, chips, large fractures, delaminations and cracks (Figure 2). Surface crumbling and chips were the most prevalent fracture types, with an overall total number of 191 and 189 incidents, respectively. There were substantially fewer instances of large fractures (27), delaminations (10) and cracks (10). Figure 3 (page 1325) shows the mean number of veneer ceramic fractures per prosthesis across time. For this analysis, we summed the total number of veneer ceramic fractures on metal or zirconia frames and divided them by the total number of zirconia-based and metal-based prostheses placed. The data show that the number of fractures per prosthesis of the veneer ceramics for zirconia was three or more times that of the veneer ceramics for metal ($P < .001$ at years 1, 2 and 3). Even at three years, the veneer ceramics for metal averaged fewer than one fracture per prosthesis.

Figure 4 (page 1325) shows the percentage of prostheses with fractures according to material and year. These data show that veneer ceramic fractures occurred across all veneer ceramics tested but were present significantly more often with the ceramics used on zirconia than with those used on metal ($P < .001$). Comparing CZR Press veneer ceramic with the other four ceramics tested for zirconia at two years, CZR Press had significantly fewer fracture events ($P < .001$). Its two-year performance was comparable with the two-year performance of the three ceramics used on metals. The other pressed-to-zirconia ceramic (IPS e.max ZirPress) had almost twice as many fracture events as did CZR Press, and its two-year performance was comparable with the two-year performance of the ceramics that were hand layered over zirconia. Pulse interface (Jensen Dental, North Haven, Conn.) pressed-to-metal ceramic prostheses had the least number of fractures at years 1, 2 and 3.

TABLE 4

Status of each prosthesis of the 10 framework–veneer ceramic systems overall and at one, two and three years, according to framework type.

FRAMEWORK/ VENEER CERAMIC*	RECALL YEAR	NO. PLACED	NO. RECALLED	NO. UNABLE TO BE RECALLED	FRAMEWORK FRACTURE	NO. OF VENEER CERAMIC FRACTURES, BY TYPE					NO. REPLACED	SURVIVAL RATE (%)†
						Surface Crumbling	Chip	Large Fracture	Delamination	Crack		
Zirconia Framework												
Cercon Zirconia/ Ceramco PFZ	1	32	30	1	0	8	10	2	1	0	1	97
	2		29	1	0	10	13	4	1	0	2	94
	3		24	2	1	13	15	8	1	0	6	81
IPS e.max ZirCAD/ IPS e.max ZirPress‡§	1	33	32	0	0	1	10	1	0	0	1	97
	2		32	0	0	6	13	3	0	0	1	97
	3		No three-year data as of press time. Veneer ceramics pressed to zirconia were not available until one year after this study was initiated.									
Everest Fully Sintered/ Initial ZR	1	33	32	0	0	8	6	1	0	0	1	97
	2		32	0	0	10	11	4	0	0	1	97
	3		28	1	1	18	14	6	0	0	4	88
Everest Presintered/ CZR Press‡§	1	33	33	0	0	0	5	1	0	0	0	100
	2		31	2	0	0	8	1	0	0	0	100
	3		No three-year data as of press time. Veneer ceramics pressed to zirconia were not available until one year after this study was initiated.									
Lava Zirconia/ Lava Ceram	1	32	31	0	0	11	15	3	2	0	1	97
	2		30	0	0	13	16	6	2	0	2	94
	3		28	0	0	14	21	8	3	0	4	87
Metal Framework												
Argedent 65SF/Pulse interface§	1	32	32	0	0	0	2	0	1	0	0	100
	2		31	1	0	0	4	0	1	0	0	100
	3		30	2	0	0	6	0	1	0	0	100
Captek/ Creation	1	32	31	0	0	1	2	1	1	4	1	97
	2		29	0	0	1	4	2	2	5	3	91
	3		27	0	0	2	6	3	4	5	5	84
Ceramco UltraCrown SF/ Ceramco SoftWear Enamels	1	32	32	0	0	3	1	1	0	0	0	100
	2		30	2	0	6	4	1	0	1	0	100
	3		30	2	0	8	7	1	0	1	0	100
Alumina Framework												
Wol-Ceram/ Cerabien Layered	1	21	18	0	3	3	5	0	0	1	3	86
	2		17	0	4	4	8	0	0	1	4	81
	3		16	0	5	5	11	1	0	3	5	76
Wol-Ceram/ Cerabien Experimental Pressed§	1	13	9	0	3	0	4	0	1	1	4	69
	2		7	0	6	1	6	0	1	1	6	54
	3		7	0	6	2	6	0	1	1	6	54
Overall												
All materials	1	293	280	1	6	35	60	10	6	6	12	96
	2		268	6	10	51	87	21	7	8	19	94
	3		190	7	13	62	86	27	10	10	31	88

* Manufacturers are listed in Table 1.
† Kaplan-Meier estimates.
‡ Not available when study initiated; entered one year later.
§ Pressed veneer ceramic.

Large veneer ceramic fractures, delaminations and cracks that compromised function or periodontal health necessitated 48 percent of the 31 prosthesis replacements (Table 5, page 1324). Although the most commonly occurring fracture events—surface crumbling and chipping—generally

TABLE 5

Reasons for replacement of 31 of the 253 prostheses recalled.

FRAMEWORK/VENEER CERAMIC* REPLACED, ACCORDING TO REASON FOR REPLACEMENT	NO. REPLACED
Framework Fracture	
Cercon Zirconia/Ceramco PFZ	1
Everest Fully Sintered/Initial ZR	1
Wol-Ceram/Cerabien Experimental Pressed	6
Wol-Ceram/Cerabien Layered	5
TOTAL	**13**
Veneer Ceramic Fracture†	
Captek/Creation	4
Cercon Zirconia/Ceramco PFZ	4
IPS e.max ZirCAD/IPS e.max ZirPress	1
Everest Fully Sintered/Initial ZR	3
Lava Zirconia/Lava Ceram	3
TOTAL	**15**
Dental Caries	
Captek/Creation	1
Cercon Zirconia/Ceramco PFZ	1
Lava Zirconia/Lava Ceram	1
TOTAL	**3**

* Manufacturers are listed in Table 1.
† Veneer ceramic fractures were defined as large pieces of ceramic missing where function, periodontal health or both were compromised.

did not necessitate prosthesis replacement, 52 percent of the fractures progressed in severity across time.

In summary, χ^2 analyses showed the following:

- Pressed veneer ceramics had significantly less surface crumbling at all recall periods ($P < .001$), with CZR Press and Pulse interface showing no surface crumbling. Pressed veneer ceramics also had significantly fewer chips ($P = .028$) and large fractures ($P < .009$). Most of the problems with pressed ceramics occurred with IPS e.max ZirPress (Table 4 and Figure 4).
- Veneer ceramics containing leucite (Creation [Jensen Dental], Pulse interface and Ceramco SoftWear Enamels [Dentsply] for metal frameworks and CZR Press for zirconia frameworks) had significantly less surface crumbling ($P < .001$) and chipping ($P = .005$) at all recall periods and significantly fewer cracks at all recall periods ($P = .014$).
- Veneer ceramics for metal had significantly fewest chips, least surface crumbling, fewest fractures (all $P < .001$) and fewest cracks ($P = .014$). The two-year performance of CZR Press for zirconia was comparable with that of the veneer ceramics for metals.

Prostheses replaced. Table 4 includes the number of prostheses replaced and the Kaplan-Meier survival rates overall and according to system at one, two and three years. Thirty-one (12 percent) of 253 prostheses recalled at this reporting period required replacement. Table 5 lists the reasons for prosthesis replacement as framework fracture (42 percent), veneer ceramic fracture (48 percent) and dental caries (10 percent). The Kaplan-Meier overall survival rate at three years was 88 percent. Figure 5 (page 1326) shows the time to prosthesis replacement for each framework/veneer ceramic system, as estimated according to the Kaplan-Meier method. Three systems not requiring any replacements were Argedent 65SF Argen, San Diego)/Pulse interface, Ceramco UltraCrown/Ceramco SoftWear Enamels and Everest Presintered (Metoxit and KaVo Dental)/CZR Press. Five systems had survival rates greater than 80 percent, and Wol-Ceram layered and pressed ceramics had survival rates of 76 percent and 54 percent, respectively, at three years. Time to prosthesis replacement according to type of framework material, determined according to the Kaplan-Meier method, shows survival rates of 68 percent for alumina, 86 percent for zirconia and 95 percent for metal (Figure 6, page 1327). χ^2 analyses of framework performance showed no differences between metal and zirconia frameworks or between the five zirconia-based and three metal-based systems.

Overall, results from this clinical evaluation indicate that

- alumina frameworks lacked the strength necessary for posterior FPDs replacing molars;
- the five zirconia framework brands tested performed equally well and were comparable with metal;
- the zirconia from three sources performed similarly;
- four of the five veneer ceramics for zirconia frameworks that we tested had multiple chips and instances of surface crumbling;
- the two pressed veneer ceramics containing leucite (CZR Press for zirconia frameworks and Pulse interface for metal frameworks) had the fewest fractures;
- Pulse interface veneer ceramic applied over metal frameworks had the fewest fracture events at all three yearly recalls.

DISCUSSION

The purpose of this clinical trial was to determine if there were differences between metal, zirconia

and alumina frameworks and between layered and pressed veneer ceramics. We detected important differences. FPDs fabricated by means of electrophoretic deposition of alumina had multiple framework fractures (11 fractured frames, all replacing mandibular first molars), demonstrating strength inadequate to support molar pontics. Other researchers have reported similar problems with FPDs replacing molars that involved the use of hand-fabricated alumina frameworks.[6,10,32-35]

Two zirconia frameworks fractured, one at 36 months and one at 40 months. Each had evidence of clinical stresses such as endodontic procedures, occlusal adjustments or possible compromise of connector dimensions. Several reports have emphasized the importance of connector dimensions on zirconia FPDs.[36-39] However, the two zirconia frameworks with fractures noted in our study did not exhibit obvious problems with the connectors, and the span lengths were not excessive (12.8 mm and 14.9 mm). Both abutment teeth of one prosthesis had received endodontic treatment; this could have weakened the zirconia frame. The veneer ceramic on both prostheses had been cut with rotary instruments to adjust occlusion, and this could have caused overheating and initiation of cracking within the zirconia framework. Neither we nor the materials' manufacturers could pinpoint the cause of the fractures. Sailer and colleagues[23] reported fracture of a zirconiaframework supporting a five-unit prosthesis after 38 months of service. They cited trauma or fatigue of the ceramic as a possible

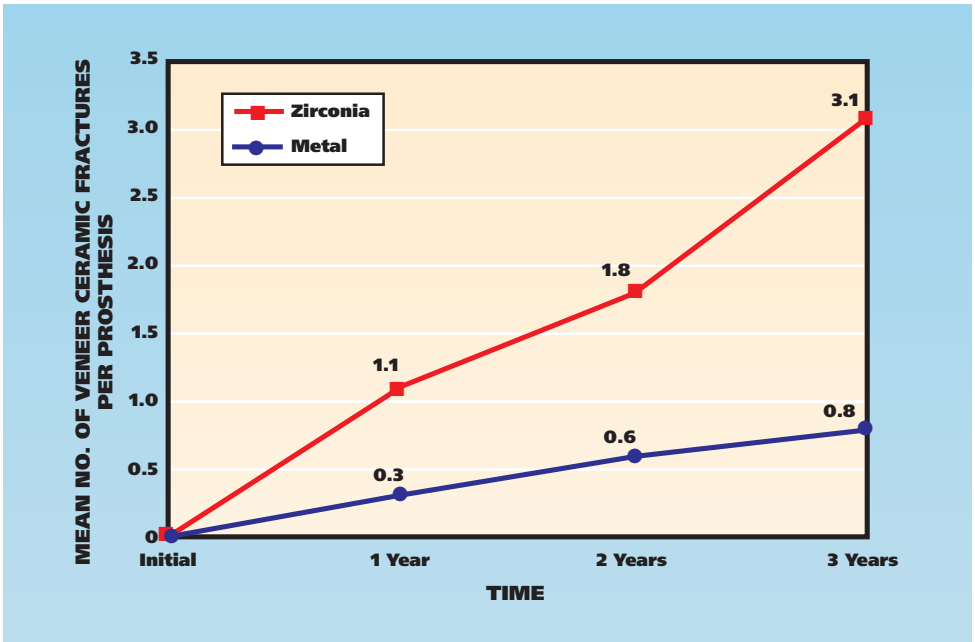

Figure 3. Mean number of veneer ceramic fractures per prosthesis across time. Veneer ceramics for zirconia frameworks had three or more times the number of fractures per prosthesis experienced by ceramics for metal frameworks.

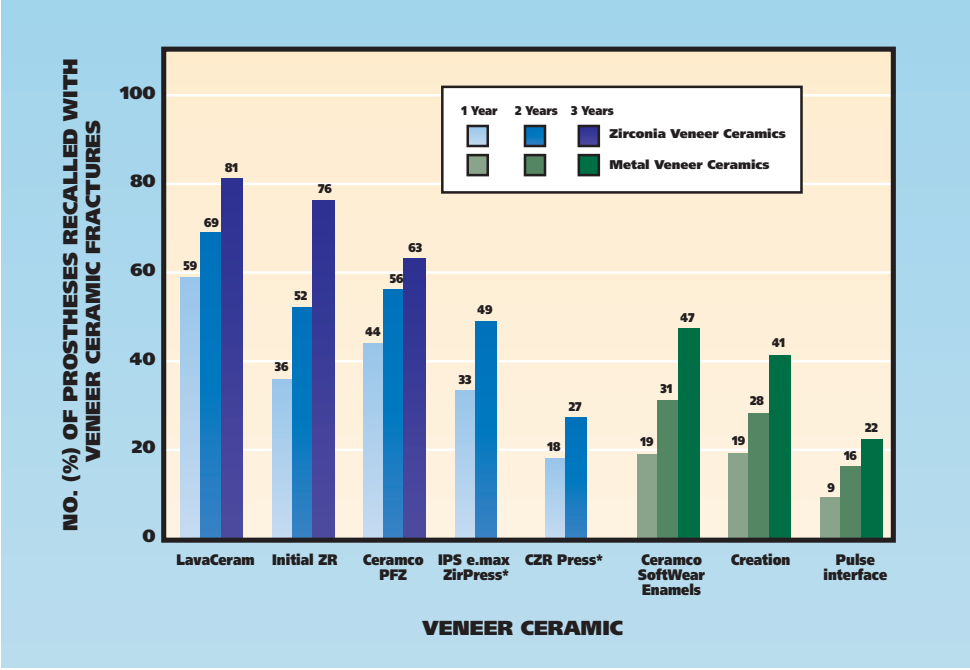

Figure 4. Percentage of prostheses with any type of fracture. Table 4 presents the numbers of each fracture type overall and according to material. An asterisk indicates the name of a material that was not available when the study began and entered the study one year later. Manufacturers are listed in Table 1.

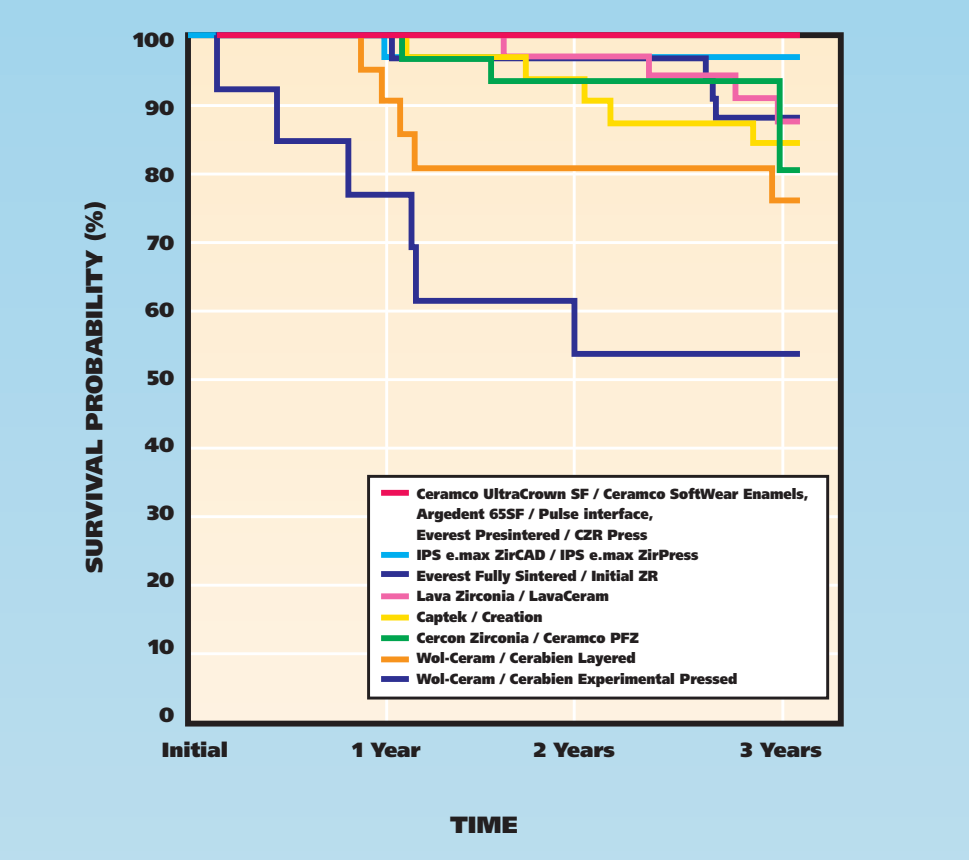

Figure 5. Time to prosthesis replacement for each framework/veneer ceramic system, as estimated according to the Kaplan-Meier method. Apparent are the early replacement of Wol-Ceram (Wol-Dent, Bad Soberheim, Germany) alumina-based prostheses with pressed and layered ceramics and the three systems that had no replacements. The other five systems all show survival rates of greater than 80 percent up to three years. (Table 1 provides product information.)

cause. They did not report the span length, but their published radiograph showed pontics replacing two premolars and a molar. Others conducting investigations of zirconia FPDs reported no framework fractures in mean clinical service times of 18 to 39 months.[24-26,40-43]

None of the metal frameworks in our study fractured, even though they were subjected to conditions and stresses similar to those experienced by the alumina and zirconia frameworks. This finding suggests that metal frameworks may be less prone to fracture in clinically stressful situations. To prove or disprove this, the patients in this study will be recalled yearly through 10 years so that we can evaluate the integrity of their prostheses.

Veneer ceramics for zirconia frameworks were an issue. In our study, 56 percent of the prostheses veneered with four of the five ceramics for zirconia tested (excluding CZR Press) exhibited one or more of the five fracture types defined in Figure 2. By contrast, 28 percent of the metal prostheses had ceramic fractures. Larsson and colleagues[24] and Sailer and colleagues[26] reported in 2006 that zirconia veneer ceramics were chipping at a higher-than-expected rate. Larsson and colleagues[24] reported that seven (54 percent) of 13 reconstructions in fully sintered zirconia had what they called "chip-off fractures" in the veneering ceramic. Since then, many others have reported undefined defects, referred to as "chips," ranging in prevalence from 0 to 25 percent on FPDs with a mean service time of 31.2 to 39.1 months.[25,31,40,44,45]

In our study, with a mean service time of 37.3 months, 71 (50 percent) of 143 zirconia prostheses met our definition of having chips (small pieces of ceramic missing that do not compromise periodontal health or occlusion and do not necessitate prosthesis replacement). By contrast, only 19 (22 percent) of 87 metal-ceramic prostheses had chips. The high number of chips we noted may be attributable to the use of ×10 magnification SEM prints of every unit of each prosthesis and its opposing dentition, thus allowing repeated opportunities to see and compare defects. Other investigators have used clinical examination alone as their assessment tool, with SEM images obtained only if problems were noted. However, it is difficult to observe white-on-white defects in the molar region of the oral cavity, thus allowing the possibility of problems' existing without the investigators' knowledge.

Although many researchers have reported about chipping of zirconia veneer ceramics,[12,24-26,31,40,44,45] to our knowledge no reports exist regarding surface crumbling, which was as prevalent as chipping in this study. Surface crumbling may be more serious than chipping because it can affect occlusion and

cause accelerated abrasion of opposing dentition. Also, small chips can be smoothed with rotary instruments, but surface crumbling is exacerbated by this treatment. We saw surface crumbling to various degrees with all veneer ceramics tested except Pulse interface and CZR Press, which had none. Lava Ceram (3M ESPE, St. Paul, Minn.), Initial ZR and Ceramco PFZ had the most frequent and most serious cases of surface crumbling.

Some proposed reasons for zirconia veneer ceramic fracture problems include the following:

- inherent deficiencies in the ceramics, such as insufficient mechanical properties[25,26] or mismatch of coefficient of thermal expansion[25,46];
- dentist or laboratory errors such as insufficient framework support,[26,40] which could have resulted from overreduced or underreduced tooth preparations, inadequate frame design software,[26] technicians' failure to customize CAD-proposed frames or technicians' ignoring veneer ceramic thickness[46];
- inexperience with the new ceramics[25] including improper firing,[47,48] need for slower cooling[46,49-51] and general handling;
- near-surface damage from the CAD/CAM process that can be controlled but never eliminated entirely;[52]
- sliding contact fatigue.[21,22,53]

Any one, several or all of these theories could be correct.

Swain[46] emphasized the importance of cooling rate, ceramic thickness and thermal expansion coefficient as necessary to control excessive chipping. We believe that all of these are important factors. Controlled clinical studies in which investigators use SEM monitoring are needed to further investigate causes of the excessive fracture events.

Results of this study indicate that ceramic formulation also could be a critical factor. We believe the CZR Press formulation deserves a close look because this ceramic's clinical performance was significantly better than that of the other four veneer ceramics for zirconia tested at all periods (Figure 4). Results from quantitative X-ray diffraction spectroscopy performed by our laboratory indicated that CZR Press was the only veneer ceramic for zirconia frameworks in this study that contained leucite crystals.

Some have suggested that the pressing technique used with CZR Press could be the key to its success, because pressing inherently involves a slower cooling process.[50,51] However, our study included two ceramics pressed to zirconia (CZR Press and IPS e.max ZirPress) that had two different formulations and two different results. IPS e.max ZirPress had almost twice as many fracture events as did CZR Press, and it had surface crumbling although CZR Press did not. We suggest that CZR Press's formulation contains information that could solve the zirconia veneer ceramic fracture problems noted internationally by many investigators. We believe the inclusion of leucite may be an important factor.

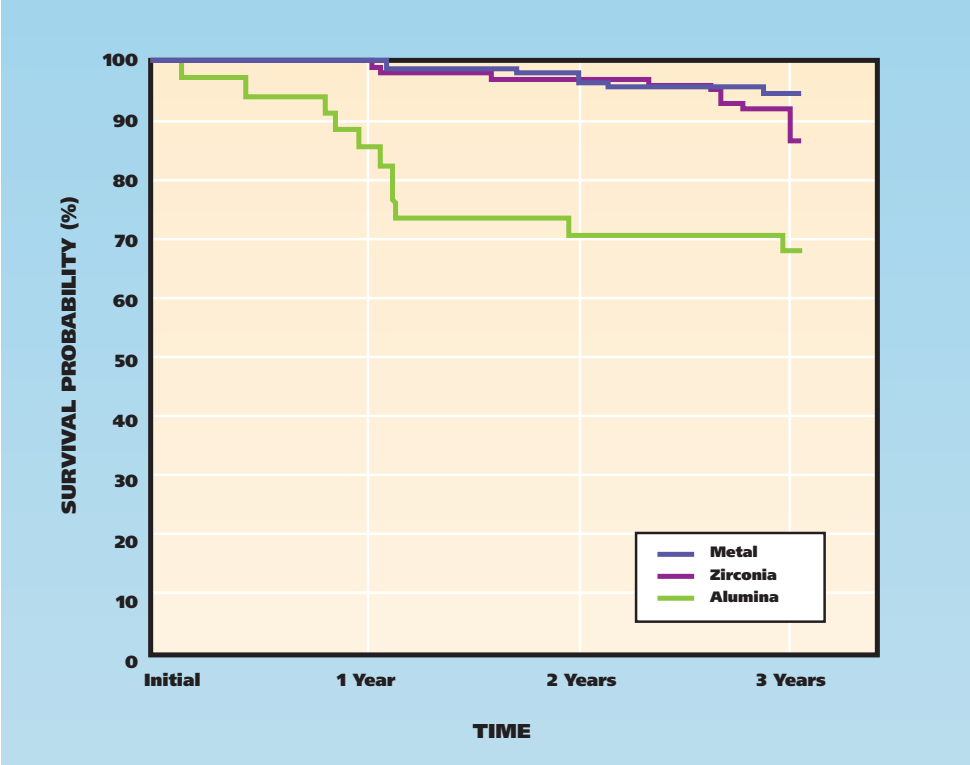

Figure 6. Time to prosthesis replacement according to type of framework material, as estimated according to the Kaplan-Meier method. The substantially reduced survival time of alumina frameworks as compared with those of zirconia and metal frameworks is apparent. Future follow-up data will indicate whether the survival rate of zirconia frameworks equals that of metal frameworks.

CONCLUSIONS

The results of this clinical evaluation after three years of FPD service provide important insights into the differences between metal, zirconia and alumina frameworks and their veneer ceramics (whether pressed or layered).

- Metal frameworks and their veneer ceramics had the best performance, with no framework fractures, 28 percent of the prostheses' having veneer ceramic fractures and an overall Kaplan-Meier survival rate of 95 percent.
- Zirconia frameworks and their veneer ceramics had the second best performance, with two framework fractures, 56 percent of the prostheses' having veneer ceramic fractures and an overall Kaplan-Meier survival rate of 86 percent. (CZR Press veneer ceramic for zirconia was the exception, with a performance comparable with that of veneer ceramics for metals.)
- Alumina frameworks had a clinically unacceptable performance, with 11 of 34 frameworks fractured, and an overall Kaplan-Meier survival rate of 68 percent.
- Veneer ceramics containing leucite and applied by pressing (Pulse interface for metal frameworks and CZR Press for zirconia frameworks) had the fewest fractures.
- The five brands of zirconia frameworks from three sources performed equally well and were comparable statistically with metal frameworks.

Overall, the data indicate that veneer ceramics for zirconia need improvement, alumina frameworks are contraindicated for posterior multiunit restorations and zirconia and metal posterior multiunit frameworks can perform equally well. In clinically stressful situations, metal frameworks may be more durable across time. ■

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