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Effects of core characters and veneering technique on biaxial flexural strength in porcelain fused to metal and porcelain veneered zirconia

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PURPOSE. The purpose of this study was to assess the impact of the core materials, thickness and fabrication methods of veneering porcelain on prosthesis fracture in the porcelain fused to metal and the porcelain veneered zirconia. **MATERIALS AND METHODS.** Forty nickel-chrome alloy cores and 40 zirconia cores were made. Half of each core group was 0.5 mm-in thickness and the other half was 1.0 mm-in thickness. Thus, there were four groups with 20 cores/group. Each group was divided into two subgroups with two different veneering methods (conventional powder/liquid layering technique and the heat-pressing technique). Tensile strength was measured using the biaxial flexural strength test based on the ISO standard 6872:2008 and Weibull analysis was conducted. Factors influencing fracture strength were analyzed through three-way ANOVA ($\alpha \leq .05$) and the influence of core thickness and veneering method in each core materials was assessed using two-way ANOVA ($\alpha \leq .05$). **RESULTS.** The biaxial flexural strength test showed that the fabrication method of veneering porcelain has the largest impact on the fracture strength followed by the core thickness and the core material. In the metal groups, both the core thickness and the fabrication method of the veneering porcelain significantly influenced on the fracture strength, while only the fabrication method affected the fracture strength in the zirconia groups. **CONCLUSION.** The fabrication method is more influential to the strength of a prosthesis compared to the core character determined by material and thickness of the core. *[J Adv Prosthodont 2015;7:349-57]*

KEY WORDS: Zirconia; Metal ceramic; Pressed ceramic; Dental porcelain; Tensile strength

INTRODUCTION

Porcelain fused to metal restorations have played a crucial role in aesthetic dental restoration since the development of ceramics in 1965.[1] The rigid metal alloy core enables use of a wide range of metal ceramic crowns, from single crown to the long-span fixed partial denture that supports the veneering ceramic. However, the metal alloy has some limitations; it blocks light transmission and causes the umbrella effect and aesthetic disharmony.[2] To overcome these limitations, all-ceramic restorations are appropriate for anterior restorations. Although many attempts have been made to improve its physical properties, the all-ceramic restoration is relatively fragile and therefore, it has been applied only to anterior

restorations or short-span prostheses. These limitations have spurred the adoption of new ceramic materials and development of different fabricating techniques. For example, dental porcelain materials developed by an enforcement mechanism have been introduced and heat-pressed ceramics using the lost-wax technique are widely known as a new fabrication technique.

Yttrium zirconia is one of the most widely used restoration materials to resolve the aforementioned troubles in metal alloy core and porcelain core. Following the introduction of Computer aided design-Computer aided manufacturing (CAD/CAM) technology, yttrium zirconia has gained rapid acceptance in clinical dentistry. This popularity is based on the material's aesthetic benefit and strength. Yttrium zirconium has been used for many aesthetic restorations. Also, the material enhances the speed, accuracy, and reliability of manufacture. Moreover, the transformation toughening that strengthens yttrium zirconia allows zirconium crowns to substitute for metal ceramic crowns.[3,4]

Despite such advantages, use of the zirconia prosthesis has been limited by its opaque shade, which lacks visual harmony with adjacent teeth. To alleviate the problem, veneering and staining techniques have been introduced. However, those methods lead to other issues, such as unstable durability of veneered ceramics and attrition of the opposing teeth. Although zirconia dental prostheses per se display high fracture strength and excellent clinical performance compared to all-ceramic restorations, high fracture rate in veneered ceramics due to the resulting mismatch in the elastic modulus and thermal expansion coefficient between the zirconia core and veneered ceramic have been reported.[5]

The present study investigated the effects of the two different core materials (metal core vs. zirconia core), core thickness (0.5 mm vs. 1.0 mm) and two veneering methods (conventional layering technique vs. heat-pressing technique) on the fracture of the porcelain veneered prostheses using the biaxial flexure strength test and Weibull analysis.

MATERIALS AND METHODS

Forty nickel-chromium (Ni-Cr) alloy (Wiron 99; Bego, Bremen, Germany) cores and 40 zirconia (IPS e.maxZircad; IvoclarVivadent, Amherst, NY, USA) cores were prepared.

Twenty of each type of core was 0.5 mm in thickness and the remaining 20 were 1.0 mm in thickness. This comprised four groups with 20 cores per group. Each group was divided into two subgroups depending on the veneering method (conventional layering technique and heat-pressing technique). Thus, the final veneering porcelain samples included eight groups with 10 samples per group (Table 1).

Forty disk-shaped specimens having a 15 mm diameter were prepared for the metal core based on the ISO standard 6872:2008(dental ceramic). The 40 waxed (Preparation wax; Bego, Bermen, Germany) specimens were divided into two groups with thicknesses of 0.7 mm (n = 20) and 1.2 mm (n = 20). Both groups were invested (CB-30; Ticonium, Gardenia, CA, USA), cast in Ni-Cr alloy (Wiron 99; Bego, Bermen, Germany) and sanded to a finish with 300, 600, 1000 and 1200 grit sand paper to a thickness of 0.5 mm or 1.0 mm.

The other forty disk-shaped specimens were prepared by milling and drying zirconia blocks (IPS e.maxZirCAD; Ivoclar Vivadent, Amherst, NY, USA) followed by sintering at 1,500°C. Like the metal core, the specimens were wet-ground with sand paper to produce the disks of 15 mm diameter and thickness of 0.5 mm (n = 20) or 1.0 mm (n = 20).
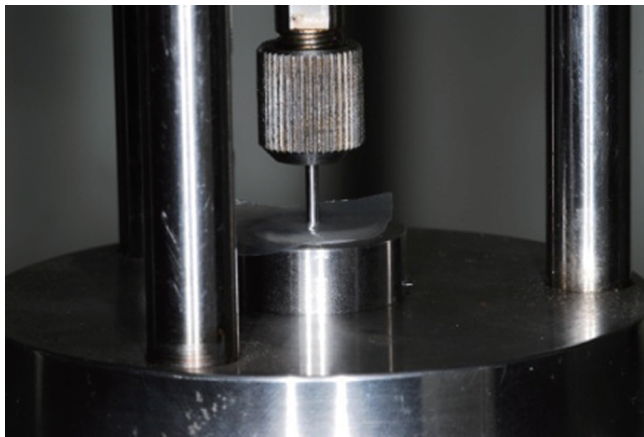
The 80 cores were sand-blasted with a pressure of 2.0 bar and ultrasonically cleaned for 10 minutes (Ultrasonic cleaner 2210; Branson, Danbury, CT, USA). For conventional layered veneering porcelain, opaque porcelain and dentin porcelain was prepared by mixing the powder/liquid, sintering following the manufacturer's instruction, and manufacturing the veneering porcelain with a thickness of 1.0 mm. For the heat-pressed veneering porcelain, the top of each core was waxed in a disk-shaped wax pattern. This was followed by an ordinary burn out process and injection of the heat-pressed porcelain ingot for the veneering process to produce a thickness of 1.0 mm. Table 2 summarizes the materials and methods used in the porcelain sintering process. The samples in the M0.5C, M0.5P, Z0.5C, and Z0.5P groups had disk-shaped cores with a 15 mm diameter and 1.5 mm thickness, while the M1.0C, M1.0P, Z1.0C and Z1.0P groups had disk-shaped cores with a 15 mm diameter and 2 mm thickness. To reproduce the oral environment, samples were tested after 6000 cycles of thermocycling in distilled water with a temperature of 5°C and 55°C (Invertech, Kwangju, Korea). The retention period

Table 1. Group characteristics

Grouping	M0.5C Group	M1.0C Group	M0.5P Group	M1.0P Group	Z0.5C Group	Z1.0C Group	Z0.5P Group	Z1.0P Group
Core material	Ni-CrMetal	Ni-CrMetal	Ni-CrMetal	Ni-CrMetal	Zirconia	Zirconia	Zirconia	Zirconia
Core thickness	0.5 mm	1.0 mm	0.5 mm	1.0 mm	0.5 mm	1.0 m	0.5 mm	1.0 mm
Veneering method	Conventional-layer	Conventional-layer	Heat-press	Heat-press	Conventional-layer	Conventional-layer	Heat-press	Heat-press

was 15 seconds for each reservoir.

The biaxial flexural strength was measured by the piston using the three ball method following ISO standard 6872:2008. The universal testing machine (Instron, Norwood, MA, USA) was used to measure the strength for the fracture with a crosshead speed of 1.0 mm/min (Fig. 1). The veneering porcelain was placed on the tensile surface and the core material was placed on the compressed surface. The thin plastic sheet (0.05 mm thick) was placed between the sample and the piston. The load for the fracture of the sample was recorded. The biaxial flexural strength was calculated using the equation below. The samples used in the study did have a heterogeneous structure where two different materials were physically attached to each other, while keeping their own physical characteristics. Since the bilayer structure has a relatively weak interface and is more vulnerable compared to the monolithic structure, it was not proper to apply the conventional equation to calculate the biaxial flexure strength. Therefore, we made

use of Roark's formulae based on the bending theory, which reflects the characteristics of each material and analyzes the stress on the tensile surface and the stress on the compressed surface separately. The formulae are :

$$R = \sqrt{1.6 * r^2 + T^2} - 0.675 * T^2$$

$$M = \frac{W}{4\pi}\left\{(1+\gamma)\log\left(\frac{6}{R}\right)+1\right\}$$

$$K_{2p} = 1 + \frac{E_b t_b{}^3(1-\gamma_a{}^2)}{E_a t_a{}^3(1-\gamma_b{}^2)} + \frac{3(1-\gamma_a{}^2)\left(1+\frac{t_b}{t_a}\right)\left(1+\frac{E_a t_a}{E_b t_b}\right)}{\left(1+\frac{E_a t_a}{E_b t_b}\right)^2 - \left(\gamma_a + \frac{\gamma_b E_a t_a}{E_b t_b}\right)^2}$$

$$\delta = \frac{6M}{t_a{}^2 K_{2P}}\left[\frac{E_b t_b(1-\gamma_a{}^2)}{E_a t_a(1-\gamma_b{}^2)} + \frac{t_a}{t_b}\left\{\frac{(1-\gamma_a{}^2)\left(1+\frac{t_a}{t_b}\right)\left(1+\frac{E_a t_a}{E_b t_b}\right)}{\left(1+\frac{E_a t_a}{E_b t_b}\right)^2 - \left(\gamma_a + \frac{\gamma_b E_a t_a}{E_b t_b}\right)^2}\right\}\right]$$

R = equivalent radius
M = maximum bending moment
r = radius (a = compressive side's, b = tensile side's)
t = thickness
T = total thickness
E = elastic modulus
δ = tensile stress
γ = Poisson ratio ($\gamma_a, \gamma_b = 0.25$)

Fig. 1. Biaxial flexural strength was measured by the universal testing machine.

The tensile stress obtained from the formula was used to compare and analyze the fracture strength of the groups. After conducting the biaxial flexural strength test, we observed the fractured samples with an optical microscope (Leica Microsystems GnbH, Wetzlar, Germany).

Since the strength of the ceramic could readily deviate from the standard distribution, Weibull analysis measured the failure probability at scale parameters and shape parameters. The Weibull parameters of shape and scale were

Table 2. Brand name, firing and pressing temperature for veneering ceramics

Materials	Group	Firing cycle	Final temperature (°C)	Rate temperature increase (°C/Min)	Holding times (Min)	Manufacturer
IPS d.SIGN	M0.5C	Opaque	890	80	1	IvoclarVivadent
	M1.0C	Dentin	870	60	1	
IPS InLine/Inline POM	M0.5P	Opaque	930	100	2	IvoclarVivadent
	M1.0P	Press	910	60	1	
IPS e.max Ceram	Z0.5C	Zirliner	403	40	1	IvoclarVivadent
	Z1.0C	Washing	403	40	1	
		Dentin	403	40	1	
IPS e.max ZirPress	Z0.5P	Opaque	930	100	2	IvoclarVivadent
	Z1.0P	Press	910	60	1	

obtained by making use of median rank regression method to measure unreliability. To assume a Weibull distribution and create a survival graph, Weibull calculator software (Excel; Microsoft, Redmond, WA, USA) was used.

RESULTS

SPSS version 18.0 (SPSS Inc, Chicago, IL, USA) was used to analyze the elements affecting fracture strength.

The average and standard deviation of the fracture strengths for core materials, core thicknesses and veneering techniques are summarized in Table 3. The metal core groups showed higher fracture strength than the zirconia core groups. The overall average strength of the metal core groups was 54.49 MPa, which was higher than the zirconia core groups (48.39 MPa). In particular, the strength of the metal core groups was 47.11 MPa for the 0.5 mm thickness and 61.87 MPa for the 1.0 mm thickness, representing a difference of 14.7 MPa. The difference of meanvalues between the conventional layering groups (41.54 MPa) and the heat-pressing groups (67.44 MPa) was 25.90 MPa.

For zirconia core groups, the fracture strength was 46.82 MPa for the 0.5 mm thick cores and 49.97 MPa for the 1.0 mm thick cores. The difference value in the fracture strength depending on the thickness was 3.15 MPa. However, the difference of mean values between the conventional layering groups (41.52 MPa) and the heat pressing groups (55.27 MPa) was 13.75 MPa. The results of the three-way ANOVA based on the descriptive statistics are shown in Table 4. The mean differences in the fracture strength were statistically significant at the 0.05 level, indicating that the three factors (the core material, thickness, and veneering method) have significant effects on the fracture strength. Among the factors, the veneering method had the highest impact on the fracture strength, followed by the core thickness and core material.

Two-way ANOVA test with four metal core groups and four zirconia core groups was done to identify the factors influencing the fracture strength for each group. In the metal core groups, both the veneering method and the metal core thickness were observed as distinct factors that influenced fracture strength. The veneering method was the most influential factor in the fracture strength (F = 117.348, P = .000) followed by the core thickness (F = 38.076, P = .000). The heat pressing groups had significantly higher fracture strength than the conventional layering method. The thicker the core was, the higher fracture strength the core had (Table 5). However, in the zirconia core groups, only the veneering method showed significant impact on the facture strength at the .05 level (F = 43.219, P = .000), while the core thickness did not have any statistically significant effect on fracture strength (F = 2.263, P = .141) (Table 6). Similar to the results in metal core groups, the heat-pressing groups had significantly higher strength than the conventional layering groups in zirconia core groups.

The number of cracked surfaces on samples was observed by optical microscopy (Fig. 2) followed by a correlation analysis. The positive correlation coefficient (Pearson Correlation = 0.735, P = .000) indicated statistically signifi-

Table 3. The average and standard deviation of the fracture strength (MPa)

			Mean	Standard deviation
Ni-Cr Metal	0.5	Conventional-Layer	35.7806	7.67029
		Heat Press	58.4557	4.70488
		Total	47.1182	13.17798
	1	Conventional-Layer	47.3085	5.10171
		Heat Press	76.4355	11.03083
		Total	61.8720	17.12381
	total	Conventional-Layer	41.5446	8.67000
		Heat Press	67.4456	12.37719
		Total	54.4951	16.83065
Zirconia	0.5	Conventional-Layer	43.2234	4.78044
		Heat Press	50.4254	5.92043
		Total	46.8244	6.40921
	1	Conventional-Layer	39.8207	3.31308
		Heat Press	60.1217	10.30236
		Total	49.9712	12.80355
	total	Conventional-Layer	41.5221	4.36707
		Heat Press	55.2736	9.57189
		Total	48.3978	10.12004

Table 4. Values of the three-way ANOVA test for fracture strength

Source	Type III Sum of squares	Df	Mean square	F	Sig.
Corrected Model	12152.028[a]	7	1736.004	34.402	.000
Intercept	211738.875	1	211738.875	4196.016	.000
Thickness	1602.166	1	1602.166	31.750	.000
Material	743.535	1	743.535	14.735	.000
Manufacturing method	7861.624	1	7861.624	155.793	.000
Thickness * Material	673.618	1	673.618	13.349	.000
Thickness * Manufacturing method	477.797	1	477.797	9.468	.003
Material * Manufacturing method	738.058	1	738.058	14.626	.000
Thickness * Material * Manufacturing method	55.230	1	55.230	1.094	.299
Error	3633.256	72	50.462		
Total	227524.159	80			
Corrected Total	15785.284	79			

a. R Squared = .770 (modified R Squared = .747) Dependent Variable: Fracture strength

Table 5. Values of the two-way ANOVA test for fracture strength in the metal core groups

| Source	Type III Sum of squares	Df	Mean square	F	Sig.
Modified model	8989.472[a]	3	2996.491	52.415	.000
Intercept	118788.528	1	118788.528	2077.850	.000
Thickness	2176.761	1	2176.761	38.076	.000
Method	6708.644	1	6708.644	117.348	.000
Thickness * Method	104.068	1	104.068	1.820	.186
Error	2058.083	36	57.169		
Sum	129836.083	40			
Modified sum	11047.555	39			

a. R square = .814 (modified R square = .798) Dependent Variable: Fracture strength

Table 6. Values of the two-way ANOVA test for fracture strength in the zirconia core groups

Source	Type III Sum of squares	Df	Mean square	F	Sig.
Modified model	2419.021[a]	3	806.340	18.429	.000
Intercept	93693.882	1	93693.882	2141.339	.000
Thickness	99.024	1	99.024	2.263	.141
Method	1891.038	1	1891.038	43.219	.000
Thickness * Method	428.960	1	428.960	9.804	.003
Error	1575.173	36	43.755		
Sum	97688.075	40			
Modified sum	3994.193	39			

a. R square = .606 (modified R square = .573) Dependent Variable: Fracture strength
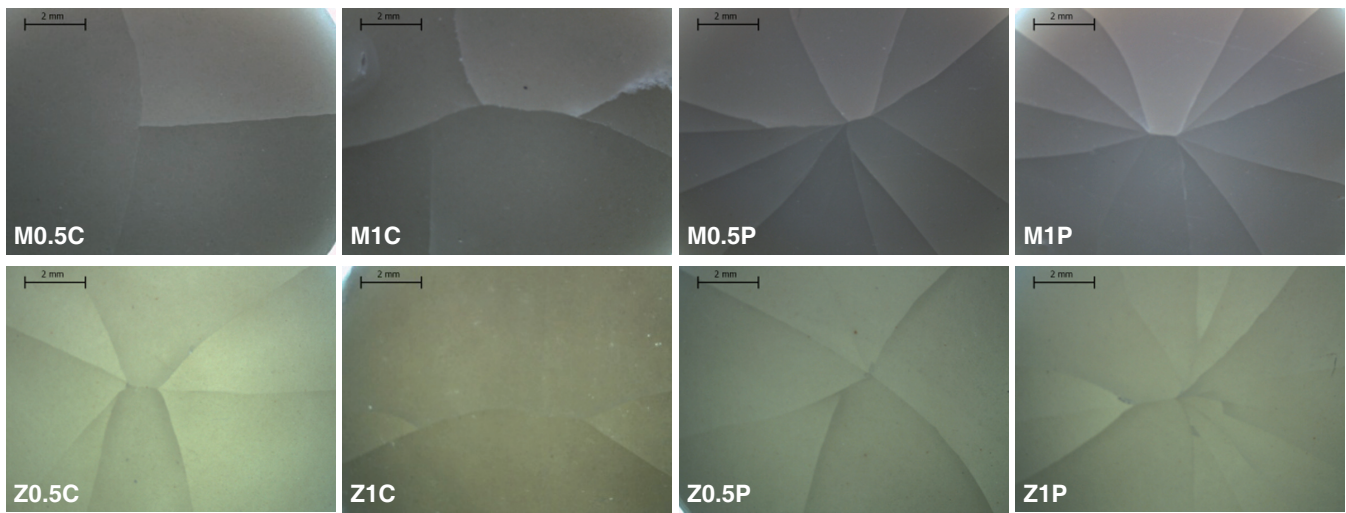
Fig. 2. Fracture status of the fragmented sample was observed through the optical microscope.

Table 7. Correlation analysis between the fracture strength and the number of cracked surfaces

		Fracture strength	Number of fragmented surfaces
Fracture strength	Pearson Correlation	1	.735**
	Sig. (2-tailed)		.000
	N	80	80
Number of fragmented surfaces	Pearson Correlation	.735**	1
	Sig. (2-tailed)	.000	
	N	80	80

**. Correlation is significant at the 0.01 level (2-tailed)

Table 8. Weibull analysis of bilayer specimens

| Grouping	M0.5C	M1.0C	M0.5P	M1.0P	Z0.5C	Z1.0C	Z0.5P	Z1.0P
Shape	5.0	9.97	12.87	7.34	9.78	12.76	8.94	6.14
Scale	38.95	49.60	60.69	81.28	45.34	41.35	53.13	64.6

cant linear relationship between the fracture strength and the number of cracked surfaces (Table 7).

Table 8 shows the results of the Weibull analysis for the biaxial flexural strength. The shape parameter indicates the probability of fracture at varying stresses. In all samples, the values of the shape parameter exceeded 1, meaning that the probability of fracture increased as stress increased. The second row in the table presents Weibull scale values, which indicated that strain with 63.2% of the materials show fracture. Fracture probability versus fracture strength was analyzed for each group (Fig. 3). From the group com-

parison analysis, two important findings were obtained. First, consistent with the results of fracture strength test, the fracture possibility increased as the fracture strength increased. Second, M1.0P was the highest scale parameter followed by Z1.0P, M0.5P, Z0.5P, M1.0C, Z0.5C, Z1.0C and M0.5C.

DISCUSSION

In dentistry, several studies reported that not only the occurrence frequency of porcelain fracture was less than
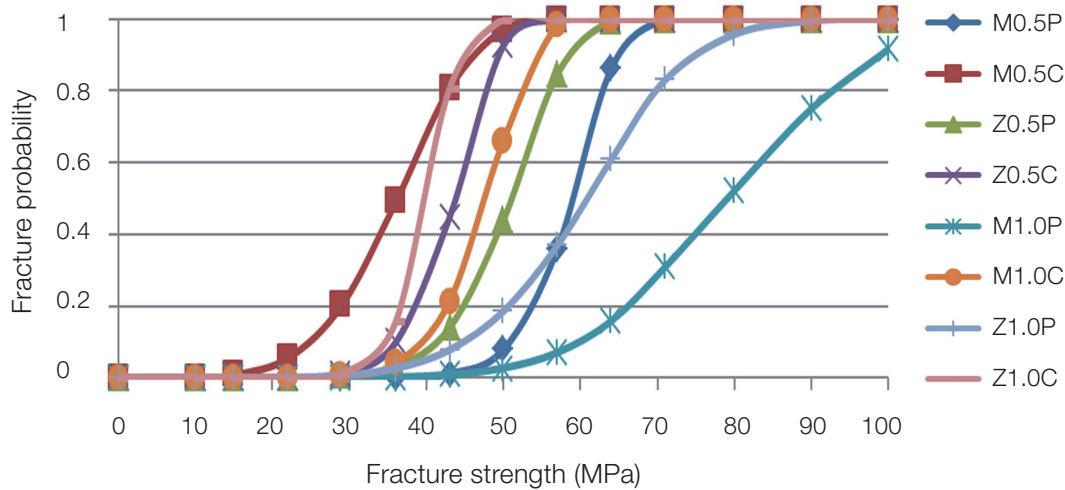
Fig. 3. Probability Weibull was analyzed for group comparisons.

3% for 20 years but also survival rate was 95.5% for 7 years in the metal ceramic crown.[6,7] However, the superiority of the metal ceramic crown in terms of fracture is still a controversial issue. For example, Sailer et al.[8] reported that the chipping rate of the metal ceramic crown is four times less than the porcelain veneered zirconia prosthesis. Other studies suggested that the chipping of the porcelain veneered zirconia prosthesis is the main factor leading to failure, showing the failure rate is 15.2% for 35.1 ± 13.8 months.[9,10] In Contrast, Quinn et al.[11] proposed that there is no difference in the fracture rate between the metal ceramic crown and porcelain veneered zirconia. Therefore, in this study, we compared the porcelain veneered zirconia to the porcelain fused to metal in terms of fracture strength with the same standard.

Recently, a number of studies have investigated how a weak interface bonding between zirconia and veneering porcelain causes clinical failure. Alhasanyah et al.[12] suggested that a proper size of core support in the zirconia prosthesis improves the fracture resistance to chipping, showing that the fracture load of 1.7 mm core is as strong as that of the metal ceramic crown, whereas 0.6 mm and 1.2 mm zirconia cores with identical whole thickness crowns have the same fracture strength and these values are smaller than values of the metal ceramic crowns. Despite the empirical findings, previous studies have some limitations. First, the thickness of veneering porcelain varies for each core. So, the studies are hindered in identifying the isolated effect of core thicknesses on fracture strength. Second, the 1.7 mm zirconia core has some limitations in clinical applications, such as the excessive tooth preparation and shade problem. To alleviate the issues, we investigated the isolated impact of core thickness on fracture strength by fixing the thickness of veneering porcelain and proposed a clinically appli-

cable range of a core thickness.

Consistent with the previous studies, we found a positive correlation between the core thickness and the fracture strength for the metal core groups with 1.0 mm veneering ceramic. One plausible explanation for the finding is that increases in the metal core thickness decrease the flexure and tensile stress for the veneering porcelain and inhibits the interface separation. Contrary to the metal core groups, difference of the fracture strength with 0.5 mm and 1.0 mm core thickness among the zirconia core groups was not significant. This infers that the zirconia core ≤ 1.0 mm thick may not resist flexure. The result that the fracture strength values of the 0.5 mm metal core groups, 0.5 mm zirconia core groups and 1.0 mm zirconia core groups were markedly smaller than the fracture strengths of the 1.0 mm metal core groups supports this suggestion. Therefore, in the limiting situation of ≤ 1 mm thickness of the zirconia core, reinforcingthe veneered zirconia is required. To strengthen the veneered zirconia, choosingthe strong veneering ceramic might be one of the most effective methods.

Millen et al.[13] measured the fracture toughness of the bilayer ceramic with the same thickness but with different coping to veneer thickness ratio and found that the veneer thickness rather than coping thickness is a more important factor of the fracture toughness. In particular, they showed that the veneering porcelain > 2 mm in thickness had strong fracture toughness. Consistent with the study, our findings also suggested that the veneering porcelain character (vs. coping thickness) has a more significant impact on the fracture strength although there is a positive relationship between the core thickness and the fracture strength of the bilayer specimen.

Accordingly, various fabrication methods of the veneer-

ing ceramic have been introduced to enhance its strength. Among them, the heat-pressed veneering method is the preferred technique in fabrication of the veneering ceramic, while the conventional layered veneering method is still widely used. In contemporary dentistry, many studies have examined how the heat-pressed veneering technique influences the fracture strength of the bilayer ceramic prosthesis. This method has two advantages. First, the heat-pressed porcelain on metal has a strong bonding between a metal and a ceramic compared to the conventional metal ceramic crown.[14] Second, since the porosity in the ceramic prosthesis weakens the material's strength, the homogeneity of the heat-pressed porcelain materials increase the physical strength.[15] Besides the physical advantages, the heat-pressing method has some clinical benefits, such that it accelerates the working speed of the dental technician and decreases the technique sensitivity. Therefore, by using this method, we are able to fabricate a more reliable prosthesis with a certain level.[16,17] Our findings indicate that the bilayer ceramics specimen had a low value of Weibull modulus, while for the ceramic materials the Weibull modulus ranged from 5 to 20. This result indicates that even heat-pressed ceramics have a structural limit caused by a defective interface and/or a difference in a heat expansion coefficient between two different materials.[18,19] The heat-pressing technique has been used for porcelain-fused-to-metal and for porcelain veneered zirconia. Heat-pressed porcelain based zirconia prosthesis shows a significantly higher performance than the conventionally made zirconia porcelain.[20,21] The defect free interface between the zirconia core and the veneering porcelain decreases the zirconia ceramic chipping and delamination.[22,23] Christensen reported that the prosthesis using heat pressing technique (vs. traditional method) had a lower fracture rate 2 years later in both zirconia and metal ceramics.[24] Consistent with the previous studies, we also found some evidence that the heat pressing technique provides stronger fracture strength than the conventional layering technique. High fracture strength of the heat pressed ceramic, homogeneity of the material and decreases in the interface porosity may be influential.

Gonzaga et al.[25] explained that the magnitude of the fracture strain was proportional to the number of fragments and the accumulated elastic energy applied to the sample increased for the higher strain. It may be that the core with low elasticity coefficient, dense veneering ceramic and strong interface have roles as storage for the strain and a strain over the capacity may cause more extensive and fritter fracture. This is similar to our experimental data and may be interpreted as an evidence to support the measured fracture strength.

In this study, the metal core groups showed higher fracture strength than the zirconia core group at 1.0 mm thickness, while the two groups had less difference in fracture strength at 0.5 mm thickness than 1.0 mm thickness. Our findings suggest that the core material influences the flexural strength of the bilayer prosthesis and interacts with core thickness. Despite of the clinical and empirical contri-

butions, this study has some limitations in that we used only 1.0 mm veneering porcelain. Thus, we need to investigate the effect of the veneering porcelain on the fracture strength by varying its thickness. Also, additional studies on the proper thickness of the zirconia ceramic with the similar bending resistance to the metal ceramic should be pursued in the future.

CONCLUSION

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

The core material, core thickness and fabrication method of the veneering porcelain affect the fracture strength and the magnitude of the impact is highest in the fabrication method of the veneering porcelain in porcelain fused to metal and porcelain veneered zirconia. The heat-pressed veneering technique provide higher fracture strength value than the conventional layering technique.

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