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Marginal adaptation and flexural strength of a leucite reinforced dental glass ceramic

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Abstract

This study was designed to investigate the adaptation of shaded (A2) and non-shaded (T2) leucite reinforced glass ceramic inlays fabricated using a hot-pressed system and to evaluate the flexural strength of these materials. Part 1: MOD inlays cemented on their respective dies using resin cement were examined for fit at 12 locations. Ten inlays per group; A2 and T2. Gap measurement (microns) of sectioned samples was performed using an SEM. Part 2: 10 bars (2.0x1.5x25 mm) were made of each ceramic type. Bars were tested in a three-point flexure on a universal testing machine. ANOVA and Duncan statistical analyses ($p \leq 0.05$) were performed on the data. The large internal gaps was mostly found in T2 inlays. Part 2: A2 bars (69.78 ± 9.5 MPa) gives lower flexural strength than T2 (98.30 ± 14.0 MPa). Overall results indicate that the color added in a glass ceramic does have an effect on the properties of a leucite-reinforced glass ceramic.

Key words : Marginal gap, adaptation, flexural strength, a leucite-reinforced glass ceramic, resin cement

Marginal adaptation and flexural strength of a leucite reinforced dental glass ceramic.

Currently in routine dental practice, many patients demand esthetic restorations (Leinfelder, 2001). Tooth colored restorative materials such as composite resins and dental porcelains have been introduced to replace missing tooth structure to achieve an esthetic appearance. Since the longevity of composite resin is still questionable because of wear resistance, loss of marginal integrity (Roulet, 1987), and volumetric polymerization shrinkage (Lutz, *et al.* 1986; Craig, 1993), alternative materials such as ceramics have been developed (Mormann, *et al.* 1989).

Ceramics, in contrast to composite resins have physical and chemical properties very similar to enamel Adair and Grossman, 1984). Ceramics are also generally accepted to be very biocompatible with oral tissue. Light absorption and light-scattering behavior provide the ability to mimic the appearance of natural teeth. There are certain limitations, however, to the use of ceramics. Ceramics, by nature, are extremely brittle and weak under tensile stress. (McLean, 1990)

At present, all-ceramic restorations can be fabricated in different manners such as: 1) conventional porcelain sintered on refractory die technique (Aluminous porcelain, Vita Zahnfabrik, Germany); 2) a castable ceramic onlay/inlay (Dicor, Dentsply, York, PA, USA); 3) hot-pressed ceramic system (Empress, Ivoclar, Schaan, Liechtenstein); 4) slip cast technique (In-Ceram, Vita Zahnfabrik, Germany); 5) CAD/CAM (computer-aided design/ computer aided manufacturing; Cerec, Siemens, Bensheim, Germany) and 6) porcelain milling system (Celay, Mikrona Technologie, Switzerland) (Giordano, 1996)

The first four techniques require an impression and a model of prepared tooth which involved in laboratory procedures. CAD/CAM system and the porcelain milling system can be used as a chairside customization procedure or in a laboratory. With all these systems, it is possible to fabricate single crowns, bridges, inlays and veneers.

The disadvantage of a conventional porcelain is that the particles are sintered together, resulting in microporosities within the porcelain itself. As a consequence, these inhomogeneities can initiate crack propagation, leading to the early failure of the restorations. The technique of casting glass-ceramic was developed in order to improve the flexural strength in which the porosities are minimized (Adair and Grossman, 1984). Nevertheless, the overall shrinkage during the controlled crystallization was also observed (Scharer, *et al.* 1988).

To overcome this disadvantage, a hot-pressed system was subsequently developed (Dong, *et al.* 1992). The leucite reinforced glass-ceramic ingot was precerammed and precolored and was heat pressed into a mold. There are two type of ingot used in this system. The shaded ingot is primarily used as a core material as for a layering technique. This means that the shaded of the prepared tooth must be first determined. The core is then veneered with its respective feldspathic porcelain in order to create the life-like appearance of an anterior teeth. The non-shaded ingot which is a highly translucency material and is designed to be used as inlays/onlays and veneers. The color of the restoration primarily depends on the external coloration in combination with the color of the cementing material.

Even though ceramic restorations give an excellent esthetic appearance, the longitudinal clinical studies have not been convincing reported (Molin and Karlsson, 1993). While the long-term clinical performance of the ceramic restoration mainly depends on several factors, the fit and the relative strength are of significant interest. The marginal inaccuracy might be a serious predisposing factor to the early failure of the restorations.

Despite the fact that a leucite reinforced dental glass ceramic provides superior esthetic restorations, the inforamation on the comparative strength is inadequate. Even though the strength data cannot be used to give an absolute prediction of clinical performance, the flexural strength is the criterion most used in industry for the testing of brittle materials and is generally considered the most satisfactory means of assessing strength (Seghi and Sorensen, 1995). The International Standards Oraganization (ISO) supports the use of the three-point-bend-test as a mean of evaluating the strength of dental ceramics. (ISO standard no. 6872, 1995)

The purpose of this study was to investigate the adaptation of shaded and non-shaded leucite reinforced glass ceramic inlays and to evaluate the flexural strength of these materials fabricated using a hot-pressed ceramic system.

Materials and Methods

Part 1: Marginal Adaptation Evaluation

An MOD premolar preparation in an ivorine tooth was used to fabricate a master die. The tooth preparation procedure was performed according to a general principle of ceramic inlay preparation. The area of isthmus and occlusal surface have a minimum thickness of 1.5 to 2 mm. The preparation had shoulder finishing line, internal round angle, 10 degrees divergence and occlusal cavosurface margin was approximately 90 degrees, as shown in Figure 1.

Impressions of a master die were made using an addition polymerization elastomeric impression material (Express, 3M Dental Products Division, St. Paul, Minnesota, USA). Twenty epoxy resin duplications (3M Dental Products Division, St. Paul, Minnesota, USA) were made and used to fabricate inlays according to the manufacturer's recommendations. Ten inlays per group were examined for fit at multiple locations, as shown in Figure 2 and Figure 3. Group 1) IPS-Empress, no color (T2 ingots); Group 2) IPS-Empress, shade A2 (A2 ingots).

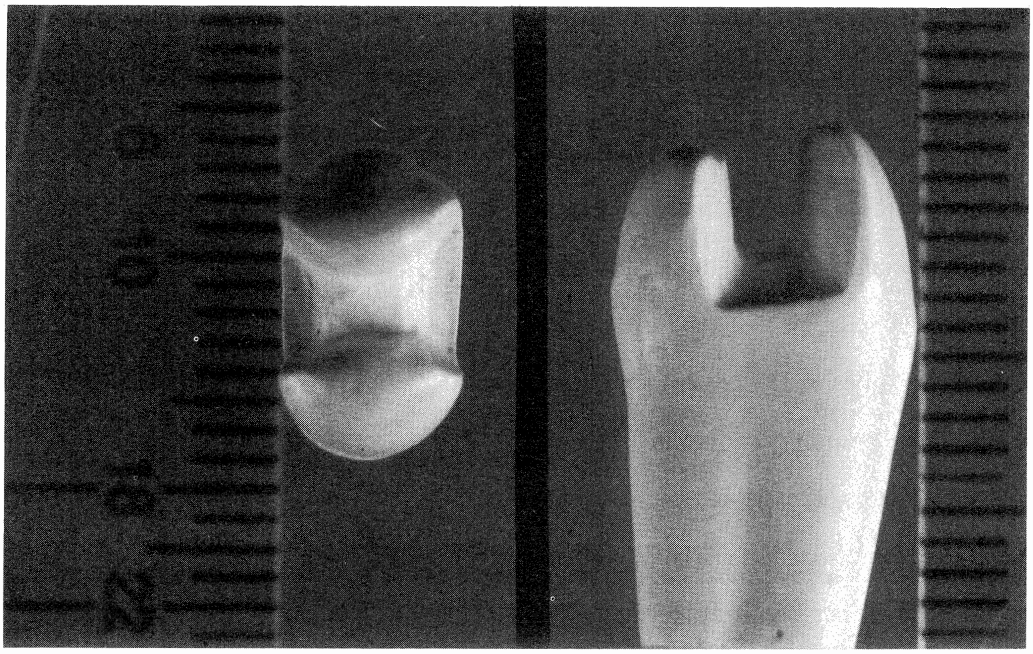

Figure 1 A MOD premolar preparation in an ivorine tooth.

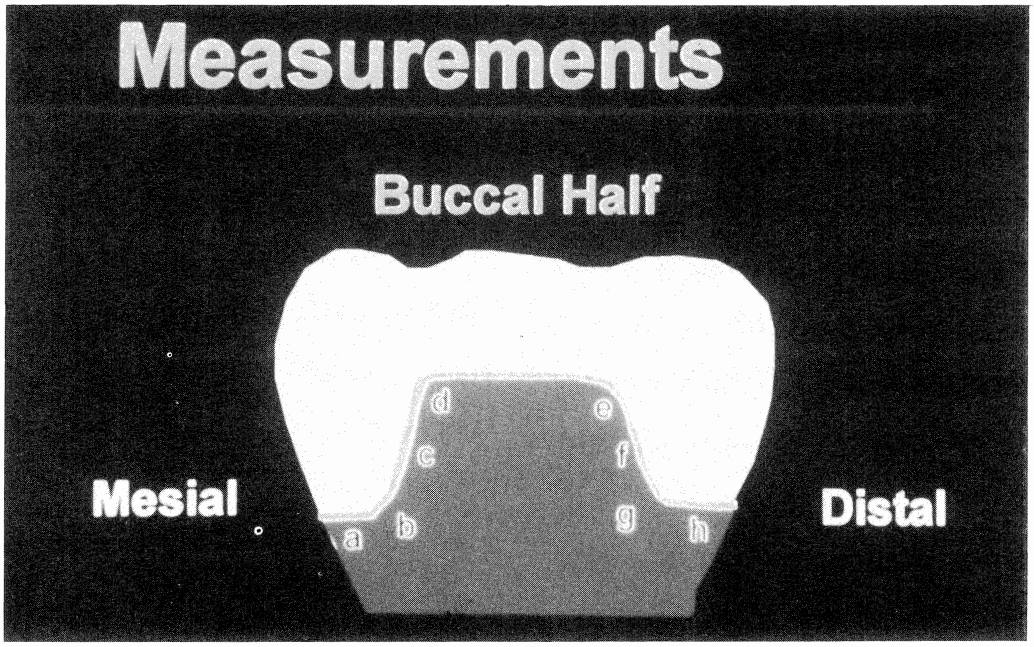

Figure 2 Measurement locations on a buccal half, section in a mesio-distal direction.

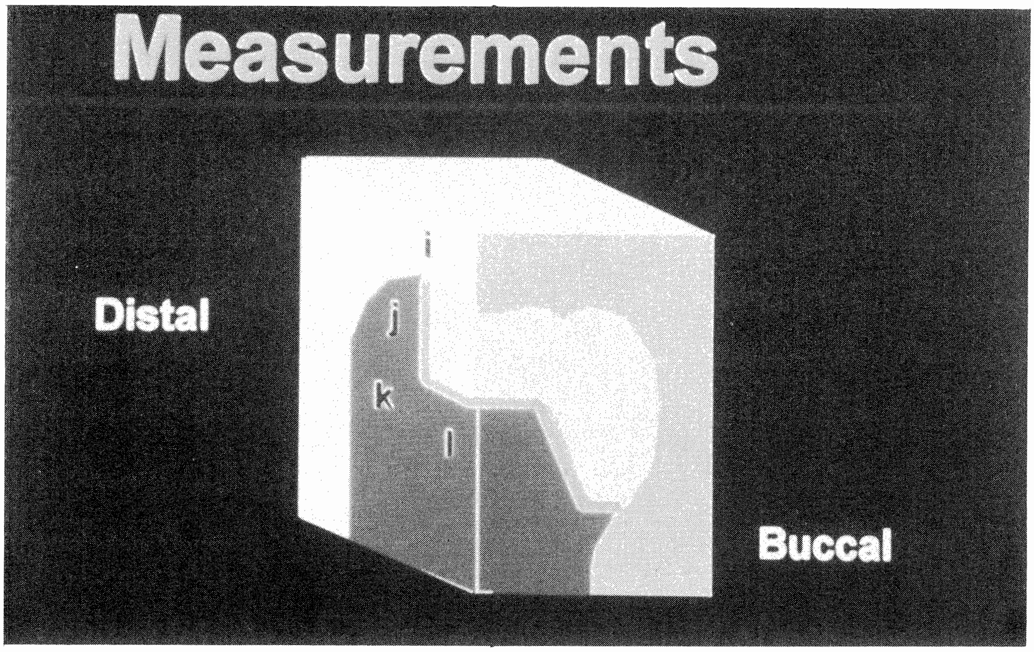

Figure 3 Measurement locations on a lingual part, section in a bucco-lingual direction.

A. Fabrication of IPS-Empress.

Wax patterns were fabricated on epoxy resin dies having a full anatomy of an upper premolar tooth, as shown in Figure 4. Wax patterns were sprued and then invested into a phosphate-bonded investment as per a lost-wax technique. 100 g powder was mixed with 15 ml special liquid and 6 ml of de-ionized water. A mold , a partially pre-cerammed leucite reinforced glass ceramic ingot and a plunger were heated in a burn-out furnace. The furnace temperature started from room temperature to 250°C, hold for thirty minutes. The mold was heated to 850°C and a ninety minute hold and then was transferred to an IPS-Empress EP 500 furnace. The mold was then heated from 500°C to 1180°C under a pressure of 5 bars having a heat rate of 60°C per minute followed by a two minute hold according to the manufacturer's recommendations. When the heating cycle was completed, the mold was then immediately removed and placed at room temperature for cooling, as shown in Figure 5. The sprues were separated form the inlay casting using a thin diamond disc (Dedeco International Inc., Long Eddy, New York 12760, USA). The inlays were finished prior to cementation.

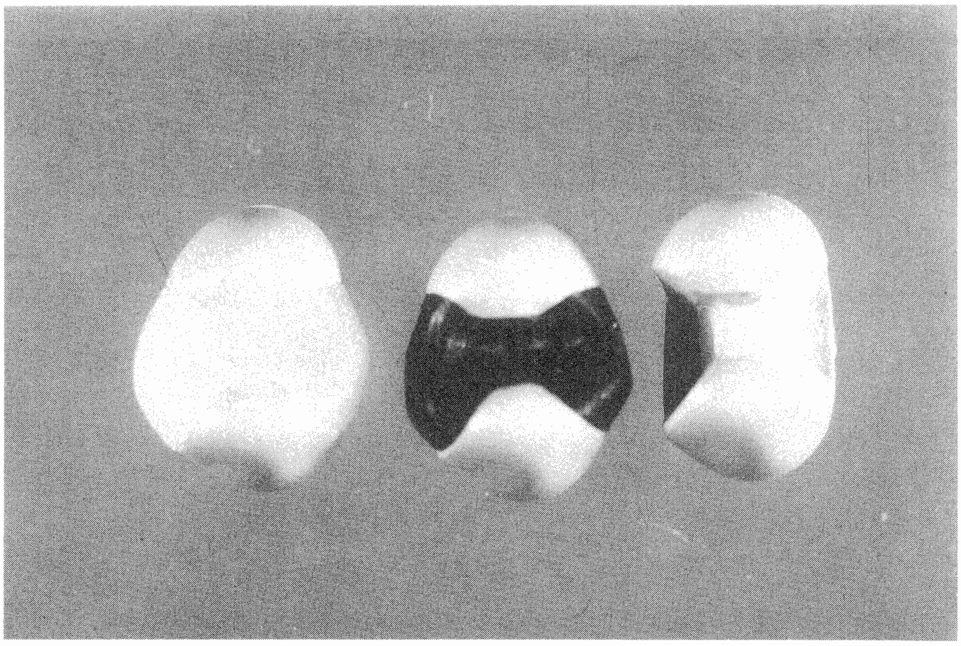

Figure 4 IPS-Empress technique: a wax pattern (left), an inlay prior to sprue removal (center), and a polished inlay (right).

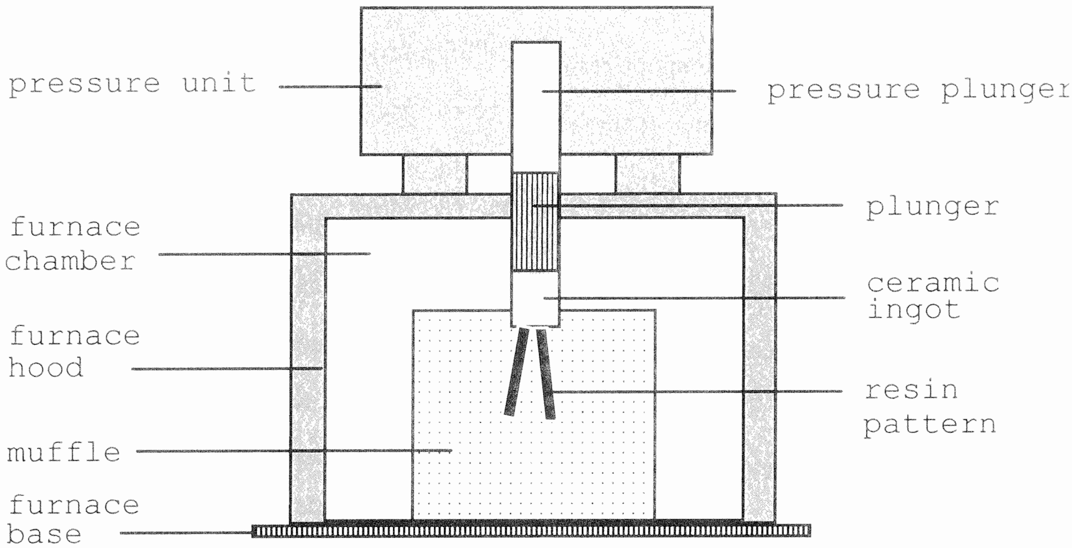

Figure 5 Diagram of the basic principle of IPS-Empress System.

B. Cementation

All inlays were washed with de-ionized water in an ultrasonic machine and air dried prior to cementation. The restorations were cemented on their respective dies under a constant load of 100 g using composite resin luting cement (Dual-Cement, Vivadent, Schaan, Liechtenstein). The luting cement was light polymerized for five minutes, one minute for each proximal surface, occlusal surface and a minute each for buccal and lingual surfaces. The crown portions were embedded in clear acrylic cubic blocks prior to sectioning in a mesio-distal direction using a high speed diamond saw cutter (Isomet 2000, Buehler Ltd., 41 Waukegan Road, Lake Bluff, Illinois 60044, USA). The lingual half was then sectioned again in a bucco-lingual direction. Gap measurements (microns) of the sectioned samples at 12 locations were performed using a scanning electron microscope (model XL20, Philips Electronics N. V., Eindhoven, The Netherlands) at 100 magnification. Mean of gap measurement and a standard deviation of each group are presented in Table 1. The statistical analyses of variance (ANOVA) and multiple comparison testing (Duncan's test) with a significance level of $p<0.05$ were applied to the data using a computer program, SPSS for Windows version 7.5 (SPSS Inc., Chicago, Illinois 60611, USA).

Part 2: Flexural strength Evaluation

Twenty high-leucite porcelain samples (IPS-Empress, Ivoclar, Bendererstrasse 2, FL-9494 Schaan, Liechtenstein) were fabricated with the size of 2.0 mm x 1.5 mm x 25 mm according to ASTM Standard C-1161-90.

Preparation of IPS-Empress bars

Twenty auto-polymerized acrylic resin patterns (GC Pattern Resin, GC Dental Products Corp., 2-285 Toriimatu-Cho, Kasugai Aichi, Japan), having a dimension of 2.0 mm x 1.5 mm x 25 mm were made. Four resin patterns were sprued in one ring with a wax wire 3 mm in diameter and 8 mm in length and then invested into a phosphate-bonded investment as per a lost-wax technique. 100 g powder was mixed with 15 ml special liquid and 6 ml of de-ionized water. A mold , a partially ceramic glass leucite ingot and a plunger were heated in a burn-out furnace and subsequently transferred to an IPS-Empress EP 500 furnace as for fabrication of Empress inlays in Part I.

Twenty bars were then randomly divided into two treatment groups. There were ten bars in each group. Bars were subjected to a three-point bend test using a universal testing instrument (Model #4202 Instron Corp., 100 Royall Street, Canton, MA 02021, USA). A crosshead speed of 0.2 mm per minute and a load cell of 1 KN. were used. The span length was 20 mm, as shown in Figure 6. After porcelain specimens are fractured, the representative bar for each group was examined with a scanning electron microscope (model XL20, Philips Electronics N.V., Eindhoven, The Netherlands) in order to study the fractured cross-sectional surface and evaluate failure origin.

Table 1 Mean and standard deviation of external and internal adaptation of shaded and non-shaded leucite reinforced dental glass ceramic inlay restorations.

Group	IPS-Empress (A2)				IPS-Empress (T2)			
location	min	max	X	SD	min	max	X	SD
a	25	83	44	20	30	101	58	20
b	22	79	**37***	21	25	126	**80***	33
c	9	31	16	8	14	42	26	9
d	33	124	94	31	25	99	53	29
e	47	108	74	21	75	177	117	39
f	7	37	16	10	13	51	27	15
g	13	58	**36+**	16	21	113	**70+**	29
h	12	49	**22^**	11	25	191	**75^**	53
i	6	69	34	21	17	182	59	48
j	9	63	32	15	20	182	66	47
k	28	126	75	42	45	153	84	36
l	31	203	85	61	26	153	83	34

Marginal gaps = a (mesial), h (distal), and I (occlusal); Axial walls = c (mesial), f (distal), and j;

Shoulders = b (mesial) and g (distal); Axio-pulpal line angles = d (mesial) and e (distal);

Internal angle = k; and Internal wall = l

(*, +, ^) Indicate significant differences at $p < 0.05$

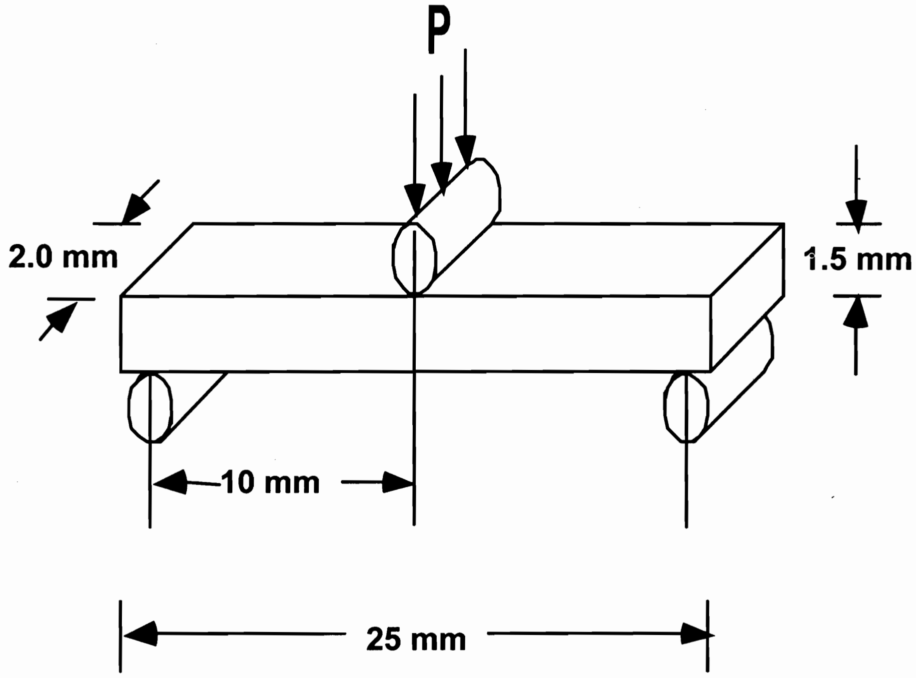

Figure 6 The Three-point fixture configuration.

Support span (L)	20 mm
Loading span	10 mm
Bearing diameter	2.0 to 2.5 mm
Width (b)	2.0 mm
Depth (d)	1.5 mm
Length (L_T)	25 mm

Results

Part 1: Marginal Adaptation Evaluation

Mean and standard deviation of gap measurements (microns) are illustrated in Table 1. IPS-Empress inlays shade A2 gave the minimum gap (22 $\pm$ 11 microns) at distal surface (h) and is significantly different ($p \leq 0.05$) than IPS-Empress T2 inlays (75 $\pm$53 microns). There was no significant difference of mesial gaps (a) and occlusal gaps (I) among IPS-Empress A2 and T2 inlays. At mesial (b) and distal (g) shoulder, gap measured from A2 (b, 37 $\pm$ 21 microns; g, 36 $\pm$ 16 microns) is significantly different ($p \leq 0.05$) lower than those of T2 inlays (b, 80 $\pm$ 33 microns; g, 70 $\pm$ 29 microns).

Part 2: Flexural strength evaluation

The flexural strength values (MPa) were calculated with the formula:

$$\frac{3PL}{2WT^2}$$

P = force recorded at fracture

L = distance between the supports (20 mm)

W = width of porcelain bar

T = thickness of porcelain bar

Equation 1 Flexural Strength Formula

Mean flexural strength and standard deviation of leucite reinforced glass ceramic bars shade A2 is 69.78 $\pm$ 9.5 MPa and is significantly ($p \leq 0.05$) lower than those of non shaded T2 bars (98.30 $\pm$ 14.0 MPa), as shown in Figure 7.

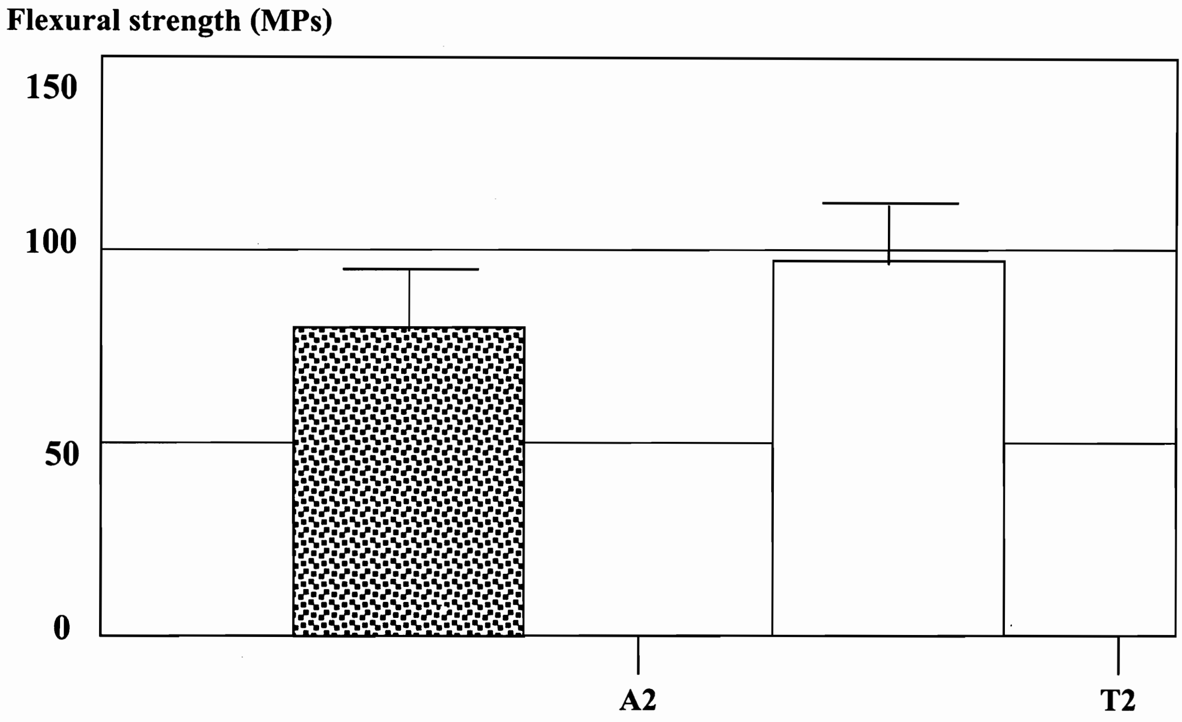

Figure 7 Bar graph representative of mean and flexural strength (MPa) and standard deviations of shaded (A2) and non-shaded (T2) leucite reinforced dental glass ceramic bars.

Discussion

The adaptability of restorations plays a major role on the longevity of the restorations. A marginal gap greater than 100 microns can accelerate the deterioration of the luting cement thus lead to the failure of the restoration. The amount of wear on the composite resin cement is associated with the marginal gap size (Kawai, *et al.* 1994).

The IPS-Empress system is a system that requires a lost-wax technique which involved in several steps such as waxing, investing, injecting and divesting. Theoretically, each additional step increases the possibility of many technical variables thus have effect on the final restorations. The adaptation of IPS-Empress inlays either by A2 or T2 ingots however, is slightly superior than inlays fabricated from either Celay machine (Kanchanatawewat, 2001) or CAD/CAM (Kawai, *et al.*, 1995) in many locations. It may be that the lost-wax technique is the technique that is familiar by most of dental technicians, the error can be minimized by good experience.

The Empress glass ceramic ingot is basically a feldspathic porcelain having the following composition in wt%: 63 SiO, 17.7 Al_2O_3, 11.2 K_2O, 4.6 Na_2O, 0.6 B_2O_3, 0.4 CeO_2, 1.6 CaO, 0.7 BaO, 0.2 TiO_2. Reinforcing component for both A2 and T2 ingots is leucite crystal. However, the difference between the A2 and T2 ingots is that the T2 has no color and the A2 has the color of shade A2. The difference in gap size between IPS-Empress A2 and T2, therefore, may be that the color frit added to produce shade A2 have some good effect on the viscosity or the flow of the heated ingot in the ceramic press furnace.

The overall results of gap measurement for IPS-Empress from this study are considered lower than the study done by Molin and Karlsson in (1993). The measurement of the replica with a microscope at 50x magnification was performed. They showed the gap (microns) between inlays and stone dies of 65.4 $\pm$ 59.0 at marginal area, 121.8 $\pm$ 97.5 at axial wall and 65.7 $\pm$ 70.0 at occlusal area.

Despite the fact that the three-point bend test is well suited to the evaluation of dental porcelain because it is simple and extremely sensitive to surface conditions (Edwards, *et al.* 1983), the results are also affected by surface flaws or defects. The tested samples have glass bead blasted surface as a result of devesting from the refractory mold. As a matter of fact, the glass bead partcles are relatively smooth and do no harm to the surface of the ceramic bars. It was an attempt of this study to investigate the actual difference among the shaded and non-shaded bars without the effect of other surface finish.

Since the shaded ingot was primarily designed to be used as a core material, the respective feldspathic porcelain is veneered in order to create an esthetic appearance. As a consequence, the coefficient of thermal expansion of both core (14.9 x $10^{-6}/^{o}C$) and veneering porcelain must be compatible. The overall strength of this restoration, therefore depends on the strength of both core and veneering porcelain. In general, the feldspathic porcelain fabricated using a sintering process give significantly lower flexural strength and is therefore required a stronger substructure as in a ceramo-metal system. (White, *et al.* 1994)

The strength of an entire crown has been recognized to influence the success of an all-ceramic crown. When a bilayer ceramic crown cemented on a prepared tooth, the core is placed under a tension side. The full anatomy of the crown is fabricated using veneering porcelain and is subjected to a masticatory load (compression side). The effect of the material forming the tensile surface on the flexural strength was of much greater magnitude than that of the compressive surface. In the case of a leucite reinforced glass ceramic crown, the flexural strength of the shaded core material is relatively low and the veneering porcelain has a flexural strength much lower than that of the core. The over all strength of this bilayer crown can not be as high as a monolayer crown because the material forming the tensile surface, the material forming the comressive strength and their interaction had a highly significant effect on the flexural strengh (White, *et al.* 1994)

In the contrary, the non-shaded ingot is designed to be used alone, the coefficient of thermal expansion is relatively high (18 x $10^{-6}/^{o}C$). If a non shaded ingot is used to fabricate a monochromatic crown, the composite resin luting cement is highly recommended. It is because the color of the restoration relies on the color of the luting cement in conjunction with the surface coloration. Since the marginal adaptation of the non-shaded restoration is far less than that of shaded restoration, the proper bonding is thought to prevent microleakage of the restoration.

Although, most of the *in vitro* studies have presented promising results (Dong, *et al.* 1992; and Kanchanatawewat, *et al.* 1997) clinical studies are necessary to evaluate the clinical performance of high leucite reinforced glass ceramic restorations. In addition, the stronger core materials should be developed in order to withstand the mastication load.

Conclusions

This study investigated the adaptations of inlays made by IPS-Empress. The following conclusions may be made:

1. IPS-Empress A2 shows superior adaptation than T2 at shoulder and marginal area.
2. Overall external marginal gap measured from inlays fabricated by both materials are between 22 - 75 microns which is considered clinical acceptable .

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