MARGINAL FIDELITY AND FRACTURE STRENGTH OF IPS EMPRESS 2® CERAMIC CROWNS ACCORDING TO DIFFERENT CEMENT TYPES

Hyun-Ok Cho, D.D.S., M.S.D., Dong-Wan Kang, D.D.S., M.S.D., Ph.D.
Dept.of Prosthodontics, College of Dentistry, Chosun University

There has been increasing use of IPS Empress 2® owing to easy fabrication method, high esthetics similar to natural teeth, good marginal accuracy, and sufficient fracture strength. However, in clinical application, although a luting agent and the tooth cementation bonding procedure influence the marginal accuracy and fracture strength restoration, there has been a controversy in the selection of proper luting agent.
This study was to measure the marginal fidelites and fracture strength of IPS Empress 2® crowns according to three cement types, Protec cem®, Variolink Ⅱ® and Panavia 21®. After construction of 12 experimental dies for each group, IPS Empress 2® crowns were fabricated and luted the metal master die prepartion of the maxillary right premolar. Marginal gaps before cementation and after cementation were measured. Buccal incline on the functional cusp of specimens were loaded until the catastrophic failure and fracture strength was measured.
The results of this study were as follows:

1. The range of gap was 34.04 ±4.84 ㎛ before cementation and 37.88 ±5.00 ㎛ after cementation, which showed significant difference by paired t-test ($p<0.05$).
   The difference in the results from marginal accuracy according to measuring point proved to be not statistically significant by two-way ANOVA test ($p>0.05$).
2. The difference in the results from marginal accuracy according to three cement types proved that The Variolink Ⅱ® cement group had the least gap, 35.43 ±5.03 ㎛, and showed superior marginal accuracy while there existed statistic significance in Protec cem® cement group, 39.06 ±4.41㎛ or Panavia 21® cement group, 39.16 ±4.39㎛ by two-way ANOVA test & multiple range test ($p<0.05$).
3. The difference in the results from fractures strength testing according to three cement type groups proved to be statistically significant ($p<0.05$). The Variolink Ⅱ® cement group shows the highest fracture strength of 1257.33 ±226.77 N, Panavia 21® cement group has 1098.08 ±138.45 N, and Protec cem® cement group represents the lowest fracture strength of 926.75 ±115.75 N.
4. Three different cement groups of different components showed acceptable marginal fidelity and fracture strength.

It is concluded that IPS Empress 2® crowns luted using Variolink Ⅱ® cement group had stronger fracture strength and smaller marginal gap than the other cement groups.
Although Variolink Ⅱ® resin cement seemed acceptable to clinical applications in IPS Empress 2® system, the IPS Empress 2® system still requires long-term research due to the lack of data in clinical applications

Key Words
All ceramics, luting agent, marginal accuracy, fracture strength

With the development of our society and culture, patients' demand for esthetics has greatly increased. In response to this demand, various esthetic restoration techniques and materials have been developed in the field of dentistry. Traditional porcelain-fused-to metal (PFM) techniques were used to satify this demand with high strength and long-term service in oral cavities, but the metallic background has been esthetically problematic in some situations. As a consequence, all-ceramic systems were developed to meet the need for superior esthetics and biocompatibility.[1]

The main weakness of dental ceramics is their low resistance to tensile stress. Furthermore, brittleness could be one of the most important clinical characteristics of ceramics, especially of glass or feldspathic ceramics. Clinical failure rates of all-ceramic restorations mentioned in the dental literature[2] confirm this weakness compared to metal ceramic restoration. Nevertheless, the esthetic and biologic advantages of all ceramic restorations have led to many efforts to improve the mechanical properties of dental ceramics.[3]

Several strengthening techniques and systems have been developed and investigated: In-Ceram®, OPC®, IPS Empress 2® system, etc. Alumina porcelain (In-Ceram; Vita Zahnfabrick, Bad sackingen, Germany) was introduced to create all-porcelain substructure for individual crowns and FPDs.[4] The In-Ceram technique uses a slip-cast alumina core infused with glass and this process impart to the material its natural color, compactness, and strength.[4] However, an Alumina core tends to decrease the translucency of an all ceramic crown and, also, requires longer processing.

Compared to the conventional IPS Empress system, IPS Empress 2® system (Ivoclar, Schaan, Liechtenstein) shows great difference in its chemical properties and crystal structure. Schewiger et al.[5] found that the interlocked lithium disilicate crystalline structure in glass matrix of IPS Empress 2® system is the main reason for higher fracture and flexural strength. The IPS Empress system had 120-200 MPa of flexural strength, whereas the IPS Empress 2® system with 350-450 MPa is being used as an anterior 3 unit bridge and posterior single crown.[5] Ceramic materials in this system are processed using a thermoforming procedure and a special furnace.[4] These days there has been an increasing use of IPS Empress 2® system as the fabrication process becomes easier.

All-ceramic systems fabricated with these various materials must fulfil high esthetic requirements and be similar to natural teeth, have marginal accuracy, and sufficient fracture strength.

As marginal leakage of restorations resulting from inaccurate margins can cause periodontal disease, dental caries, or hypersensitivities and thus shorten the lifespan of restorations, it is very important to prepare margins as accurate as possible that ceramic restorations can adapt well.[6] Ferrari et al.[7] reported on the effects of resin cement on the marginal accuracy of IPS Empress ceramic crowns. Bernal[8] studied on the marginal fitness before and after the cementation of Cerestore, PFM, and Dicor, and reported that the kinds of cement and cementing procedure can affect marginal fitness.

All-ceramic crowns should have sufficient fracture strength to resist masticatory pressure during functional movement as well as good marginal accuracy. Neiva[1] studied the fracture strength according to the type of all-ceramic crowns and Yoshinari et al.[9] reported on the fracture strength of In-Ceram ceramic crowns. Some clinical situations provide evidence that the selection of a luting agent and tooth cementation procedures can affect the strength and marginal gap of all-ceramic restorations.[8] Various cements have been used for luting all-ceramic restorations. Also, many investigators reported that different luting agent can affect the all-ceramic restoration strength and marginal accuracy. Grossman and Nelson[10] fabricated 50 Dicor crowns to fit identically prepared extracted human teeth and found that crowns luted using zinc phosphate cement had significantly lower crushing strength than crowns luted using Dicor® light-activated resin cement. Mclnnes-Ledoux et al.[11] determined that surface treatment of enamel and dentin increased the bond strength of glass-ionomer cement and that Dicor® light-activated resin cement produced a higher bond strength than three different glass-ionomer cements.

Though studies on these all-ceramic crowns are being made incessantly these days, studies on marginal accuracy and fracture strength according to the luting agents of IPS Empress 2® ceramic crowns fabricated by layering technique developed rather recently are insufficient. The purpose of this study is to examine the influence of three luting systems on the fracture strength and marginal fidelities of IPS Empress 2® system with layering technique by stereomicroscope and universal testing machine and to evaluate the possibility of clinical application.

MATERIALS AND METHODS

1. Die construction

For this study, a maxillary right premolar in a dentiform having shoulder preparation and a rounded axiogingival internal line angle was prepared. The die was fabricated from cobalt-chromium-molybdenum alloy (Remanium Dentaurum, Ispirgen, Germany). The rounded shoulder width was 1.0 mm, the occlusal reduction 2.0 mm and the axial reduction 1.5 mm in a preparation design with 6-degree convergence angle.

2. IPS Empress 2®rown fabrication with IPS Empress 2® system layering technique

To consider all possible sources of error in the fabrication process (e. g., Impression taking and production of working die), this study followed clinical procedure. Impressions of the prepared metal dies were made using additional silicon materials (Exaflex(r) GC Co, Japan), and 36 stone dies (MG, crystal rock®, Maruishi gypsum CO. LTD, Japan) were made.

All clinical and technical steps during the fabrication of IPS Empress 2® crowns followed the procedures indicated by the manufacturers. To fabricate specimens with equal thickness, all crowns were made using a silicone template of full contour wax-up of the crown previously made on the master die and were checked with vernia calipers to the accuracy of 0.1 mm.

The prepared surfaces, except for the area within 1.0mm from the margin, were covered with two layers of die spacer to allow proper thickness of cement. After the crown was waxed to full contour with the wax recommended by the manufacturer, cut back to 0.8mm of framework thickness with vernia calipers. The wax pattern was sprued and invested using the crucible and investment material provided by the manufacturer. The wax was then eliminated in a burnout furnace at 850° C and crowns were pressed in the system's pressing furnace (IPS Empress EP 500 press furnace, Ivoclar Leichtenstein). The wax pattern was eliminated and IPS Empress 2® glass ceramic ingot was heat pressed in a hot-press furnace. The glass ceramic was pressed into a mold at 920° C with a holding time of 20 minutes. Molding cycle ended, the mold was left to cool to room temperature. After cooling, the crowns were devested by blasting away the investment using glass beads at 2-bar pressure(80 μm glass bead). Crowns were provided with ultrasonic cleansing for 10 minutes and the sprues were removed. Pressed crowns were adjusted and fitted with diamond instruments in a handpiece to give the framework (core coping) a thickness of 0.8㎜. The framework was covered with wash powder, fired and veneered with IPS Empress 2® layering porcelain to create the final crown shape. The veneered final crowns were fired by furnace (Programat P80, Ivoclar). Thirty-six IPS Empress 2® crowns were fabricated. (Fig. 1)

3. Measurement of marginal accuracy before cementation

The marginal accuracy was determined at four predetermined marks beneath each metal die margin. The marks were positioned at the midfacial surface (mesial, distal, buccal, and lingual surface)

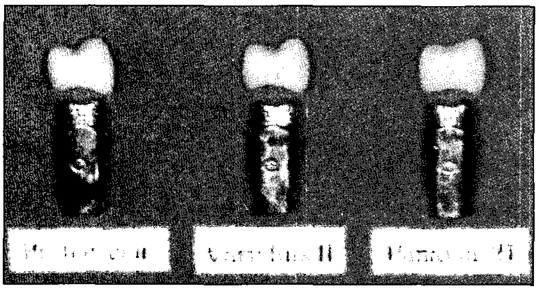

Fig. 1. Metal master die & IPS Empress 2® crown specimen

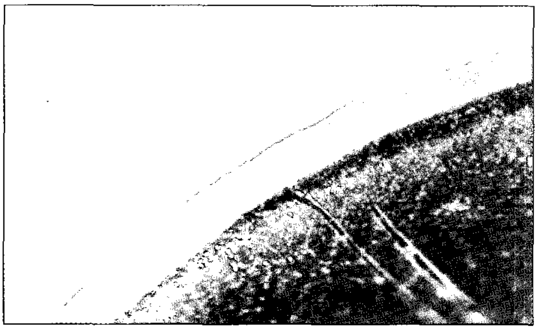

Fig. 2. Stereomicroscopic view of IPS Empress 2® crown specimen & measuring point before cementation

with 90° interval of each master metal die. The marginal gap was determined as the vertical opening between the prepared metal master die margin and the external edge of the IPS Empress 2® crown margin. Two indepedent examiners measured with ×70 maginfication stereomicroscope (SZ-ST®, Olympus, Japan) and camera. (Fig. 2, Fig. 4)

4. Cementation of IPS Empress 2® crowns.

Inner surfaces of IPS Empress 2® crown were etched with IPS Empress etching solution for 1 minute, cleaned by ultrasonic cleansing for 5 minutes and air particle abraded with 50㎛ aluminum oxide at the pressure of 5 to 6 bar. All crown were given equal finger pressure for three minutes and cemented on the master die according to the manufacturer's recommendation for each group. The experimental cement groups were Protec cem®, Variolink Ⅱ ® and Panavia 21®. After cementaion, all crowns were stored in distilled water at 37° C for 24 hours. (Table I, Fig. 3)

5. Measurment of marginal accuracy after cementation

The marginal accuracy was redetermined at four predetermined marks beneath each metal die margin. (Fig. 4)

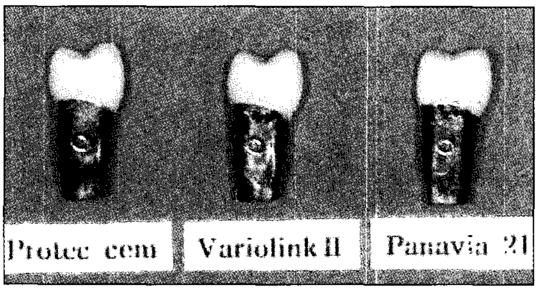

Fig. 3. IPS Empress 2® crown specimen after cementation

6. Loading of the specimens

Fracture strength testing was carried out using a universal testing machine (AGS-1000D®, Shimadzu, Japan) at the cross head speed of 1 ㎜/min with the load of 200 ㎏f. All crowns were loaded until catastrophic failure occurred. Universal testing machine was used with 4㎜ stainless steel ball on the loading point. Lower parts of die specimens were placed into the holding apparatus of Universal testing machine and occlusal surfaces of the crowns were kept parallel to the floor. The loading point was on the buccal incline of the functional lingual cusp of the specimen. (Fig. 5)

7. Statistical Analysis

SPSS version 8.0 software for Windows was adopted for the analysis. The significance of difference of the results was estimated by paired t-test, two-way ANOVA, one-way ANOVA and multiple range test at a 95% level of significance.

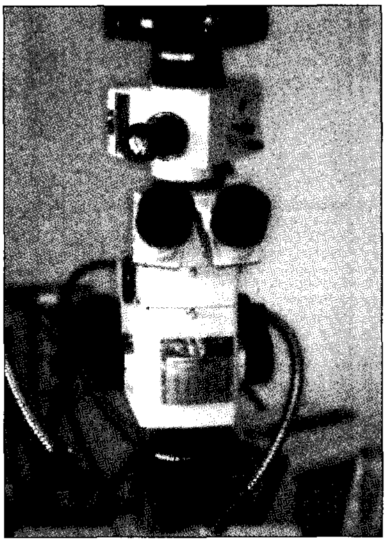

Fig. 4. Stereomicroscope(SZ-ST®, Olympus,Japan)

Fig. 5. Universal testing machine(AGS-1000D®, Shimadzu, Japan)

Table Ⅰ. Cement classifycation of the experimental group

Cement	Content	Manufacturer	The number of specimens
Protec cem®	Self-cured hybride ionomer cement (resin-modified glass ionomer cement)	Ivoclar-Vivadent Liechtensin	12
Variolink Ⅱ®	Dual-cured resin cement	Ivoclar-Vivadent Liechtensin	12
Panavia 21®	Self-cured resin cement	Kuraray	12

RESULTS

1. Results of the marginal accuracy

The gap range was 34.04 ±4.84 ㎛ before cementation and 37.88 ±5.00 ㎛ after cementation, which showed significant difference by paired t-test. ($p<0.05$)

Table II shows mean values and standard deviations of marginal fidelity according to cement type and measuring point. To find out the effects of cement type and measuring point on marginal fidelity and correlation between the two factors, two-way ANOVA test was performed. Table III shows that no correlation was found between the two, and cement type was found to affect more greatly the marginal accuracy than measuring point. ($p<0.05$)

The results of multiple range test (Scheffe' s test) are represented in Table 4 based on Table II in a trial to determine the relation ship between cement type and marginal accuracy. In this test, Variolink Ⅱ® cement group had the least gap of 35.43±5.03 ㎛, and showed superior marginal accuracy while there existed statistic significance with Protec cem® or Panavia 21® cement groups. ($p<0.05$) (Fig. 6-1, 2, 3)

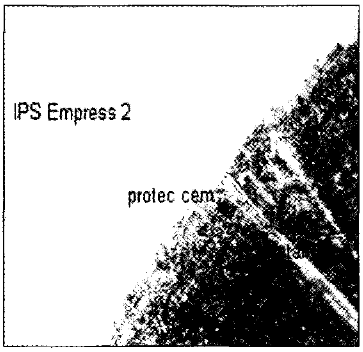

Fig. 6-1. Stereomiscopic view of Protec cem(r) cement group

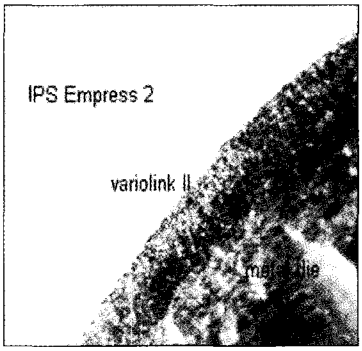

Fig. 6-2. Stereomicroscopic view of Variolink Ⅱ® cement group

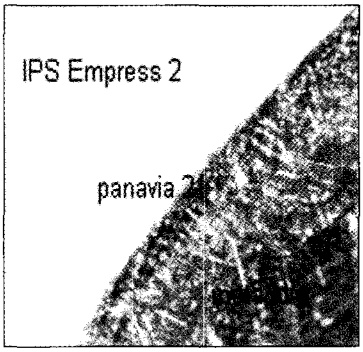

Fig. 6-3. Stereomicroscopic view of Panavia 21® cement group

Table Ⅱ. Marginal fidelity of IPS Empress 2® specimens according to cement type and measuring point (unit: ㎛)

	Protec cem® (Mean±SD)		Variolink Ⅱ® (Mean±SD)		Panavia 21® (Mean±SD)	
	Before	After	Before	After	Before	After
Mesial	30.16±1.99	36.41±4.03	31.58±5.71	36.41±6.52	36.08±5.50	41.00±5.18
Distal	35.08±3.87	39.08±4.85	31.66±4.59	36.16±5.09	33.50±4.03	39.41±3.55
Buccal	37.83±4.44	41.66±4.27	32.66±5.06	34.33±4.73	34.16±4.89	37.75±5.02
Lingual	36.66±4.07	39.08±3.17	33.25±4.28	35.83±5.14	35.91±4.10	38.50±3.34
Total	34.93±4.65	39.06±4.41	32.29±4.83	35.43±5.03	34.91±4.65	39.16±4.39

Table Ⅲ. Results of two-way ANOVA test for marginal fidelity according to cement type and measuring point ($p<0.05$)

Source	DF	SS	MS	F value	Pr>F
Model	11	697.722	63.429	2.91	0.0018
Cement type	2	432.930	216.465	9.93	0.0001*
Measuring point	3	0.388	0.129	0.01	0.9994
Cement type* measuring point	6	264.402	44.067	0.02	0.0672
Error	132	2878.500	21.806		
Corrected total	143	3576.222			

Table Ⅳ. Results of mutiple range test (Schffe' test) for marginal fidelity according to cement types. Means with the same letter are not significantly different.

Cement type	Mean	N	Scheffe Grouping
Panavia 21®	39.1667	48	A
Protec cem®	39.0625	48	A
Variolink Ⅱ®	35.4375	48	B

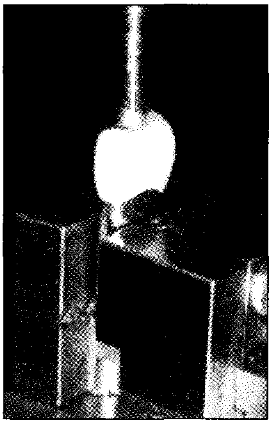

Fig. 7. Loading condition of IPS Empress 2® crown specimen

Fig. 8-1. Fractured specimen of protec cem® cement group

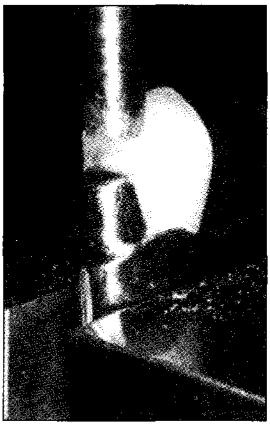

Fig. 8-2. Fractured specimen of Variolink Ⅱ® cement group

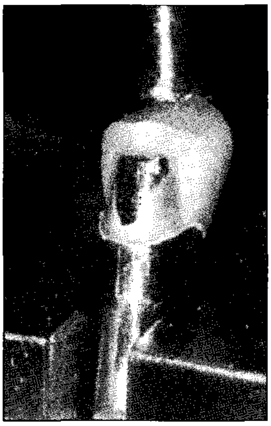

Fig. 8-3. Fractured specimen of Panavia 21® cement group

2. Results of the fracture strength testing

Table V shows mean values and standard deviations of fracture strength according to cement type. The results of one-way ANOVA test to determine the correlation between cement type and fracture strength are shown in Table VI. The results of mutiple range test (T test(LSD)) are represented in Table VII. Variolink Ⅱ® cement group shows the highest fracture strength of 1257.33 ±226.77 N, Panavia 21® cement group has 1098.08 ±138.45 N, and Protec cem® cement group represents the lowest fracture strength of 926.75 ±115.75 N. There is statistically significant difference. ($p<0.05$) (Fig. 7, 8-1, 2, 3)

3. Fracture pattern of specimens

Fracture pattern of each cement group had similarity, which showed vertical fracture lines spreading to marginal areas along mesial or distal proximal surfaces right below the loading site, and resulted in separation of fracture part from the metal die. Observation of the fracture surfaces of specimens through scanning electron microscope led to the conclusion that while Variolink Ⅱ®

Table Ⅴ. Fracture strength of IPS Empress 2 specimens according to cement type (unit:N)

Cement type	Obs	Mean SD
Protec cem®	12	926.75 ±115.75
Variolink Ⅱ®	12	1257.33 ±226.77
Panavia 21®	12	1098.08 ±138.45

Table Ⅵ. Results one-way ANOVA test for fracture strength according to cement types ($p<0.05$)

Source	DF	SS	MS	F value	Pr>F
Model(cement)	2	656004.055	328002.027	11.72	0.0001*
Error	33	923885.833	27996.540		
Correctal Total	35	1578889.888			

Table Ⅶ. Results of mutilple range test (T test(LSD)) for fracture strength according to cement types. Means with the same letter are not siginificantly different.

Cement type	Mean	N	T-Grouping
Variolink Ⅱ®	1257.33	12	A
Panavia 21®	1098.08	12	B
Protec cem®	926.75	12	C

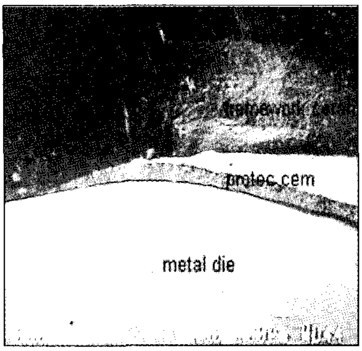

Fig. 9-1. SEM x 50 of Protec cem® cement group

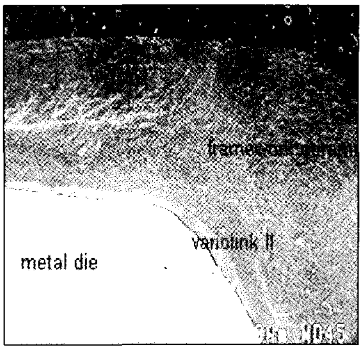

Fig. 9-2. SEM x 50 of Variolink II® cement group

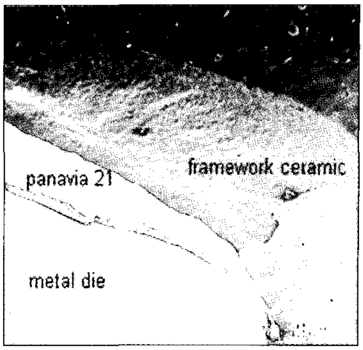

Fig. 9-3. SEM x 50 of Panavia 21® cement group

cement group adapted very well to inner surfaces of the crowns to make them look like one unit, and to form a dense and equal adhesive layer, Protec cem® cement group showed sparce and rough surfaces of adhesive layers. (Fig. 9-1, 2, 3)

DISCUSSION

Lack of natural translucency associated with metal ceramic crowns has provided the impetus for the development of all ceramic systems. The ultimate aim of such a system is to provide all ceramic crowns and bridges with sufficient mechanical strength to resist occlusal forces while maintaining excellent esthetics and biological properties.[12]

A few significant developments in dental ceramics were achieved during the past few years. Porcelain jacket crowns have been used widely in dentistry since Land developed the platinum foil technique in 1963.[13] In 1965, alumina-reinforced porcelain crowns were introduced.[14] These crowns were constructed of coping or core of a ceramic material containing 40% to 50% alumina with an outer layer of translucent porcelain. In 1983, Cerestore system was introduced by Sozio and Riley that represent a process and a material injection molding of the coping of all ceramic crown.[15] In 1984, Dicor system was introduced and became available by Adair that used to cast crown by the lost wax process.[16] However, the demand for ceramics with better physical properties is being continued.

Recently two all ceramic restorative systems have been introduced: In-Ceram system(Vita, Bad Sackingen, Germany) and the IPS Empress system(Ivoclar AG, Schaan, Liechtenstein)

In-Ceram system was introduced by Sadoun[17] and used alumina powder in a slip casting procedure to create a core material for crowns and fixed partial denture. The resulting bend strength of the materials is the highest ever reported for dental ceramics.[18]

The IPS Empress system uses guided crystallization leucite-reinforced glass ceramics, a lost-wax process, and ceramic material that is processed using a thermoforming procedure and a special furnace.[18] This system permits light to be reflected, scattered, and absorbed throughout the entire crown and underlying tooth structure, satisfying high esthetic standards demanded from restorations such as inlays, onlays, crowns, and veneers.[5]

In 1999, to reinforce the physical properties of IPS Empress system IPS Empress 2 system were introduced and fabricated by Schweiger, Hoand and Ivoclar Co. Ltd. The physical properties of this system had flexural strength of 350±50 MPa exceeding 250 MPa and high fracture toughness of 3.2 ±0.3 MPa · m0.5. As a result, the main objective in the development of IPS Empress 2® was to produce a material with which 3-unit FPDs and posterior crowns could be fabricated.[5]

The IPS Empress 2 glass ceramics represents a new types of material that does not bear any resemblance to the leucite glass-ceramic IPS Empress system as far as materials science is concerned. IPS Empress 2 system is a Lithium disilicate glass-ceramic, and the chemical basis for the material is the SiO2 -Li2O.[5] IPS Empress 2 system is composed of two layers: framework ceramic and layering ceramic. Framework ceramic is glass-ceramic containing lithium disilicate and lithium orthophate crystals with higher strength and is pressed in the IPS Empress EP 500 press furnace (Ivoclar AG) at the temperature of 920° C at which the material undergoes viscous flow. Because the microstructure of IPS Empress 2 glass ceramic after the processing procedure shows very dense lithium disilicate crystals in glass matrix and interlocked crystal pattern to inhibit crack propagation, IPS Empress 2 system increases fracture toughness and flexural strength.[5] By Mito et al.[19] In comparison of various all ceramic fixed partial denture, IPS Empress 2® system was compatible to In Ceram® system in the value of fracture strength. Layering ceramic is composed of glass ceramic containing very dense fluroapatite crystals and sintered at 800° C. This material is biocompatible and translucent similar to enamel, providing high esthetics with natural tooth structure.[5]

In dentistry, fidelity means faithfulness of reproduction of the tooth preparation margin with the restoration. Poor marginal fidelity resulting in a large marginal gap, easy attacks of caries, overcontouring, or a rough surface increases plaque accumulation, inducing gingival inflammation.[20] Clinicians placing these restorations need to be aware of the periodontal results of their restorative dentistry though ideal prostheses without gap are very difficult to fabricate. The factors affecting this gap include inaccurate preparation, finishing line type, risks of lab procedure, kind of ceramics, fabrication method, kind of cement(film thickness and viscosity) etc.[21]

Recently, various types of adhesive resin cement have been introduced. By Rosenstiel[22], the following factors should be considered for dental luting agent; biocompatibility, caries or plaque inhibition, microleakage, strength and other mechanical properties, solubility, water sorption, adhesion, setting stresses, wear resistance, color stability, radiopacity, film thickness of viscosity, and working and setting time. Also, successful cementation by luting agents depends on the following; temporary cement removal, smear layer removal, powder/liquid ratio, mixing temperature and speed, seating force and vibration, and moisture control.

Pera et al.[4] demonstrated better marginal fit of In-Ceram ceramic crowns fabricated on gingival chamfer and 50° degree shoulder tooth preparation compared with 90° degree shoulder margins. Also, the thickness of cement in all cases examined was within the clinically acceptable range of 50㎛. Malament et al.[6] recommended deep chamfer and rounded shoulder with axial reduction of 1.2 to 1.5㎜ in the cast glass restorations. Holmes et al.[23] mentioned phosphate-bonded investment by using ceramic crowns. The combination of investing and casting seems to be the key contributor to a marginal misfit. The investment material must compensate for thermal shrinkage of the casting from the soildification temperature to room temperature. The attainable limits of marginal fit theoretically should result in zero discrepancy at the carvosurface margin of the preparation. Practically a perfect result is not possible. Rinke et al.[24] demonstrated that median value of the marginal adaptation of In-Ceram crowns was 45㎛ for premolar crowns. Holmes et al.[23] reported average value of 48㎛ for marginal fit of Dicor crowns. Therefore, the practical range of fit clinically acceptable seems to be approximately 50 to 100 ㎛. In this study, the finishing line of the tooth preparation was a rounded shoulder. type According to this test, in case of Protec cem®, marginal gap was measured 39.06 ±4.41㎛, Variolink Ⅱ®, it was 35.43 ±5.03㎛, and Panavia 21®, 39.16 ±4.39㎛. This result shows better marginal adaptation in general compared to all ceramic crowns.

Conventionally, resin cement has been used for all ceramic restorations. Use of resin cements for ceramic restorations in clinical practice is complicated and technique-sensitive. Conventional glass ionomer luting cement has an anticariogenic potential through fluoride release, a coefficient of thermal expansion similar to tooth structure, a low in vivo disintegration rate, and it also adheres to tooth structure. Unfortunately, conventional glass ionomer cements have low tensile strength and fracture toughness, and they are susceptible to attack by moisture during the initial setting period. [25]

In the late 1980s, products described as hybrids of glass ionomer cement and composite were introduced to the dental profession and were called resin ionomers. Resin-ionomers can be divided into resin-modified glass ionomer cements, polyacid-modified resin cements, and fluoride-releasing resin cements.[25] Recently, Protec cem® known to have least expansion, as self-cured hybrid ionomer cement (Vivadent, Ivoclar, Ltd) with Ba-Al Fluorosilicate glass, Metaacrylate modified polyacrylic acid, additional content and Variolink Ⅱ®as dual-cured adhesive resin cement (Vivadent, Ivoclar, Ltd) with microhybride composite have been introduced. The clinical use of these cements have been reported to be applied by the IPS Empress 2® system with layering technique. In clinical situations, luting cements on margin of crowns may absorb oral fluid and expand. When conventional resin-ionomer cements(hybrid ionomer cement) were inserted into glass capillary tubes, their expansion caused the tubes to break during storage. If expansion is great enough, it will cause fractures in all ceramic crowns. Conventional acid-base glass ionomer expand considerably less in an aqueous environment. Cracking of both In-Ceram and IPS-Empress ceramic crowns has been reported in vitro when these cements were used as luting agents, and it was concluded that the expansion of these cements was sufficient to give rise to fractures in In-Ceram and IPS-Empress crowns stored in saline solution without any load applied. Because of this expansion, conventional resin-modified glass ionomer cement is no longer used for cementation of all ceramic crowns.[25] But the manufacturer (Ivoclar Ltd) of IPS Empress 2® system with layering technique recommends Protec cem® a hybid ionomer cement and Variolink Ⅱ® a resin cement for IPS Empress 2® system cementation.

In this study, two types of cement recommended by the manufacturer were compared with Panavia 21® (Kuraray) self-cured resin cement and phosphate monomer contented in terms of marginal gap within physical characteristics difference of each cement material. One of the results we could get through this study is that Variolink Ⅱ® cement group shows smaller marginal gap than the other cement groups. Also, during our experiments cracks and fractures were not found when Pretec cem®, hybrid ionomer cement was used. This result maybe attribute to the difference in chemical properties, film thickness and viscosity of each cement. Film thickness of each cement can be influenced by base catalyst ratio or powder liquid ratio in cement mixing, mixing time and cementation procedure, etc. Also, fabrication and ceraming process(combined with investing and casting) of IPS Empress 2 crown appear to play an important role in the final fit of the crowns.[23]

Many attempts have been made to fabricate all ceramic system not only with excellent esthetics but also with high strength. The strength of all-ceramic crowns can be affected by the following factors; occlusion of the patient, shape of the prepared tooth, all-ceramic crown system, thickness of the porcelain crowns, defects within the porcelain, and luting cement system used. These all could be responsible for the clinical fracture of all-ceramic crowns.[25] Compbell et al.[2] demonstrated that the rigidity, or stiffness of the substructure (core in all ceramic system) plays an important role in the relative strength and support of the veneering porcelain. Mito et al.[19] demonstrated that in fracture strength comparison of In Ceram system and IPS Empress 2 system in fixed partial denture fabrication, In Ceram system was 1300N and IPS Empress 2 system was 1650N. But this result was not statistically significant. Also, it is recommended that IPS Empress 2 system be replaced by In-Ceram® system. Leevoiloj et al.[25] evaluated the fracture incidence of In-Ceram® and VitaDur Alpha porcelain jacket all ceramic crowns cemented with 5 luting agents. (Fuji I, Fuji Plus, Vitremer, Advance and Panavia[13] The result was that for In-Ceram® crowns, cement type did not influence failure load while for porcelain jacket crown, Fuji I (110.5 kg) was significantly higher than vitremer (86.6kg). Bernal et al.[8] compared the effect of the different luting agents on fracture strength. Dicor crowns were significantly stronger when resin cement was used for cementation than when glass ionomer or zinc phosphate cements were used.

This study was therefore designed to attempt to elucidate the factors involved in this resistance to fracture, using simulated clinical techniques whenever possible. It was not possible to simulate the conditions under which tooth fracture may occur in vivo, but the standardized method of application of force in the study may at least allow comparison to be made between the different luting materials utilized. The laboratory construction of the crowns was standardized as closely as possible, and the crowns were made by one technician.

According to the present study, Variolink II® resin cement group was stronger than any other cement groups. There are some reasons for this. In recent literature, researchers demonstrated that fracture strength of resin cement was higher than that of resin modified glass cement.[22] Other workers have examined fracture resistance of all-ceramic crowns using conventional types of cement. In a study by Jensen et al.[26], when a glass ionomer luting cement was used to lute a group of dentin-bonded all-ceramic crowns, fracture resistance was lower than that obtained with those luted in position with dentinal bonding agents (Scotchbond, 3M Dental, and Gluma, Bayer Dental) and a dual-curing composite resin cement. In the specimens luted with the glass-ionomer cement, it may be expected that some bonding would have occurred between dentin and the glass-ionomer cement. Additional research is needed to further clarify the effect of the following factors upon restoration strength when resin cements and bonding procedures are used; aspects of tooth preparation design such as total occlusal convergence and occlusocervical finish line location, etching of the internal ceramic surface, and the precementation treatments of the prepared tooth surfaces.

Another aspect that needs to be evaluated is the mechanism by which the resin cement improves the strength of the restoration. The superior fracture resistance may also be explained by the synergistic nature of the bonding together of dentin to resin cement and resin cement to porcelain by the intermediary luting cement. Alternatively, the inferior physical properties of non resin cements may be involved. Another contributing factor has been proposed by Marquis[14], who concluded that the use of a resin-based luting material may reduce the potential for crack propagation by healing surface flaws, thereby producing a better performance than other "conventional" luting materials. He also considered that this might be a factor in good performance of veneer restorations. A further reason for the "strengthening" effect of resin-based luting materials has been proposed by Nathanson.[27] He indicated that, although shrinkage during resin polymerization is generally viewed as a negative property, within certain limitations, the composite resin polymerization shrinkage may help to strengthen porcelain by exerting a force on inner porcelain surface that stresses porcelain molecules together rather than away from each other. Burke et al.[28] investigated that the effect of dentinal bonding and ceramic etching procedures on fracture resistance of all-ceramic crowns compared with nonadhesive conventional cement(e.g., ZPC). Significant superior fracture resistance was obtained when dentinal bonding was incorporated into the luting procedure together with etching of the ceramic fitting surface and with the use of resin-based luting material. It therefore appears that while ceramic etching and application of silane solution to porcelain may enhance tensile strength of the porcelain- to-resin bond, it does not enhance the bond strength when predominantly compressive forces are applied to the specimens, as in the present investigation.

Fracture pattern of porcelain crowns in this study represented a wedge shape where fracture lines spread from its loading point to mesial and distal proximal surfaces and went further to the cervical areas of labial surfaces, which again split lingual and labial surfaces of all ceramic crowns. Such fracture patterns as dissolution in chronic stress and strain, thermal stimulus, and wet condition in oral cavities were not observed. Crescent fractures in gingival area resulting from lacks of porcelain were not observed, either. This pattern is identical to one reported by Proster et al.[18] Though failure from chronic stress and strain in oral cavities could not be reproduced, it is thought to be more significant than an experiment on flexural strength from a clinical point of view. Variolink Ⅱ®, when it fractured after being applied to Empress crowns with bonding procedure, showed a clear boundary forming one unit of crown and fracture part. Among the other cement groups, one showed a clear boundary, while the other showed cement layer left behind when it fractured.

In the present study, observation of the fracture surfaces of specimens through scanning electron microscope led to the conclusion that while Variolink Ⅱ® cement group adapted very well to inner surfaces of the crowns to make them look like one unit, and to form dense and equal adhesive layer, Protec cem® cement group showed sparce and rough surfaces of adhesive layers.

One of the basic evaluation guidelines of clinical success in all ceramic system is higher fracture strength during functional occlusion loading. A few examiners reported that the recommended condition of physical properties of all ceramic crown needed to be as 400 N for anterior teeth area and 600 N for posterior teeth area. These strength value were not supported by many researchers but have been used as a standard in clinical application of all ceramic systems.[29]

In this study, IPS Empress 2®crowns luted using Variolink Ⅱ® cement group had stronger fracture strength and smaller marginal gap than the other cement groups. IPS Empress 2 systems showed no less than 600 N of fracture load which might be enough a single crown in any arch or an anterior 3 unit bridge. Nevertheless, there is a significant difference from clinical practice as IPS Empress 2® crowns were cemented and measured in a metal die in the present study.

CONCLUSION

This study was to measure the marginal fidelites and fracture strength of IPS Empress 2® crowns according to three cement types, Protec cem®, Variolink Ⅱ® and Panavia 21®. After construction of 12 experimental dies for each group, IPS Empress 2® crowns were fabricated and luted a the metal master die prepartion of the maxillary right premolar. Marginal gaps before cementation and after cementation were measured. Buccal incline on the functional cusp of specimens were loaded until the catastrophic failure and fracture strength was measured.

The results of this study were as follows:

1. The range of gap was 34.04 ±4.84 ㎛ before cementation and 37.88 ±5.00 ㎛ after cementation, which showed significant difference by paired t-test ($p<0.05$).
   The difference in the results from marginal accuracy according to measuring point proved to be not statistically significant by two-way ANOVA test ($p>0.05$).
2. The difference in the results from marginal accuracy according to three cement types proved that The Variolink Ⅱ® cement group had the least gap, 35.43 ±5.03 ㎛, and showed superior marginal accuracy while there existed statistic significance in Protec cem® cement group, 39.06 ±4.41㎛ or Panavia 21® cement group, 39.16 ±4.39㎛ by two-way ANOVA test & multiple range test ($p<0.05$).
3. The difference in the results from fractures strength testing according to three cement type groups proved to be statistically significant ($p<0.05$). The Variolink Ⅱ® cement group shows the highest fracture strength of 1257.33 ±226.77 N, Panavia 21® cement group has 1098.08 ±138.45 N, and Protec cem® cement group represents the lowest fracture strength of 926.75 ±115.75 N.
4. Three different cement groups of different components showed acceptable marginal fidelity and fracture strength.

It was concluded that IPS Empress 2® crowns luted using Variolink Ⅱ® cement group had stronger fracture strength and smaller marginal gap than the other cement groups.

Although Variolink Ⅱ® resin cement seemed acceptable to clinical applications in IPS Empress 2® system, the IPS Empress 2® system still requires long-term research due to the lack of data in clinical applications

REFERENCES

1. Nevia, G. Yaman, P. Dennison, J.B.. "Resistance to Fracture of Three All-ceramic Systems." J Esthet Dent., 10:60, 1998.
2. Campbell, S.D.. "A comparative strength study of metal ceramic and all-ceramic esthetic materials: modulus of rupture." J Prosthet Dent., 62:476, 1989.
3. Groten, M. Proster, L.. "The Infulence of different Cementation Modes on the Fracture Resistance of Feldspathic Ceramic Crowns." Int J Prosthodont., 10:169-177, 1997.
4. Pera, P. Gilodi, S. Bassi, F. Carossa, S.. "In vitro marginal adaption of alumina porcelain ceramic crowns." J Prosthet Dent., 72:585-90, 1994.
5. Schweiger, M. Holand, W.. " IPS Empress 2 : A New Pressable High-Strength Glass-Ceramic for Esthetic All-Ceramic Restoration." QDT., 143, 1999.
6. Ferrai, M.. "Cement Thickness and Microleakage leakage under Dicor Crowns." Int J Prosthet. 4:126-131, 1991.
6. Malament, K.A. Grossman, D.G.. "Clinical application of bonded Dicor crown〔IADR abstract 1523〕." J Dent Res., 69(special issue):299, 1990.
7. Ferrai, M.. "Cement Thickness and Microleakage leakage under Dictor Crowns." Int J Prosthet. 4:126-131, 1991.
8. Bernal, G. Jones, M.R. Brown, D.T.. "The Effect of Finish Line Form and Luting Agent On the Breaking Strength of Dicor Crowns." Int J Prosthet., 6:286-290, 1993.
9. Yoshinari, M. Derand, T.. "Fracture strength of All-Ceramic Crowns." Int J Prosthet., 7:329, 1994.
10. Grossman, D.G. Nelson, J.W.. "The bonded Dicor crown〔IADR abstract 800〕." J Dent Res., 66(special issue):206, 1987.
11. Mclnnes-Ledoux, P.M. Ledoux, W.R. Weinberg, R..

"A bond strength study of luted castable ceramic restorations." J Dent Res., 68:823-825, 1989.
12. Grey, N.J.A. Piddock, V. Wilson, M.A.. "In vitro comparison of conventional crowns and a new all-ceramic system." J Dent., 21:47-51, 1993.
13. Land, C.. "Porcelain dental arts." Dent Comos., 45(8):615-620, 1903.
14. Marquis, P.M.. "The Infulence of cements on the machanical performance of dental ceramics." Bioceramics. 5:317-546, 1993.
15. Sozio, R.B. Riley, E.J.. "The Shinkage-free ceramic crowns." J Prosthet Dent., 49:182, 1983.
16. Adair, P.J. Grassman, D.G.. "The castable cermaic crown." Int J periodont Rest Dent., 4:32, 1984.
17. Sadoun, M.. "All Ceramic bridges with the slip casting technique." Presented at the 7th international symposium on ceramics, Paris, September, 1988.
18. Proster, L.. "Compressive Strength of Two Modern All-Ceramic Crowns." Int J Prosthet., 4: 409-414. 1992.
19. Mito, W.T. Mito, Sorensen, J.A.. "Fabrication of Fixed Partial Dentures with Empress 2." QDT. 164, 1997.
20. Sorensen J.A.. "A standardized method for determination of crown margin fidelity." J Prosthet Dent., 64:18, 1990.
21. Schneider, D.M. Levi, M.S. Mari, D.F.. "Porcelain shoulder Adaptation using direct refractoary dies." J Prosthet Dent., 36:583, 1976.
22. Rosenstiel, S.F. Land, M.F. Crispin, B.J.. "Dental Luting Agents : A review of the current literature." J Prosthet Dent,. 80:280, 1998.
23. Holmes, J.R. Sulik, W.D. Holl, G.A. Bayne, S.C.. "Marginal fit of castable ceramic crowns." J Prosthet Dent., 67:594-599, 1992.
24. Rinke, S. Huls, A.. "Marginal Accuracy and Fracture Strength of Conventional and Copy-Milled All-Ceramic crowns." Int J Prosthet., 8:303-310, 1995.
25. Leevailoj, C. Platt, J.A. Cochran, M.A. Moore, B.K.. "In vitro study of fracture incidence and compressive fracture load of all-ceramic crowns cemented with resin modified glass ionomer and other luting agents." J Prosthet Dent., 80:699-707, 1998.
26. Jensen, J.E. Sheth, J.J. Tolliver, D.. "Etched-porcelain resin-bonded full-veneer crowns. In vrtro fracture resistance." Compend Contin Educ Dent., 10:336-347, 1989.
27. Nathanson, D.. "Principles of porcelain use an an inlay/onlay material." Chicago:Quintessence., 32-37, 1994.
28. Burke, F.J.T.. "The Effect of Variations in Bonding Procedure on Fracture Resistance of Dentine-Bonded All-Ceramic Crowns." Quintessence Int., 26:293-300, 1995.
29. De Boever, J.A. McCall, W.D. Holden, S. Ash, M.M.. "Functional occlusal force: An investigation by telemetry." J Prostet Dent., 40:326-333, 1978.

Reprint request to:
Dr. Dong Wan Kang
Dept. of Prosthodontics, College of Dentistry,
Chosun University, 588, Seoseok Dong, Dong-Gu,
Kwangju, 501-759, Korea
E-mail: dwkang@ chosun.ac.kr