FRACTURE STRENGTH AND MARGINAL FIT OF IN-CERAM, COPY-MILLED IN-CERAM, AND IPS EMPRESS 2 ALL-CERAMIC BRIDGES

Jung-Won Hwang, D.D.S., M.S.D., Jae-Ho Yang, D.D.S., M.S.D., Ph.D., Sun-Hyung Lee, D.D.S., Ph.D.
Department of Prosthodontics, College of Dentistry, Seoul National University

All-ceramic restorations have become an attractive alternative to porcelain-fused-to-metal crowns. In-Ceram, and more recently IPS Empress 2 were introduced as a new all-ceramic system for single crowns and 3-unit fixed partial dentures. But their strength and marginal fit are still an important issue. This study evaluated the fracture resistance and marginal fit of three systems of 3 unit all-ceramic bridge fabricated on prepared maxillary anterior resin teeth in vitro. The 3 all-ceramic bridge systems were: (1) a glass-infiltrated, sintered alumina system (In-Ceram) fabricated conventionally, (2) the same system with copy-milled alumina cores (copy-milled In-Ceram), (3) a heat pressed, lithium disilicate reinforced glass-ceramic system (IPS Empress 2). Ten bridges of each system with standardized design of framework were fabricated. All specimens of each system were compressed at 55° at the palatal surface of pontic until catastrophic fracture occurred. Another seven bridges of each system were fabricated with standard method. All of the bridge-die complexes were embedded in epoxy resin and sectioned buccolingually and mesiodistally. The absolute marginal discrepancy was measured with stereomicroscope at $\times 50$ power. The following results were obtained:

1. There was no significant difference in the fracture strength among the 3 systems studied.
2. The Weibull modulus of copy-milled In-Ceram was higher than that of In-Ceram and IPS Empress 2 bridges.
3. Copy-milled In-Ceram(112μm) exhibited significantly greater marginal discrepancy than In-Ceram (97μm), and IPS Empress 2 (94μm) at P=0.05.
4. The lingual surfaces of the ceramic crowns showed smaller marginal discrepancies than mesial and distal points. There was no significant difference between teeth (incisor, canine) at P=0.05.
5. All-ceramic bridges of three systems appeared to exhibit sufficient initial strength and acceptable marginal fit values to allow clinical application.

Key Words
All-ceramic bridge, In-Ceram, Copy-milled In-Ceram, IPS Empress 2, Fracture strength, Marginal fit

All-ceramic restorations provide esthetics seldom rivaled by metal ceramic restoration. While patients are primarily concerned with improved esthetics, dentists are interested in the marginal accuracy and fracture strength of restorations to ensure clinical success. The high strength value of the In-Ceram ceramic and IPS Empress 2 ceramic, and the outstanding dimensional and finishing characteristics of those new materials are the reason enough not to limit its use to traditional crown-and-bridge technology.

In-Ceram is a material that utilizes an aluminum oxide substructure strengthened by a slip-casting technique involving infiltration glasses. It has been shown by several authors that the new glass-infiltrated alumina ceramic (Vita Zahnfabrik, Bad Sä̀ckingen, Germany) has three to four times greater flexural strength than traditional ceramics or glass materials.[1] In vitro studies have consistently reported flexural strengths in excess of 446MPa,[2] and investigations of marginal integrity have demonstrated marginal adaptation comparable to that of metal margins.[3,4] It allows the creation of fixed partial denture substructures with flexural strengths that approach those of porcelain-fused-to-metal.[5] The Celay system (Mikrona AG. Spreitenbach, Switzerland), introduced in 1992, is possible to produce alumina core for all-ceramic crowns and bridges by copy-milling. A resin pattern of the coping is traced for the manually guided copy-milling. Similar to the conventional In-Ceram technique, the completed alumina core is veneered with aluminous porcelain (Vita alpha, Vita Zahnfabrik). The glass-infiltrated copy-milled alumina blanks have a 10% higher flexural strength (500MPa) than the conventional core material.[6]

IPS Empress 2 system (Ivoclar, Liechtenstein) was developed to meet the biomechanical requirements for the fabrication of ceramic fixed partial dentures. It allows fabrication of a ceramic three-unit fixed partial denture that can replace a missing tooth up to the first premolar.[7] As with the original leucite-reinforced IPS Empress system, the lost-wax technique and the heat-pressed technology are used in the fabrication of IPS Empress 2 restoration. However, it differs from its predecessor both in its chemistry and crystalline structure.[8] The new ingredient in the IPS Empress 2 core material is the lithium disilicate crystal (SiO_2-Li_2O). These long crystals grow in the glass up to 60vol % during the sintering and heat-pressing process contribute to the high strength and the high fracture toughness of the system. The thickness of the lithium disilicate glass core must always exceed that of the veneering ceramics, and its thickness should never be reduced to less than 0.8mm.[9] In vitro studies have shown a higher flexural strength for the IPS Empress 2 system as compared to the leucite-reinforced IPS Empress system. A three-point bending test of the lithium disilicate glass-ceramic, after a pressing procedure, demonstrated a flexural strength of 350 ± 50MPa. In addition lithium disilicate glass-ceramic showed high fracture toughness.[7]

For all-ceramic fixed partial dentures (FPDs) to be esthetically pleasing, they must be delicately designed. But when this is done, there is the danger that they will be fractured under functional loading. Marginal adaptation is also one of the important criteria used in the clinical evaluation of fixed restorations. The presence of marginal discrepancies in the restoration exposes the luting agent to the oral environment. The longevity of the tooth could be compromised, not only by caries but also by periodontal disease.[10] To provide patients and dentists with a predictable success rate for a new all-ceramic system, in vitro investigation concerning long-term stability should be undertaken before clinical use.

The purpose of this study was to compare the in vitro fracture resistance and marginal fit of three all ceramic bridge systems: the heat-pressed lithium disilicate glass-ceramic (IPS Empress 2), the densely sintered high-purity alumina porcelain (In-Ceram), and the copy milled In-Ceram bridge.

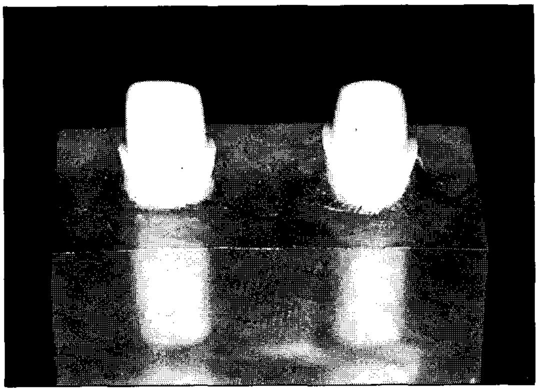


Fig. 1. Maxillary central incisor and canine tooth embedded in a resin block as a fixation for the testing procedures.

MATERIAL AND METHODS

Die fabrication and fixed partial denture construction

1) Specimens for strength test

Each of thirty maxillary resin incisor and canine (A50-121 prepared teeth, Trimunt Co., Kyoto, Japan) were fixed in autocuring resin block with same position and distance by using hard silicone index. Those ready-made resin teeth were custom prepared for all-ceramic crown and had sloping shoulder margin with internal rounded angle and made of high strength epoxy resin. The long axis of tooth was placed perpendicular to the block (Fig. 1). The 10 master dies of resin teeth in each group were specially numbered and impressions were taken using poly (vinyl siloxane) (Wash and Putty, Extrude, Kerr) in custom trays. A total number of 30 impressions were made and poured using type Ⅳ dental stone

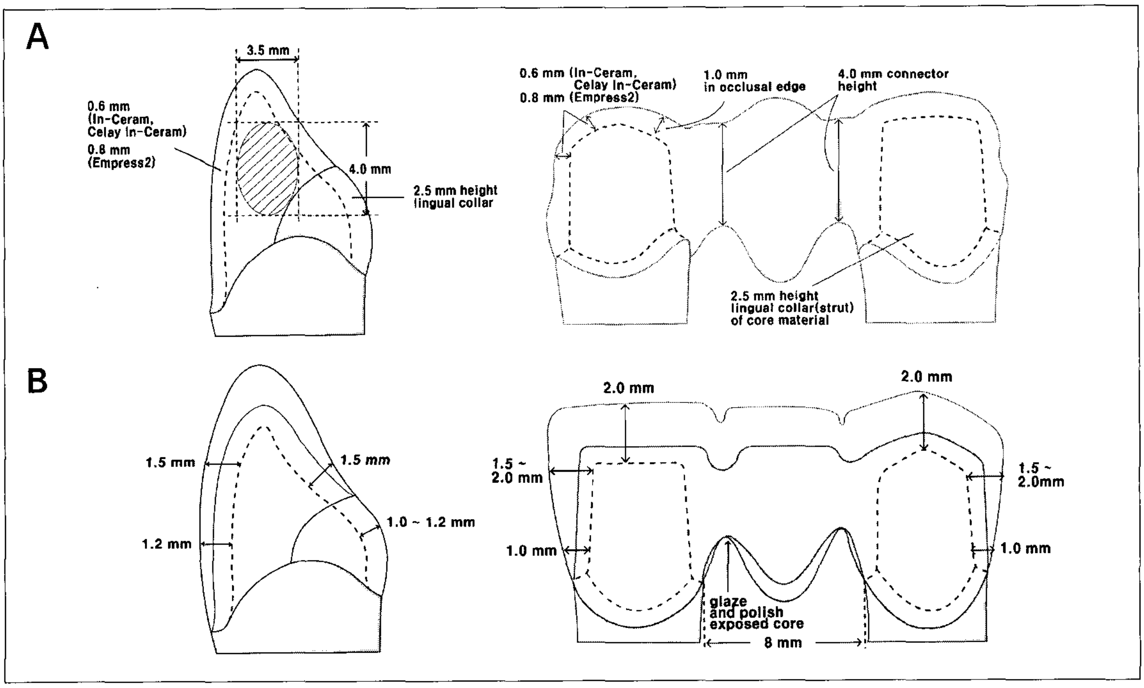


Fig. 2. Schematic presentation of the dimensions of the all-ceramic bridge forms.
A, The dimension of the substructure. B, The dimension of all-ceramic bridge.

(Silky-Rock, Whip-Mix). The 30 stone dies were evenly distributed among the three following groups : In-Ceram bridges (Vita) ; copy-milled In-Ceram bridges ; IPS Empress 2 bridges (Ivoclar). All bridges were fabricated according to manufacturer' s recommendations. To compare the fracture strength, the same dimension of all specimens is an important factor. Therefore, this study applied modified method in the fabrication process of In-Ceram and copy-milled In-Ceram bridges.

① In-Ceram bridges

The In-Ceram bridges were fabricated following the manufacturer' s recommendations. Two layers of die spacer were painted onto the working dies, which were then coated with a wax-isolating microfilm (Isolit, Degussa). The framework design used consisted of an interproximal struts, a 2.5mm lingual collar, and joints with 4mm height and 3.5mm width (Fig. 2). The thickness of substructure in the region of veneer application was 0.6mm thick as suggested by the manufacturer. Instead of the standard brush technique, an injection molding technique was used for application of slip cast on the die. This technique provides greater predictability and control for uniform dimension of the substructure.[11] The first piece of substructure was modeled with the wax-up technique using hard wax and the dimensions of the framework were carefully checked and maintained within $\pm$0.1mm at several points. It was used as a pattern for a silicone mold. The silicone template were made and seated on the 10 working models. The successive wax pieces were obtained by injecting molten wax into the molds and allowing them to remain for 24 hours at room temperature. The wax-models obtained were separated into two pieces before proceeding to the perfection of the marginal seal. The measurements were carefully checked and the margins resealed. The marginal seal was achieved by cutting the last millimeter of apical wax, adding new wax, and then refining it. The connection between the sectioned elements was made with hard wax. In this way, ten wax-substructures of same dimension were made and seated on their respective working die. Vents and sprues are also formed to allow for application of the slip cast by an injection molding technique. The space between pontic and the ridge of master die was filled with wax for pontic support and siliconee impression was made for special plaster die (In-Ceram Special plaster, Vita Zahnfabrik) needed to compensate for the sintering shrinkage of the slip casting. Also, silicone rubber impression (Extrude Wash, Kerr) with outer plastic cylinder frame was made of the wax-pattern to form the mold. The freshly mixed slip cast was injected with a syringe into the mold.

The cast models were then finished with a sharp scalpel and any flash was removed through careful shaving. Afterward, they were coated with a framework strengthener, glued onto special aluminum oxide trays. The bridge frameworks that were prefabricated in this way were subjected to the usual firing process and glass infiltration process as indicated by the manufacturer. Any excess glass present was removed by grinding and airborne abrading (aluminum oxide 50μm grain/3bar). After the surface of the bridge construction was cleaned, the bridges were veneered with aluminous porcelain (Vitadur Alpha, Vita Zahnfabrik). A polyvinyl siloxane (Extrude putty, Kerr) template was fabricated using a complete contour wax pattern on the die. This index was used to obtain identical dimension. The specimens were veneered by filling aluminous porcelain in silicone mold. Veneering porcelain was applied in the following sequence: (1) thin wash of dentin, (2) first body bake, (3) correction bake, and (4) autoglazing. The thickness of the ceramic substructure and porcelain veneer was controlled to an accuracy of 0.1～0.2mm. The inner surfaces of the crowns were conditioned by sandblasting ($50\mu m$ $Al2O3$/2.5bar) and ultrasonically cleaned in distilled water for 10 minutes.

② Copy-milled In-Ceram Bridges

For the production of copy-milled crown structures, two layers of die spacer were applied on the working dies. Since it was very difficult to control the photopolymerized resin (Celay Tech, Espe, Seefeld, Germany) pattern with same dimension, modified method was used. The same silicone template used for In-Ceram was used to obtain copy-milled In-Ceram substructures. Ten wax patterns for copy-milled In-Ceram substructures were made on the respective working dies as above method and cast using non-precious metal. Those 10 metal substructures were then fixed in the scanning unit of the Celay system. The structures were scanned using Celay system (Mikrona AG. Spreitenbach, Switzerland) and simultaneously milled from an industrially sintered aluminum-oxide blank (Vita Celay Alumina Blank, Vita Zahnfabrik). One operator milled all the units following a standardized routine. Subsequent to the milling process, specimens were removed from the vise and finished. No sintering was necessary. The alumina structures were then infiltrated with a special glass in a conventional porcelain furnace for 40min at 1,100 ℃. Excess glass was removed, and the completed In-Ceram copings were veneered with aluminous porcelain (Vitadur Alpha, Vita Zahnfabrik) with same dimension as described method above. The inner surface of the bridge were conditioned by the same method with In-Ceram

③ IPS Empress 2 Bridges

The dimension of IPS Empress 2 framework was all the same with that of In-Ceram except the thickness of the veneering portion. The template used in In-Ceram was seated on the working dies and filled with molten wax. After duplication of wax pattern of In-Ceram bridge substructure, additional wax was applied to the veneering portion to make the thickness of 0.8mm. Silicone template of the first wax pattern for IPS Empress 2 was also made. The following wax substructures were made as above described method using a silicone template. The dimensions of wax patterns were controlled with wax calipers. The IPS Empress 2 bridges were fabricated following the manufacturer' s recommendations. 10 wax patterns of IPS Empress 2 substructures were sprued and invested in phosphate-bonded investment using the crucible that was provided by manufacturer. The wax was eliminated in a burnout furnace. The IPS Empress 2 glass-ceramic ingot was heat pressed in a hot-press furnace (EP500, Ivoclar). The glass-ceramic was pressed into a mold at 920℃ with a holding time of 20 minutes and 20 bar pressure. Once the molding cycle ended, the mold was left to cool to room temperature. Subsequently, the pressed parts were divested from the mold by blasting the mold material with carborundum powder and glass beads using 1 to 2 bar pressure. The bridge copings were veneered with layering porcelain to create the final bridge form in the manner as described for the In-Ceram bridges. Veneering porcelain was sintered on the heat-pressed frameworks as above using a sintering furnace (Programat P80, Ivoclar) at 800 ℃. The inner surfaces of the crowns were conditioned by etching with hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar) for 20 seconds as recommended by manufacturer.

2) Specimens for evaluation of marginal fit

Impressions of master die which was used for fracture test were made using poly(vinyl siloxane) (Wash and Putty, Extrude, Kerr) in custom trays. A total number of 21 impressions were made and poured using epoxy resin (Modralit-3K, Dreve-Dentamid GMBH, Germany). The epoxy resin dies were divided into three groups of 7 dies each. All ceramic bridges were fabricated according to their respective manufacturer's recommendations. It was not so important to control the same dimension of specimen as in the strength test, but following the standard procedure of fabrication was more important in the evaluation of marginal fit. For conventional In-Ceram specimens, the standard brush technique was used for application of slip. Specimens for the copy-milled In-Ceram were fabricated by using photopolymerized resin prototype (Celay Tech, Espe, Seefeld, Germany) as recommended by manufacturer. The wax pattern of IPS Empress 2 substructure was made by wax-up technique instead of molten wax injection technique.

Therefore, the following specimens were prepared; (1) total 30 specimens of all-ceramic bridges for strength evaluation on the reinforced epoxy teeth master models, (2) 21 specimens for marginal fit evaluation on the epoxy resin dies.

Analysis of fracture strength

Prepared resin teeth were initially cleaned with rubber cup and polishing paste and the surfaces were washed, dried, and etched with 37% phosphoric acid for 60seconds (Panavia etching agent V, Kuraray). All-ceramic bridges were bonded to the respective dies with the use of an autopolymerizing composite (Panavia 21 TC, Lot 41184, Kuraray). The bridges were cemented with a finger pressure for 10minutes. During the setting of the luting resin, the excess composite was removed with sponge pellets. An air-blocking gel (Oxyguard II, Kuraray) was then applied during the setting of the resin cement (7minutes). Finally the restoration were washed and stored for 24 hours in saline before strength testing.

Fracture strength testing was carried out using a universal testing machine (Instron 6022, Instron Co., U.K.) at a crosshead speed of 1mm/min. All bridges were loaded until catastrophic failure occurred. The loads required to catastrophic fracture the bridges were recorded automatically in newtons. Catastrophic failure was defined as fracture through the core material as other study showed.[12] The load was transferred through a 4mm diameter stainless steel ball 1.5mm below the incisal edge of the pontic. The extra-axial load was applied at an angle of 55° to the long axis of the tooth(Fig. 3). A 1mm thick aluminum foil was placed between the specimen and the opposing stainless steel ball so that stress distribution on the ceramic could be achieved.

The fracture mode of each bridge was inspected and classified as: A=fracture of the bridge structure only; B=fracture of the resin tooth with bridge segment below the level of the tooth neck. The fracture resistances of all bridges were reported, and the data gathered from specimens that failed through the ceramics (all of mode A and B) were included in the statistical analysis.

An one-way analysis of variance (ANOVA) was performed on the strength data at the 0.05 level of significance. Statistical analysis using methods for Weibull distribution was also chosen. The description of the Weibull distrubution is given by the formula : $Pf=1- \exp[-(\sigma/\sigma_{no})^m]$, where Pf

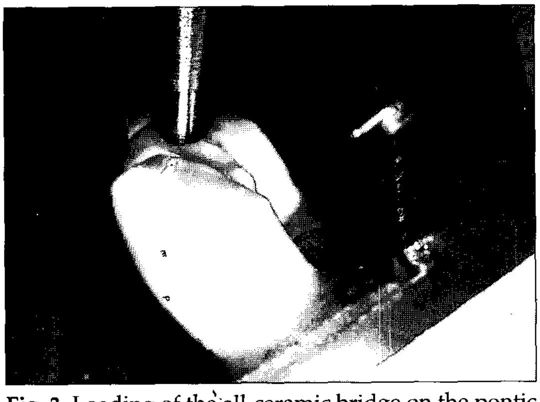


Fig. 3. Loading of the all-ceramic bridge on the pontic by a stainless steel ball in the universial testing machine. In the test samples the pontic had no contact to the resin mold.

is the probability of failure, σ is strength at a given P_f, σ_{no} is the characteristic strength, and m is the Weibull modulus. Two parameters characterize this distribution function: the B10 strength defined as the strength at which 10% of the specimens will fail, and the shape parameter m (Weibull modulus) that is a constant related to the distribution of the failure data. The m-value and strength at a predicted 10% probability of failure calculated using an iterative procedure in order to assess the material reliability. Microscopic examination of the fracture zone was completed on each bridge system tested for strength.

Analysis of marginal fit

The bridges were cemented in a standardized manner to the respective epoxy resin counterpart with a loading jig that applied 10kg of seating pressure for 10minutes with the use of an autopolymerizing composite (Panavia 21 TC, Lot 41184, Kuraray). During the setting of the luting resin, the excess composite was removed with sponge pellets. An air-blocking gel (Oxyguard Ⅱ, Kuraray) was then applied during the setting time of the resin cement.

Twenty-one bridge-die complexes for testing of marginal fit were embedded in epoxy resin and were allowed to cure for 24 hours. Using guide marks on the epoxy resin mold, the samples were sectioned with a diamond wheel cutter (51CA, Accutom-2, Stryers, Denmark) in both the faciolingual and mesiodistal direction at the midpoint of each surface of abutments. The cut surfaces were finished sequentially with 100 grit diamond wheel polisher (Plamopol-3, Stryers, Denmark) and 200, 400 and 600 grit silicone carbide abrasive paper for removing cutter-induced distortions. The space lost between specimen faces was approximately 1.0mm.

This sectioning allowed examination at eight points around the each crown, one view on each side of the cut. The epoxy-embedded, sectioned bridges were photographed at 50 power with an Olympus zoom stereomicroscope and PME3 camera (Olympus /Optical Co.,/Ltd., Tokyo, Japan). A custom made camera reticle with a scale divided into 10μm increments provided pictures with the scale superimposed on the prints for standardization and calculations. The 3×5 inch color prints were then used for measurement of the marginal discrepancies.

The determination of the measurement point is illuminated in Fig. 4. The linear distance from the cavosurface angle of the preparation to the margin of the restoration is defined as the absolute marginal discrepancy[13] and was chosen for this study. When a margin appeared rounded, the point chosen on that margin was along a line bisecting the angle between the main contours of the die or castings. The absolute marginal discrepancy always represents the maximum measurement of misfit at the margin. Measurements of the absolute marginal discrepancy were made at the middle of the facial, lingual, mesial and distal surface for each tooth. Each point was composed of 2 opposing surface, and the mean value of the 2 points was obtained. That resulted in total 336 measure-

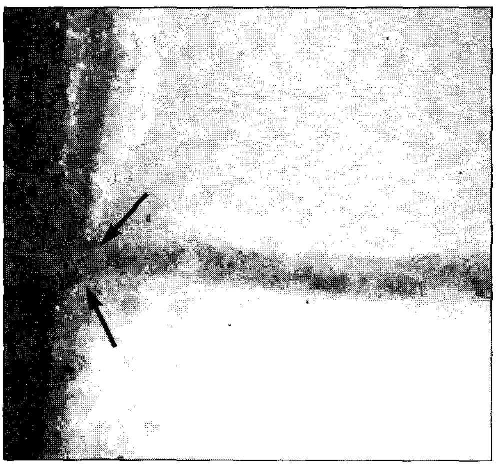


Fig. 4. Measurement point of absolute marginal discrepancy (×50).

ment points and 168 measurement values obtained for the all-ceramic bridge system. All of the measurements were made by one operator.

A two-way analysis of variance (ANOVA) was computed for statistical significance among three variables and the effect of interaction at P=0.05: (1) the bridge systems, (2) the measuring surfaces, and (3) the abutment tooth. A one-way ANOVA and Scheffe post hoc analysis was used to evaluate the significant difference among the materials and the measuring surfaces.

The clinical relevance of the results was interpreted by comparison with the acceptable marginal discrepancy of 120μm as proposed by McLean and von Fraunhofer.[14]

RESULTS

Fracture strength

The ultimate load-bearing capacity of the all-ceramic bridges in the different systems is shown in Table Ⅰ. The mean failure load of the In-Ceram, copy-milled In-Ceram, and IPS Empress 2 bridges were 502N, 495N, and 477N respectively. No statistical difference was found among the three systems in Table Ⅱ. (one-way ANOVA : P>0.05). All of the fractures in the all-ceramic bridges occurred at the connector area between the pontic and abutment (Fig. 5). The initial crack originated from the load point and propagated to the joint underneath. Total 3 specimens (2 of copy-milled In-Ceram, 1 of IPS Empress 2) showed simultaneous fracture of one side of connector and the other side of resin abutment below the level of the tooth neck (mode B). Homogeneous structure of the core and tight junction to the veneer porcelain was observed in scanning electron microscopic view of fracture surfaces (Fig. 6). But there were also few voids at the interface between core material and veneer porce-

Table Ⅰ. Fracture strength (N) and mode of fracture of the ceramic bridges

	In-Ceram		Copy-milled In-Ceram		IPS Empress 2	
	Strength	Mode	Strength	Mode	Strength	Mode
1	454.7	A	530.2	A	457.6	A
2	633.7	A	530.2	A	532.1	A
3	401.9	A	490.0	A	630.0	A
4	496.2	A	495.5	A	446.7	A
5	448.4	A	487.4	B	323.1	B
6	563.4	A	380.1	B	530.6	A
7	545.9	A	531.8	A	446.7	A
8	526.9	A	543.0	A	503.0	A
9	468.4	A	487.3	A	493.6	A
10	478.7	A	478.0	A	407.9	A

A=Fracture of ceramic only; B=Fracture of one of resin tooth with ceramic bridge segment.

Table Ⅱ. Descriptive data of fracture strength

System	N	Mean	Standard Deviation	Standard Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
In-Ceram	10	501.82*	67.08	21.21	453.83	549.80	401.90	633.70
Copy-milled In-Ceram	10	495.35*	46.87	14.82	461.82	528.87	380.10	543.00
IPS Empress 2	10	477.13*	82.29	26.02	418.26	536.00	323.10	630.00
Total	30	491.43	65.52	11.96	466.97	515.90	323.10	633.70

* Not significantly different(P>0.05).

Table Ⅲ. Data computation under Weibull distributions

System	m	Standard Error	95% Confidence Interval of m	Characteristic strength So (N)	95% Confidence interval of So (N)	B10 strength (N)	95% Confidence interval of B10 (N)
In-Ceram	8.01	1.85	5.09-12.6	530.69	488.82-576.15	400.69	336.9-476.5
Copy-milled In-Ceram	16.44	4.35	9.79-27.61	513.03	493.27-533.58	447.40	408.8-489.7
IPS Empress 2	6.65	1.57	4.19-10.57	510.11	462.27-562.89	363.79	294.9-448.8

m=estimated shape parameter(Weibull modulus).

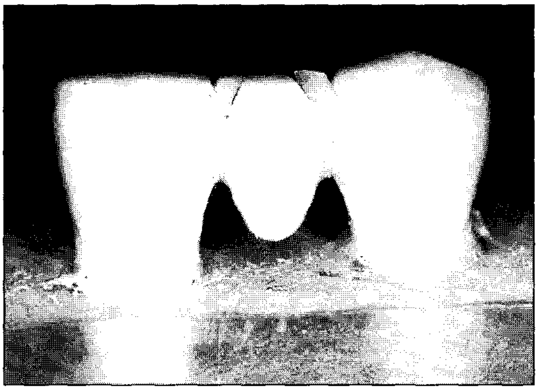
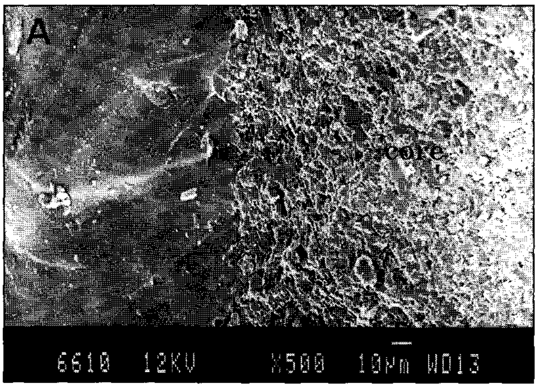
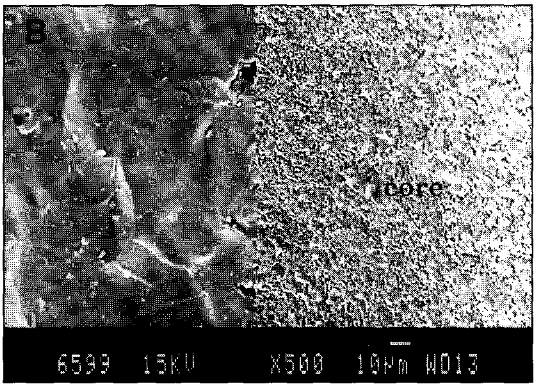


Fig. 5. Fracture pattern of all-ceramic fixed partial denture.

lain.

From the Weibull plots of the bridge systems (Fig. 7), the fracture resistance of the bridges at 10 % probability of failure (B10 strength) was calculated (Table Ⅲ). The B10 value is commonly used in manufacturing industries as a threshold for design requirements. All confidence intervals overlapped with each other at B10 strength and there was no significant difference in B10 strengths among the 3 all-ceramic bridge systems. The Weibull modulus value(m) for copy-milled In-Ceram was higher than those for other





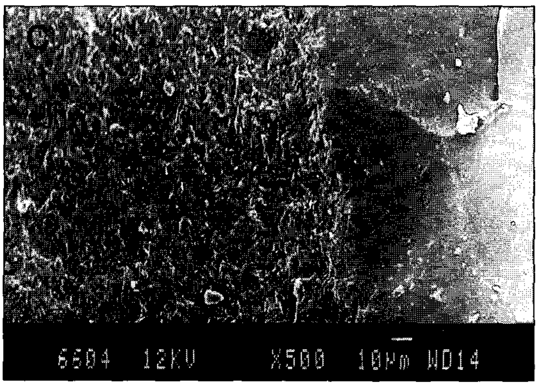


Fig. 6. SEM view of homogeneous structure of the core material and tight junction to the veneer porcelain : A, In-Ceram. B, Copy-milled In-Ceram. C, IPS Empress 2. (Original magnification ×500.)

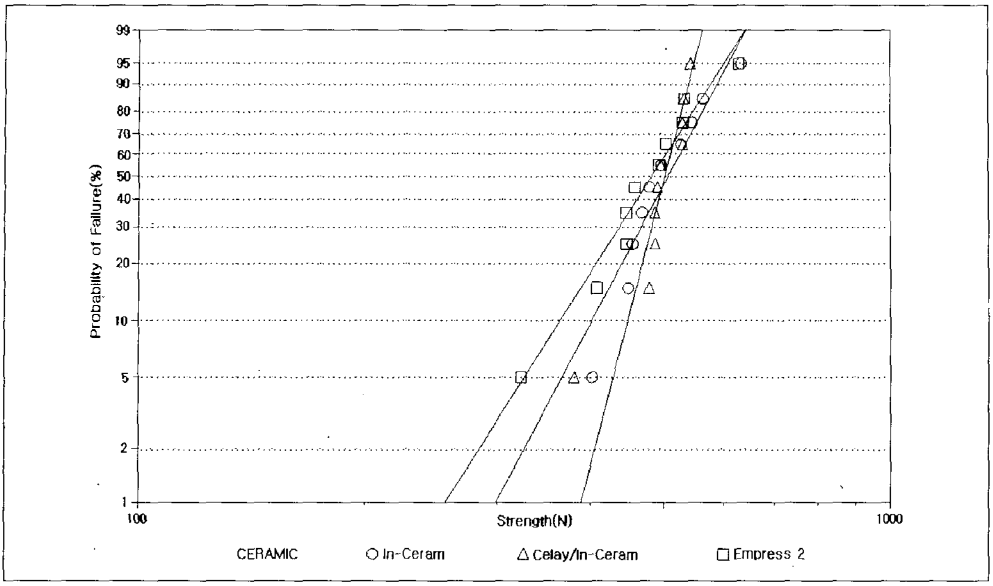


Fig. 7. The failure probability of all-ceramic bridge systems.

Table Ⅳ. Two-way ANOVA of data

Effect	F	P
System*	12.511	0.000
Surface*	5.297	0.002
Tooth	1.162	0.283
System X surface*	2.810	0.013
System X Tooth	1.527	0.221
Surface X Tooth	1.855	0.140

* Marked effects significant at P<0.05.

Table Ⅴ. Means and standard deviations of the absolute marginal discrepancies (μm) of three ceramic systems

System	N	Mean	Standard Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower	Upper		
In-Ceram	112	96.9[a]	23.52	90.6	103.12	54.8	170.2
Copy-milled In-Ceram	112	112.25[b]	23.45	105.97	118.54	56.1	169.5
IPS Empress 2	112	93.62[a]	21.15	87.95	99.28	42.7	145.6
Total	336	100.92	24.02	97.27	104.58	42.7	170.2

Means within the column with the same superscript were not different (P=0.05).

Table Ⅵ. Means and standard deviation of the absolute marginal discrepancies (μm) of various surfaces

Position	N	Mean	Standard Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower	Upper		
Facial	84	102.32	22.42	95.33	109.30	60.6	157.8
Mesial	84	106.53	27.27	98.03	115.03	42.7	170.2
Lingual	84	90.02	20.22	83.71	96.32	56.1	132.2
Distal	84	104.84	22.89	97.70	111.97	54.8	169.5

Table Ⅶ. Means and standard deviation of the absolute marginal discrepancies (μm) of three ceramic bridge systems on various surfaces

System		Facial	Mesial	Lingual	Distal	Total
In-Ceram	Incisor	97.81(21.73)	117.10(25.74)	80.81(16.32)	83.33(17.62)	94.76(24.42)
	canine	104.19(25.62)	103.27(21.86)	81.73(20.82)	106.95(17.39)	99.04(22.83)
Copy-milled	incisor	112.81(24.73)	119.50(17.27)	104.96(17.90)	123.04(24.94)	115.08(21.47)
In-Ceram	canine	118.73(21.15)	125.13(2.24)	83.50(17.01)	110.36(23.07)	109.43(25.36)
IPS Empress 2	Incisor	93.26(16.64)	104.07(19.93)	95.24(20.25)	100.14(11.03)	98.18(16.92)
	canine	87.10(11.61)	70.09(22.22)	93.86(23.17)	105.19(26.43)	89.06(24.12)
Total		102.32(22.42)	106.53(27.27)	90.02(20.22)	104.84(22.89)	100.92(24.02)

( ) means standard deviation.

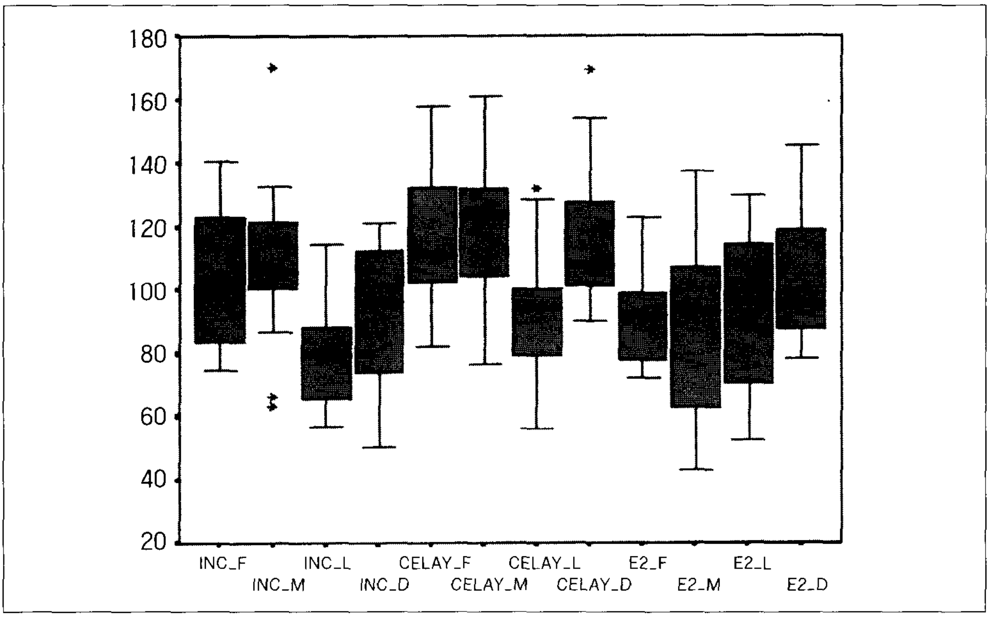


Fig. 8. Box plots of the measurements for the marginal fit. The medians are indicated by the horizontal line within the box; the box represents the interquartile range; *indicate outside values. (INC=In-Ceram; CELAY=Copy-milled In-Ceram; E2=IPS Empress2; F=facial; M=mesial; L=lingual; D=distal)

systems. IPS Empress 2 and In-Ceram bridges showed similar value of modulus(Table Ⅲ).

Marginal fit

Two-way ANOVA revealed significant differences among the three ceramic bridge systems, among the various surfaces, and among the system-surface interaction ($P<0.05$) (Table Ⅳ). There were no significant differences in the absolute marginal discrepancies between abutments ($P>0.05$).

One-Way ANOVA and Sheffe post hoc analysis showed that the copy-milled In-Ceram group (112μm) possessed significantly larger marginal discrepancy than either the conventional In-Ceram group (97μm) or the IPS Empress 2 (94μm) group (Table Ⅴ). The mean marginal discrepancy of the three ceramic systems met the criterion of an acceptable marginal discrepancy at 120μm .

The one-way ANOVA and Scheffe post hoc analysis showed that the lingual location had a significantly smaller absolute marginal discrepancy than mesial and distal position (Table Ⅵ). Table Ⅶ and Fig. 8 depicts the absolute marginal discrepancies of the three bridge systems at each marginal location. All marginal locations of the three systems met the 120μm criterion.

DISCUSSION

Fracture strength

The present study revealed that there were no significant differences in fracture strength of In-Ceram conventional bridges, copy-milled In-Ceram bridges, and IPS Empress 2 bridges. The Weibull method could be the statistics of choice for the failure analysis of brittle materials.[15] Having selected the Weibull method to analyze the current data, the authors compared the B10 strengths[16] of the all-ceramic systems rather than the characteristic strength (probability of failure at 63.2%) as some investigators did.[16,17] As discussed earlier, the B10 strength is the strength of the system when it is probable that 10% of the specimens in the system could fail. The use of B10 strength in reporting and comparing data should be more stringent and clinically more meaningful than the use of characteristic strength or mean strength values. The use of characteristic strength as the parameter to report and compare findings will render the conclusion drawn too optimistic. The Weibull parameter (m) reflects the distribution of data according to the frequency of occurrence. The m value for copy-milled In-Ceram, at 16.4, was higher, than those for other systems, which ranged from 6.7 to 8.0. A higher m value implied less variation in the resistance to fracture, which was indicative of product consistency. Compared with the conventional In-Ceram technique and IPS Empress 2 system, using an industrially sintered alumina core material might lead to a lower variation of the fracture forces.

Direct comparisons of the results of this study with others are difficult because the study designs are different. The compressive testing of the crowns is not a standard method like a bending test of a geometrically well-defined bar. Many factors influence the results: preparation design, crown thickness, direction of the applied load, location of load application, and radius of the loading stylus.[18,19] Therefore, the current result with those reported previously for the fracture strength of all-ceramic single crown is also various. Two studies did not show any significant difference in fracture resistance between In-Ceram and original IPS Empress anterior crowns.[20,21] One study revealed that the fracture resistance of In-Ceram premolar crowns was significantly higher than that of original IPS Empress premolar crowns.[22] However, no significant differences were found between the 2 crown systems after they were fatigued in a wet environment.[23]

In the comparative study of the fracture strength with conventional and copy milled In-Ceram, Rinke et al.[6] reported that there was a significant difference in the fracture strength in anterior crowns. In the current studies, In-Ceram crowns fabricated from machine-milled copings did not possess fracture resistance significantly different from conventional In-Ceram or IPS Empress crowns.[22,24]

There was no reported data about fracture strength of all-ceramic bridge systems only but In-Ceram bridges. Kern et al. demonstrated in an in vitro study[25] that the fracture strength of all-porcelain, resin-bonded In-Ceram FPDs is dependent on the framework and prosthesis design and values of up to 500N were reported when these units were bonded onto rigid metal abutment. In the studies that considered artificial oral condition including human extracted teeth, artificial periodontal membrane, and thermal cycling, In-Ceram resin bonded anterior FPD and In-Ceram posterior FPD exhibited fracture strength of 171.7

~296N[26] and 334N (mean value)[27] respectively.

All specimens in this study were loaded in a universal testing machine until fracture occurred. Initial fracture originated from the locally induced stresses of the load application, and crack propagated along the plane of maximal tensile stress. It was observed in the specimens by progression of the cracks from the load point to the joint undersides. This fracture mode is consistent with other previous studies.[27-29] Three specimens were fractured completely in one side of connector and, as a result, the opposite side of resin tooth were subjected cantilever load so that the fracture occurred below the tooth neck. The fracture strength value of those specimens was included in statistics, because the peak value for those specimens also could be considered as the fracture resistance value of connector of ceramic bridge.

In the analysis of clinically failed In-Ceram bridges[30] and IPS Empress 2 bridges[12] revealed that fracture occurred through the core material and through the connector between abutment and pontic. Finite element analysis[29] of the all-ceramic bridges found that maximum tensile stresses would occur at the connector portion of the model, especially at the core-veneer interface if there was appropriate elastic modulus differences between the ceramics and if a small amount of abutment rotation was allowed. With abutment tooth rotation constrained, the highest stresses predicted to occur on the lower surface directly below the applied load. The stress distribution pattern in all-ceramic bridges was consistent within several studies.[7,31,32] All of the all-ceramic systems used in this study are composed of core and veneering ceramic. Core ceramics are generally high elastic modulus/high strength materials compared with veneering ceramics. Since core ceramics are used internally in FPD pontics and connectors, those portions of the prostheses become trilayer laminate structures. Stress distribution, and therefore failure behavior, can be quite different in laminate structures. Interfaces can be the site of unique defects, boundary phases, and thermal incompatibility stresses, in addition to those stresses arising from elastic property discontinuities. Veneering ceramic controls failure of the all-ceramic FPD connector. The fractographic evidence[29] of failed In-Ceram bridge described two separate failure sources contributed by the veneer, one from the external surface and the other at the interface, as opposed to one failure source, at the interface for the core material. Porosities in the veneer porcelain promoted initial cracks, and crack growth led to a reduced fracture resistance.[33] A potential reinforcement of the core material might be partially neutralized by imperfection of the veneer porcelain.

In this study, although In-Ceram has higher flexural strength than IPS Empress 2, there was no statistically significant difference in fracture strength of among systems. IPS Empress 2 material have more favorable mechanical properties than Al_2O_3 sintered ceramics, since its modulus of elasticity of 90 to 100 GPa is considerably lower.[7] It also might be contributed to the high fracture strength of IPS Empress 2 bridge. An influence of the using presintered copy-milled In-Ceram blank on the mechanical properties of the In-Ceram was not detected. The difference in the strength of veneered high-strength all-ceramic bridges was not so great as expected. The survivability of multimaterial clinical structures will be influenced by material thickness ratios, geometric design factors, processing variables, and thermal history in addition to the mechanical and elastic properties of component materials.

Several studies used metal,[1,21,34] resin dies[16,17,35,36] or natural teeth[26-28,37] for the fracture testing of crown. The advantage of metal and resin die is the possibility of a standardized preparation and the identical physical quality. However, abutment made of steel or resin do not reproduce the actual force distribution that occurs on crowns cemented to natural teeth. Frequently used metal abutments, for example, have a high modulus about 200 GPa in comparison to human teeth with moduli between 5 and 23 GPa.[17] Influences of different abutment moduli of the fracture strength may lead to a false evaluation of the properties of the tested restorations; the greater deformation of the teeth results in a higher shear stress at the inner crown surface. The high strength resin teeth was selected in this study because it has a modulus of elasticity more closer to reported modulus of human dentin (18.3MPa)[38] than metal teeth and it responds to acid etching (34% phosphoric acid) by creating microundercuts to allow bonding.[39,40]

All ceramic bridges were adhesively luted to the abutments. Many studies showed a strong enhancement of the breaking strength of all-ceramic crowns bonded to dies or teeth versus nonbonded crowns.[22,41] It was hypothesized that a "die-crown" unit is created by cementing the all-ceramic crowns onto the resin dies. This hypothesis can be substantiated by the change in the surface flaw geometry that occurs as consequence of the hydrofluoric acid-etching procedure, by the reduction of stresses at the flaw tips as the stresses are transferred to the bonding medium, and by the intimate contact between the crown and the die that minimizes the weak link of the system.[42] In other words, there is a potential flaws and shape of the porcelain flaws and enables the resin cement to penetrate to the flaw tips as it fills the gap between the crown and the die.

Even though hydrofluoric acid promotes etching and improves the bond strength of glass ceramics and most of the feldspathic porcelains with low and medium alumina content, it neither affects the surface nor improves the bond strength of the high alumina-content core ceramics.[43] Therefore, the internal surface of In-Ceram bridges was treated by sandblasting with 50μm aluminum oxide at 2.5 bar and ultrasonically cleaned in distilled water for 10minutes. This sandblasting method roughens the internal surface of the alumina core and increases the area available for bonding.

In an attempt to correlate the results of this study with published clinical studies, the authors can find only incomplete clinical data concerning the long-term performance of In-Ceram and IPS Empress 2 bridge. Caution must be exercised when extrapolating laboratory data to the clinical situation because many in vivo variables are excluded from a controlled laboratory study. Although the model used resembled clinical conditions, it did not simulate the movement of abutment teeth within the periodontal ligament. Minor periodontal movements enhance the flexural strain between the abutments in the interproximal position.[1,29,32] Also, static testing gives no clues about the long-term material properties under cyclic stresses. However, compressive strength studies of crown systems within their limits give an idea for the load-bearing capacity in simulated clinical situations.

Maximal forces that may appear in the anterior dental area vary between 98N and 360 N,[44] however, the normal anterior physiologic forces generated during chewing procedures are much smaller and fall in the range of 10~35N.[45] From the previous in vitro investigations of this type demands on the mechanical strength of all ceramic fixed partial dentures were formulated: an initial strength of 400N for the anterior tooth and of 600 N for the posterior tooth area has to be attained. This requirement maintains the premises that the fatigue strength only amounts to approximately 60% of the initial strength and that average maximum bite forces of nearly 200N occur in the anterior tooth area while forces of 300N occur in the posterior tooth area. Although that is only a very modest minimum requirement, which is not supported by any in vivo study, it may be stated that In-Ceram as well as IPS

Empress 2 bridges within the limit of this study showed a sufficient initial strength to allow clinical testing of these all-ceramic bridges

In all ceramic three-unit fixed partial dentures, achieving adequate occlusogingival height for the connector is of primary importance. Connector dimensions ranging between 4mm in height and 4mm in width (a surface area of $16mm^2$) at the anterior area, and 5mm in height and 4mm in width at the premolar area, are recommended for preventing a catastrophic failure.[12] Since the core ceramic is stronger than veneer ceramic, the substructure for the fixed partial denture should be designed so as to maximize the core material and only minimum amounts of sintered glass-ceramic should be applied to the lingual area of the fixed partial dentures to improve the load-bearing properties of the material.

Marginal fit

There was a significant difference among the systems and a trend toward higher marginal discrepancy with 112μm of the copy-milled In-Ceram bridges than conventional In-Ceram(97μm) and IPS Empress 2 (94μm) bridges. This result is not in agreement with findings of Rinke et al.[6] who found no statistical difference between the In-Ceram and copy-milled In-Ceram groups. The lingual margin of the all-ceramic crowns shows smaller marginal discrepancy than distal surfaces. The phenomenon of greater marginal discrepancy mesial-distally observed in the metal-ceramic FPDs[35] was not present in this study.

The ceramic coping fabrication accounted for the different marginal discrepancy of the ceramic system.[46] The lost wax technique is used for the fabrication of Empress copings. The wax pattern is fabricated on a stone die with die spacer applied. The thickness of the die spacer recommended ranges from 25 to 40μm.[47] Thermal shrinkage of approximately 0.2%[48] of the ceramic coping is also expected after casting. This thermal shrinkage is compensated by setting and thermal expansion of a phosphates-bonded investment at approximately 0.3%[49] and 0.2%, respectively. Thus the net dimension of a cast ceramic coping is the result of the expansion and contraction of various materials used in its fabrication. The intricate balance and control of the materials are necessary for an acceptable fit.

The fabrication of the In-Ceram aluminous core consists of two stages: condensation of the aluminum oxide powder onto the refractory die followed by a glass-infiltration process. Careless shaving of excess slip material and adjustment of sintered framework at the margin area could potentially lead to increased marginal discrepancy.[5,50] In copy-milled In-Ceram, the skillful management of proto-type resin pattern and the scanning sensitivity is important. After the glass-infiltration firing for both conventional and copy-milled technique, the excess glass must be trimmed using a rotary instrument and then sandblasting. This procedure also must be performed carefully and may influence to marginal integrity.

The error occurred at each step of the fabrication of an all-ceramic system would be either compound or offset previous errors. Although the number of steps involved in the fabrication of all-ceramic crowns was not a direct indication of the quality of the marginal integrity, it may be suggested that the more the steps involved, the more likely it is that technical errors will occur.

The cementation phenomenon adds another important variable to the vertical marginal discrepancy of a crown system. Jorgensen study,[51] which compared pre-and post-cementation marginal adaptation values, clearly showed that any study aimed at determining the marginal adaptation of a crown system requires cementation of the crowns with procedures that simulate the clinical situation. The hydrodynamic intracoronal pressures that develop during cementation and that prevent complete seating of crown have been well documented.[52,53] Studies that seat various crowns on test dies and measure marginal openings without cementation will not correctly reflect the marginal adaptation.

Comparison between the present and previous studies must be made cautiously. The values reported often depend more on study design and measurement method than on the materials tested. Generally, the evaluation of the marginal discrepancy of crowns depends on several factors: treatment (such as aging procedures) after cementation; Kind of microscope; Measurement of cemented or not-cemented crowns; Storage time and enlargement factor used for measurement; Kind of abutment used for measurements. Therefore, previous studies involving various materials and techniques have resulted in a tremendous range of value for measurement of fit. The marginal fit of different all-ceramic crowns has been studied. The results show a high variation within one crown system. In one study, the mean value was $28\pm3.13\mu m$,[54] and in another study it was $160\pm45.98\mu m$.[47] Rinke et al.[6] also found that the marginal discrepancy of cemented In-Ceram crowns ranged from 1 to $153\mu m$ (median $32.5\mu m$) with a conventional technique, and from a 3 to 153 μm (median $38\mu m$) with a copy-milled technique. All data should be analyzed under the consideration of the study design.

The cross-sectional method is time-consuming, requires additional steps, and sacrifices the crown. This method precludes measurement of marginal distortion at the various stages of porcelain firing on the same samples, but the additional steps and effort provide more information and greater accuracy of measurement. The cross-sectional evaluation of margins allows greater precision in determination of measuring points and permits determination of the degree of horizontal discrepancy that is not possible with the direct viewing technique. In addition to that, to observe the marginal discrepancy adjacent to the connector in this study, specimens should be sectioned. The absolute marginal discrepancy chosen for this study always represents the maximum measurement of misfit at the margin and always greater than (or equal to) the vertical margin discrepancy or marginal gap in this study. From a practical standpoint, most experienced clinicians would be satisfied with discrepancies in marginal fit of $50\mu m$ or less and provably deem a fit of $100\mu m$ clinically acceptable in some cases. McLean and von Fraunhofer[5] in a 5-year clinical study of 1000 restorations concluded that $120\mu m$ was the maximum acceptable marginal opening. All systems in this study met the criterion for acceptable marginal discrepancy of $120\mu m$.

CONCLUSIONS

Within the conditions and limitation of this study, the following conclusions were drawn :

1. There was no significant differences in the fracture strength among the three all-ceramic bridge systems.
2. The Weibull modulus of copy-milled In-Ceram was higher than that of In-Ceram and IPS Empress 2 Bridges.
3. The mean absolute marginal discrepancy of the all ceramic bridges in descending order was: copy-milled In-Ceram ($112\pm23\mu m$), In-Ceram($97\pm24\mu m$), and IPS Empress 2 (94 ± 21 μm). Copy-milled In-Ceram showed significantly greater marginal discrepancies than the other systems.
4. The lingual surfaces of the ceramic crowns showed smaller marginal discrepancies than mesial and distal points. There was no significant difference between teeth (incisor, canine).
5. All-ceramic bridges of three systems appeared to exhibit sufficient initial strength and acceptable marginal fit values to allow clinical application.

Acknowledgment
I would like to express thanks to professor Jae-Ho Yang for his scientific advice and guidance. I dedicate this thesis to my family and thank for their love and support.

REFERENCES

1. Kappert HF, Knode H. In-Ceram : testing a new ceramic material. Quint Dent Technol 1993;16:87-97.
2. Seghi RR, Sorensen JA, Engleman MJ, Roumanas E, Torres TJ. Flexural strength of new ceramic materials (abstract 918). J Dent Res 1990;69:299.
3. Sorensen JA. A standardized method for determination of crown margin fidelity. J Prosthet Dent 1990; 64:18-24.
4. Sorensen JA, Kang SK, Kyomen SM, Avera SP, Faulkner R. Marginal fidelity of all-ceramic bridges (abstract 2192). J Dent Res 1991;70:540.
5. Prübster L, Diehl J. Slip-casting alumina ceramics for crown and bridge restorations. Quintessence Int. 1992;23:25-31.
6. Rinke S, Hüls A, Jahn L. Marginal accuracy and fracture strength of conventional and copy-milled all-ceramic crowns. Int J Prosthodont 1995;8:303-10.
7. Schweiger M, Holand H, Frank M, Drescher H, Rheinberger V. IPS Empress 2 : A new pressable high-strength glass-ceramic for esthetic all-ceramic restorations. Quint Dent Technol 1999;22:143-51.
8. Sorensen JA. The IPS Empress 2 system: Defining the possibilities. Quint Dent Technol 1999;22:153-63.
9. Sorensen JA, Mito WT, Chamberlain TH. Core ceramic flexural strength from water storage and reduced thickness (abstract 906). J Dent Res 1999;78:219.
10. Sorensen JA. A rationale for comparison of plaque-retaining properties of crown systems. J Prosthet Dent 1989;62:264-9.
11. Kappert HF, Knode H, Manzotti L. Metallfreie Brücken für den Seitenzahnbereich. Dent Labor 1990;38:177-83.
12. Sorensen JA, Cruz M, Mito WT, Raffeiner O, Meredith HR, Foser HP. A clinical investigation on three-unit fixed partial dentures fabricated with a lithium disilicate glass-ceramic. Prac Periodont Aesthet Dent 1998;11:95-106.
13. Holmes JR, Bayme SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent 1989;62:405-8.
14. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107-11.
15. Scherrer SS, de Rijk WG, Belser UC. Fracture resistance of human enamel and three all-ceramic crown systems on extracted teeth. Int J Prosthodont 1996;9:580-5.
16. Chai J, Takahashi Y, Sulaiman F, Chong KH, Lautenschlager EP. Probability of Fracture of all-ceramic crowns. Int J Prosthodont 2000;13:420-4.
17. Scherrer SS, de Rijk WG. The fracture resistance of all-ceramic crowns on supporting structures with different elastic moduli. Int J Prosthodont 1993;6:462-7.
18. Friedlander LD, Munoz CA, Goodacre CJ, Doyle MG, Moore BK. The effect of tooth preparation design on breaking strength of Dicor crowns. Part I. Int J Prosthodont 1993:159-68.
19. Dickinson AJG. A comparative study of the strength of aluminous porcelain and all ceramic crowns. J Prosthet Dent 1989;61:297-304.
20. Prübster L. Compressive strength of two modern all-ceramic crowns. Int J Prosthodont 1992;5:409-14.
21. Strub JR, Beschnidt SM. Fracture strength of 5 different all-ceramic systems. Int J Prosthodont 1998;11:602-9.
22. Yoshinari M, Dérand T. Fracture strength of all ceramic crowns. Int J Prosthodont 1994;7:329-38.
23. Sobrinho LC, Cattell MJ, Glover RH, Knowles JC. Investigation of the dry and wet fatigue properties of three all-ceramic crown systems. Int J Prosthodont 1998;11:255-62.
24. Strub JR, Beschnidt SM. Fracture strength of 5 different all-ceramic system. Int J Prosthodont 1998;11:602-9.
25. Kern M, Schwarzbach W, Strub JR. Stability of all-porcelain, resin bonded fixed restorations with different designs. An in vitro study. Int J Prosthodont 1992;5:108-13.
26. Kern M, Fechtig T, Strub JR. Influence of water storage and thermal cycling on the fracture strength of all-porcelain, resin-bonded fixed partial denture. J Prosthet Dent 1994;71(3):251-6.
27. Loose M, Rosentritt M, Leibrock A, Behr M, Handel G. In vitro study of fracture strength and marginal adaptation of fibre-reinforced-composite versus all ceramic fixed partial dentures. Eur J Prosthodont Rest Dent 1998;6:55-62.
28. Kern M, Douglas H, Fechtig T, Strub JR, DeLong R. Fracture strength of all-porcelain, resin-bonded bridges after testing in an artificial oral environment. J Dent 1993;21:117-21.
29. 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(6):1253-8.
30. Sorensen JA, Kang SK, Torres TJ, Knode H. In-Ceram fixed partial dentures : three-year clinical trial results. J Calif Dent Assoc 1998;26:207-14.
31. Pospiech P, Rammelsberg P, Goldhofer G, Gernet W. All-ceramic resin-bonded bridges : a 3-dimensional finite-element analysis study. Eur J Oral Sci 1996;104:390-5.
32. Kamposiora P, Papavasiliou G, Bayne SC, Felton

DA. Stress concentration in all-ceramic posterior fixed partial dentures. Quintessence Int 1996;27:701-6.
33. McLean JW, Jeansonne EE, Chiche GJ, Pinault A. All-ceramic crowns and foil crowns. In:Chiche GJ, Pinault A(eds). Esthetics of Anterior Fixed Prosthodontics. Chicago : Quintessence, 1994;P. 97-113.
34. Campbell SD, Sozio RB. Evaluation of the fit and strength of an all-ceramic fixed partial denture. J Prosthet Dent 1998;59:301-6.
35. Neiva G, Yaman P, Dennison JB, Razzoog ME, Lang BR. Resistance to fracture of three all-ceramic systems. J Esthet Dent 1998;10:61-6.
36. Rosentritt M, Plein T, Kobeck C, Behr M, Handel G. In vitro fracture force and marginal adaptation of ceramic crowns fixed on natural and artificial teeth. Int J Prosthodont 2000;13:387-91.
37. Burke FJT, Watts D. Fracture resistance of teeth restored with dentin-bonded crowns. Quintessence Int 1994;25:335-40.
38. Craig RG. Restorative Dental Materials, ed 10. St Louis : Mosby, 1997.
39. Aliya W, Yaman P, Razzoog ME, Dennison JB. Bond strength of four resin cements to an alumina core. J Dent Res 1996;75(Spec Issue):378.(Abstr).
40. Dwan A, Yaman P, Razzoog ME, Wang FP. Effect of cement on fracture resistance of all-ceramic crowns. J Dent Res 1996;75(Spec Issue):284.(Abstr).
41. Croten M, Pröbster L. The influence of different cementation modes on the fracture resistance of feldspathic ceramic crowns. Int J Prosthodont 1997;10:169-77.
42. Kern M, Thompson VP. Bonding to glass infiltrated alumina ceramic : adhesive methods and their durability. J Prosthet Dent 1995;73:240-9.
43. Sorensen JA, Engelmann MJ, Torres TJ, Avera SP. Shear bond strength of composite resin to porcelain. Int J Prosthodont 1991;4:17-23.
44. Köber KH, Ludwig K. Maximale kaukraft als berechnungsfaktor zahntechnischer konstruktionen. Dent Labor 1983;31:55-60.
45. De Boever JA, McCall WD, Holden S, Ash MM. Functional occlusal forces : an investigation by telemetry. J Prosthet Dent 1978;40:326-33.
46. Sulaiman F, Chai H, Jameson LM, Wozniak WT. A comparison of the Marginal fit of In-Ceram, IPS Empress, and Procera Crowns. Int J Prosthodont 1997;10:478-84.
47. Richardson DW, Fletcher VA, Gardner LK, Allen JD. Film thickness of die coating agents. J Prosthet Dent 1991;66:431-4.
48. Dong JK, Luthy H, Wohlwend A, Scherrer P. Heat-Pressed ceramics : Technology and strength. Int J Prosthodont 1992;2:9-16.
49. Eden GT, Franklin OM, Powell JM, Ohta Y, Dickson G. Fit of porcelain fused to metal crown and bridge castings. J Dent Res 1990;58:2360-8.
50. Grey NJ, Piddock V, Wilson MA. In vitro comparison of conventional crowns and a new all-ceramic system. J Dent 1993;21:47-51.
51. Jørgensen KD. Structure of the film of zinc phosphate cement. Acta Odontol Scand 1960;18:491-501.
52. Ishikiriama A, Oliveira CD, Viera DF, Mondelli DC. Influence of some factors on the fit of cemented crowns. J Prosthet Dent 1981;45:400-4.
53. Webb EI, Murray HV, Holland GA, Taylor DF. Effect of preparation relief and flow channels on seating full coverage castings during cementation. J Prosthet Dent 1983;49:777-80.
54. Pera P, Gilodi S, Bassi F, Carossa S. In vitro marginal adaptation of alumina porcelain ceramic crowns. J Prosthet Dent 1994;72:585-90.

Reprint request to:
Dr. Jae-Ho Yang
Dept. of Prosthodontics, College of Dentisity,
Seoul National University.
28-1 Yeongun-Dong, Chongno-Gu, Seoul Korea 110-749,
Tel:+82-2-760-2661, Fax:+82-2-760-3860