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열 순환과 반복하중이 전부도재관의 기계적 성질에 미치는 영향

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〈Abstract〉

Effect of thermo-cycling and repeated loading on the mechanical properties of all ceramic restorations

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파절 저항성은 전부세라믹관의 실험 군으로 ICE zircon, IPS e.max Press, Zmatch zirconia, Lava zirconia, Prettau zirconia, Ceracube, and Zmatch full contour zirconia를 사용하였으며, 대조군으로는 Ni-Cr계의 비귀금속 합금을 사용하였다. 파절 저항성은 열 순환과 기계적 피로시험 전, 후의 파절 저항성을 one-way ANOVA로 분석한 결과, 처리 전의 파절 저항성은 Prettau zirconia군과 Zmatch full contour zirconia군이 가장 높게 나타나 나머지 실험 군과 유의성 있는 차이가 있었고($P<0.05$), 처리 후는 Prettau zirconia군이 가장 높은 파절 저항성을 보여 나머지 실험 군과 유의성 있는 차이를 나타냈다($P<0.05$). 각각의 실험 군의 열 순환과 기계적 피로시험 전, 후의 파절 저항성을 t-test로 분석한 결과, IPS e.max Press군, Zmatch full contour zirconia군의 파절 저항성은 처리 후 유의성 있게 감소하였고($P<0.05$), 다른 군에서는 유의차를 보이지 않았다($P>0.05$). 파절양상은 금속 세라믹, ICE zircon, Zmatch zirconia, Lava zirconia군에서는 복합파절이 나타났으며 IPS e.max Press, Zmatch full contour zirconia, Prettau zirconia, Ceracube군에서는 응집파절이 나타났다.

결론적으로, 열적 및 기계적 순환 후 파절저항성 실험 결과를 기반으로 Lava zirconia군이 임상적 사용에 있어서 가장 적합한 모델임을 확인할 수 있었다.

Key words : 지르코니아 전부 도재관, 전단결합강도, 파절저항성, 열 순환, 기계적 순환

Ⅰ. INTRODUCTION

Feldspathic porcelain for dental applications has been used in dentistry as the aesthetic restorative material for approximately more than a century. Originally, these restorative materials were it was used all in the form of ceramics, but it these ceramics exhibited poor mechanical properties in the oral environment did not resist the capabilities in the mouth and they were more prone to fracture. Thus, metal substructure was used to improve mechanical property of ceramic restorations. These metal ceramic restoration which feature excellent fracture and tensile strengths and feasibility have been widely used up

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to now. However, zirconia all ceramic restorations have recently been introduced to overcome the lack of the aesthetics of metal ceramic restoration such as the limited light permeability of metal substructure and discoloration of gingiva caused by the release of metal ions(Rosenblum and Schulman, 1997). In addition, zirconia all ceramic restoration for CAD/CAM systems showed superior mechanical strength compared to other conventional all ceramic restorations(Komine et al 2004).

In the early 1990s, yttrium oxide partially stabilized tetragonal zirconia polycrystals(Y-TZP) was introduced as a core material for all ceramic restorations in dentistry through CAD/CAM technology. Owing to the toughening transformation of zirconia polycrystal structure, zirconia exhibits better mechanical properties as compared to other all ceramic tube systems(Tan et al., 2004; Raigrodski, 2004; Guazzato et al., 2004). Because zirconia is able to withstand high occlusal force, it can be used for crowns and bridges with more than four units(Raigrodski, 2004; Tinschert et al., 2007; Sundh and Sjogren, 2004). In addition, zirconia has shown high stability as a core material, and the fracture resistance of zirconia used in dentistry has not been reported yet(Sailer et al., 2007; Feher et al., 2006; Raigrodski et al., 2006). The strength of a ceramic crown is mainly affected by the type of ceramic used, the preparation technique of the ceramic crown and abutment, and the bonding technique of the abutment and ceramic crown. Also, differences in the coefficient of thermo expansion of the ceramics used, improper design of the substructure, use of an excessively thick ceramic without a lower support, errors in the preparation of the ceramic, excessive occlusion, and improper tooth preparation also affect the mechanical strength of all ceramic restorations(Ozcan et al., 2003). Especially, the amount of axial and occlusal surfaces removed, the axial gradient, and the margin preparation technique are thought to affect the mechanical strength of all ceramic restorations.

The biggest weakness of all ceramic restorations is brittleness. Limited property in plastic change is shown first when overloaded(Drummond et al., 2000). Another problem is the impact that is suddenly applied to all ceramic restorations when unexpectedly hard matter is chewed(Nagashima et al., 1997). In this case, the retention of veneered all ceramic restorations is affected by factors such as cohesion of materials, residual stress, and structural dispersion(Tinschert et al., 2000).

When all ceramic restorations are exposed to oral conditions with thermo and mechanical variations, the lifetime of the restoration materials will be reduced as a result of a physicochemical transformation. The occurrence of a repetitive force during mastication results in continuous focused stresses on the all ceramic restorations, and thermo changes can causes fatigue either in the material itself or at the interface with other materials(Kelly, 1990). Moisture condition is necessary to induce mechanical periodicity in the ceramics because the presence of moisture plays a chemical role at the cracks and reduces the strength of the ceramics(Smyd, 1961). During mastication, factors such as high strength and repetitive stress may cause material fatigue, which leads to cracks. A fatigue test is very important for evaluating the mechanical properties of ceramic materials. It provides more information than other studies that have run experiments using equal loading rates(Wagner et al., 1996; Wen et al., 1999; Esquivel-Upshaw et al., 2001; Scharrer et al., 1996).

The purpose of this study was compared and evaluated the fracture resistance of seven types of all ceramic crowns after thermo-cycling and mechanical fatigue.

II. MATERIALS AND METHODS

1. Materials

1) Materials used for fracture resistance test

Four veneered all ceramic restorations, ICE zircon (Zirkonzahn®, Italy), IPS e.max Press(Ivoclar, Liechtenstein), Lava zirconia(3M, USA), and Zmatch zirconia(Zmatch, Dentaim, Korea), and three full zirconia all ceramic restorations, Prettau zirconia(Prettue, Zirkonzahn®, Italy), Ceracube(BruxZir, Glidewell, USA), and Zmatch full zirconia(Zmatch, Dentaim, Korea) were used as the experimental groups for the fracture resistance test. A Ni-Cr series(Remanium®, Dentaurum, Germany) was used as the metal ceramic control group. IPS d.sign(Ivoclar, Liechtenstein) was used as the veneering ceramic in the metal ceramic core, IPS e.max Ceram(Ivoclar, Liechtenstein) was used for the all ceramic cores except the Lava core, and Lava Ceram(3M, USA) was used for the Lava all ceramic core(Table 1).

Table 1. Materials of metal ceramic system, four types of ceramic core-veneering ceramic restoration and three types full contour zirconia restoration in the study

System	Brand name	Code	Composition	Company	Core temperature (℃)	Veneering temperature (℃)
Metal Ceramic	Remanium®,	MC	Ni 61%, Cr 26%, Mo 11%, Si, Fe, Co, Ce	DENTAURUM	1350	
	IPS d.sign		SiO_2, Al_2O_3, other oxides	Ivoclar		870
Zirconia core - veneering ceramic	ICE zircon	IC	Zirconia (ZrO_2/Al_2O_3/Glass)	Zirkonzahn®	1500	
	IPS e.max Ceram		SiO_2, Al_2O_3, other oxides	Ivoclar		750
	Lava zirconia	LA	Zirconia (ZrO_2)	3M	1500	
	Lava Ceram		SiO_2, Al_2O_3, other oxides	3M		810
	IPS e.max Press	EM	Lithium disilicate ($Li_2Si_2O_5$)	Ivoclar	925	
	IPS e.max Ceram		SiO_2, Al_2O_3, other oxides	Ivoclar		750
	Zmatch	ZM	Zirconia (ZrO_2)	Dentaim	1600	
	IPS e.max Ceram		SiO_2, Al_2O_3, other oxides	Ivoclar		750
Full contour zirconia	Prettau zirconia	PR	Zirconia (ZrO_2)	Zirkonzahn®	1600	
	Ceracube	CE	Zirconia (ZrO_2)	Glidewell	1600	
	Zmatch full zirconia	ZF	Zirconia (ZrO_2)	Dentiam	1600	

2. Methods

1) Preparation of the specimen

The main model used in this study was prepared using a metal master die(stainless steel, AISI type 303, Korea) with an upper diameter of 7.95 mm, a bottom diameter of 9.00 mm, a height of 5.00 mm, and a 6° taper. Ten specimens were prepared in each group(Figure 1).

2) Fabrication of metal ceramic specimen

The control group was a metal ceramic(MC) Ni-Cr series(Remanium®, Dentaurum, Germany). A wax pattern with 0.5 mm width was used to prepare the control specimen using the lost-wax technique. 150 g of Univest®Plus(Metalor, Switzerland), which is a carbon-free phosphate -bonded investment, was mixed with 36 ml of electrolyte solution under vacuum for 60 s to invest wax specimen. After 1 h of, the invested specimen was placed in a burnout furnace. The heating rate in furnace was 5 ℃/min, and soaking conditions were at 250 ℃ for 30 min and at 850 ℃ for 30 min. Casting was performed using an electric resistance heating furnace(Super Cascom, KDF, Japan). After slow cooling, the cast specimen was trimmed carefully. D.sign A2 opaque(Ivoclar, Liechtenstein) was applied to the completed core to a thickness of 0.3 mm. The dentine with A2 color was sintered at 870 ℃, resulting in sample 1.5 mm width. The dentine ceramic was added and sintered at 870 ℃. After that, glazing was carried out at 830 ℃(Figure 2).

3) Fabrication of ICE all ceramic specimen

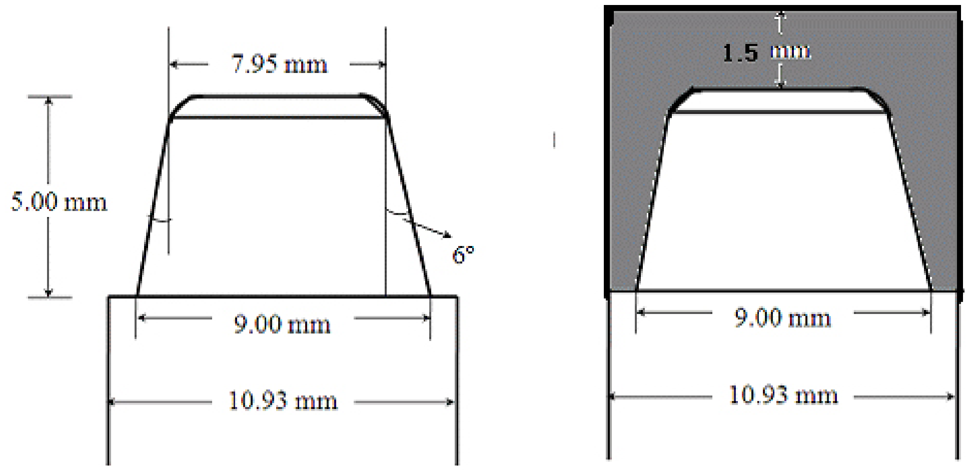
After the green ICE Zircon block was cut and placed in the zir sintering furnace. The temperature was increased up to 1500 ℃ from 20 ℃ and maintained for 2 h in a zirconia sintering furnace to prepare the zirconia core. After ZirLiner(Ivoclar, Liechtenstein) was applied in width of 1.5 mm to the whole surface of the core specimen, the coated specimen was sintered at 960 ℃. Dentine with IPS e.max Ceram(Ivoclar, Liechtenstein) A2 color was applied to the ZirLiner-coated specimen and then the specimen was sintered at 750 ℃. Additional dentine ceramic was applied in order to compensate for the shrinkage of the final product. After that, glazing of the final specimen was carried out at 725 ℃(Figure 2).

4) Fabrication of Lava all ceramic specimen

In the Lava system, ceramic crown of green stage with ZrO_2 ingredient was cut and sintered at 1500 ℃ for 8 h. After ZirLiner(Ivoclar, Liechtenstein) was applied to a completed core, it was sintered at 960 ℃. Dentine with IPS e.max Ceram(Ivoclar, Liechtenstein) A2 color was sintered at 750 ℃ in width of 1.5 mm. Dentine ceramic was added as much as it was shrunk and it was sintered at 750 ℃. After that, glazing was made at 725 ℃(Figure 2).

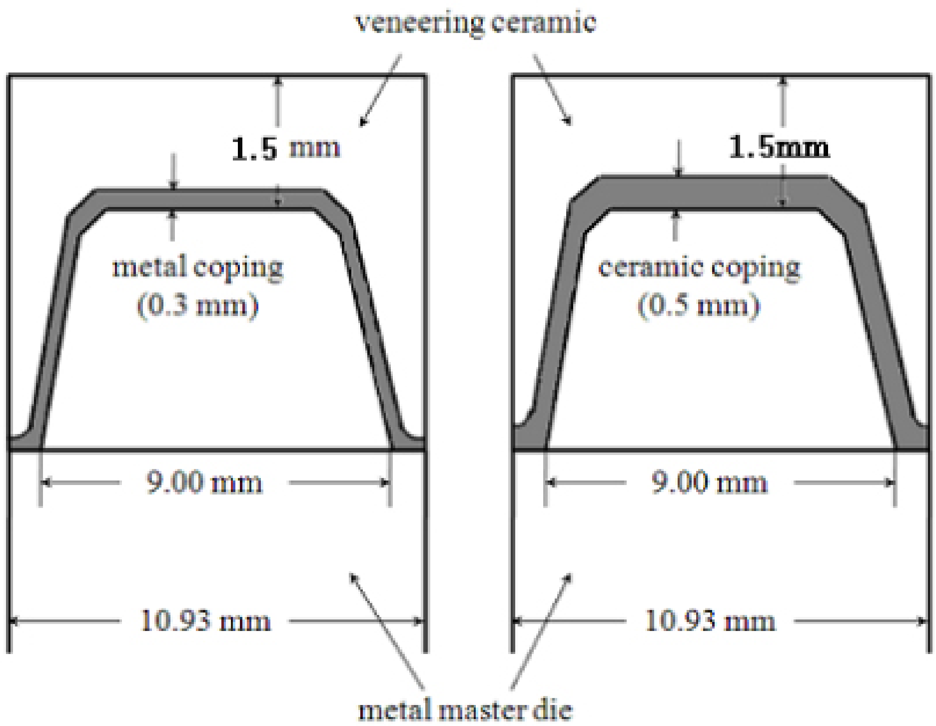
5) Fabrication of IPS e.max Press all ceramic specimen

IPS e.max system used the lost wax process. After it was cut them into pieces in width of 0.5 mm, the prepared wax pattern was immersed in the investment materials (PressVEST Speed, Ivoclar, Liechtenstein) under vacuum mixing for 60 s. After 45 min of investment, burnout was performed at 850 ℃ for 1 h. An MO1-shade ingot of lithium disilicate was injected to the mold in the investment ring at 925 ℃ for 15 min by using a press furnace(EP5000, Ivoclar, Liechtenstein). After slow cooling, the specimens are blasted with 50 ㎛ alumina(Pen-Blaster, Shofu Co., Japan). After the residual investment material was removed, the finished ceramic copings were soaked in a 1% hydrochloric acid solution(Invex Liquid, Ivoclar, Liechtenstein) for 10 min. Dentine with IPS e.max Ceram A2 color(Ivoclar, Liechtenstein) was applied to the prepared specimen, and then the specimen was sintered at 750 ℃ in width of 1.5 mm. Additional dentine ceramic was applied to compensate



(a) (b)

Figure 1. Schematic drawing of the metal master die (a), and all ceramic crowns such as PR, CR, ZF (b).



(a) (b)

Figure 2. Schematic drawing of metal ceramic core and veneering crown (a), and all ceramic core and veneering crowns such as LA, EM, IC, ZM (b).

for the shrinkage of the final product. After that, glazing of the final specimen was carried out at 725 ℃(Figure 2).

6) Fabrication of Zmatch all ceramic specimen

The green Zmatch block with the ZrO_2 ingredient was cut and placed in the zir sintering furnace. The temperature was increased up to 1500 ℃ from 20 ℃ and maintained at 1500 ℃ for 2 h in a zirconia sintering furnace in order to prepare the zirconia core. After ZirLiner(Ivoclar, Liechtenstein) was applied to the whole surface of the core specimen, the specimen was sintered at 960 ℃. Dentine with IPS e.max Ceram A2 color(Ivoclar, Liechtenstein) was applied to the ZirLiner-coated specimen, and then the specimen was sintered at 750 ℃ in width of 1.5 mm(Figure. 2). Additional dentine ceramic was applied to compensate for the shrinkage of the final product. After that, glazing of the final specimen was carried out at(Figure 2).

7) Fabrication of Prettau all ceramic specimen

The green Prettau full contour zirconia block with the 1.5 mm width ZrO_2 ingredient core was produced at 1500 ℃ for 2 h(Figure 1).

8) Fabrication of Ceracube all ceramic specimen

The green BruxZir full contour zirconia block with the 1.5 mm width ZrO_2 ingredient core produced at 1550 ℃ for 11 h(Figure 2).

9) Fabrication of Zmatch all ceramic specimen

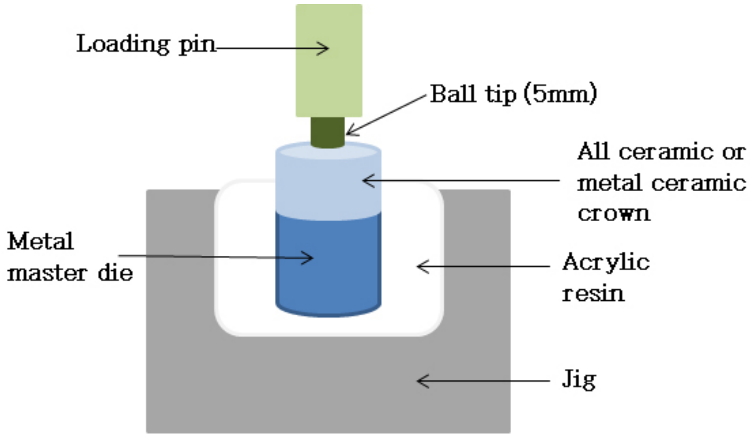
The green Zmatch full contour zirconia block with the 1.5 mm width ZrO_2 ingredient core was produced at 1600 ℃ for 2 h(Figure 2).

10) Measurement of fracture resistance

Each sample was cemented with a self adhesive resin cement(Rely-X Unicem, 3M, USA), pressed by the static load with the weight of 2 kg for 10 s. And then immersed in distilled water at 37 ℃ for 24 h(Figure 3). Thermo-cycling was performed 20,000 times by alternating the temperature between 5 ℃ and 55 ℃ at intervals of 30 s in a thermo-cycling system(KD-TCS30, Gwangdeok P.A., Korea). After thermo-cycling, each specimen was put on a jig to be loaded repetitively, and mechanical force was added axially to simulate mastication. To simulate the force applied on the molars during functional work, the force of the repetitive load was set at 20 N(Picton, 1974). Teeth come into contact with each other during mastication and 30 times during swallowing if it is assumed that people eat four times a day. Also, tooth contact is 400 times in the day time and 80 times at night without eating. Therefore, the total frequency of tooth contact per day would be approximately 2310 times(Graf, 1969). Thus, the load was applied 16,000 times at a speed of 1 Hz assuming seven mastication days(Park et al, 2012)(Figure 4). The fracture resistance was measured at a crosshead speed of 1 mm/min to the sample with the universal testing machine(Figure 5).

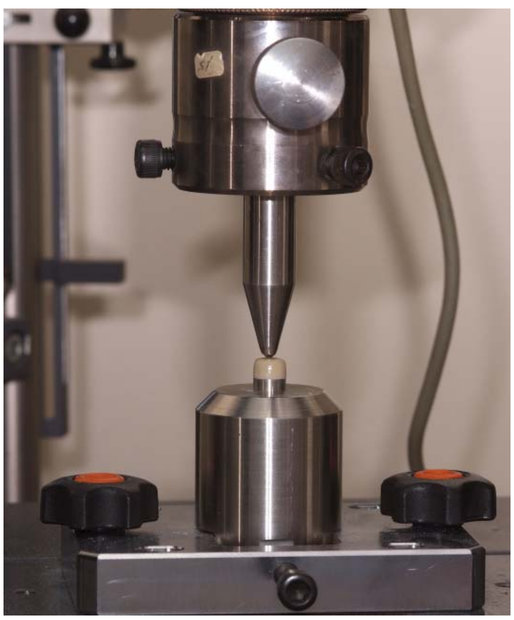
Figure 3. Completed specimens seated on metal master dies that were impregnated in acrylic resin.

(a)

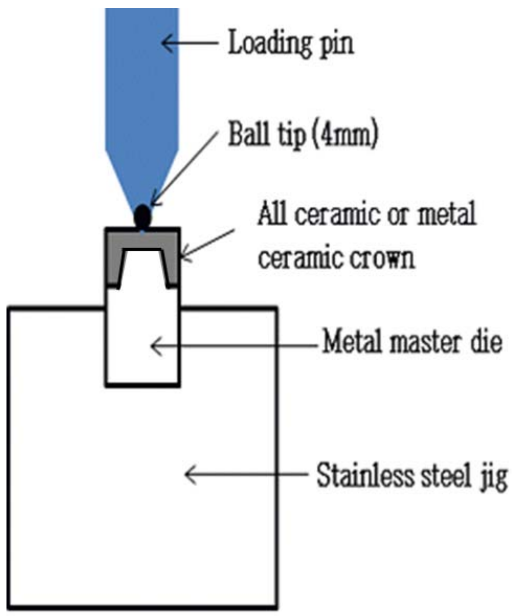


(b)

Figure 4. Assembly designed for cyclic loading machine (a), and a schematic diagram of circled area (b).



(a)



(b)

Figure 5. Assembly designed for measuring the fracture resistance of fabricated crown on an universal testing machine (a), and a schematic diagram of circled area (b).

3. Failure mode

Fracture patterns were observed by using a scanning electron microscope(SEM; JSM 6360, JEOL, Tokyo, Japan) at 8× and 15× magnification. One SEM image for each group was obtained in order to determine the failure mode of the specimen. The failure mode was classified in terms of cohesive, adhesive, or mixed failure.

4. Statistical analysis

All results except the fracture resistance after thermo and mechanical cycling were analyzed with one-way ANOVA by using SPSS Ver. 12.0(SPSS GmbH, Munich, Germany), and a post hoc test was performed by Duncan's multiple range test(α = 0.05). In terms of the fracture resistance of the zirconia all ceramic restorations before and after thermo and mechanical cycling, the values between groups were statistically analyzed by a paired t-test.

Ⅲ. RESULTS

Figure 6 illustrates the results of the fracture resistance of all groups(one control, four veneering all ceramic, and three full contour zirconia restorations) treated by thermo and mechanical cycling. Comparing the results between groups before(uppercase letters in Figure 6) and after(lowercase letters in Figure 6) thermo and mechanical cycling, the PR and ZF groups showed significantly higher fracture resistance as compared to other groups before cycling($P<0.05$), and the PR group had the highest fracture resistance after cycling($P<0.05$). Comparing the fracture resistance before and after cycling within the same experimental group as analyzed by t-test, the fracture resistance of the EM and ZF groups showed a significant decrease after thermo and mechanical cycling($P<0.05$), but the fracture resistance of other groups did not show any significant difference after cycling.

The results and representative images of the failure modes are shown. In all specimens in the MC group, mixed failure occurred at the interface of the metal and opaque layer. In addition, cohesive failure occurred in the EM, ZF, PR, and CE groups, and mixed failure occurred at the interface of the core and veneering in the IC, ZM, and LA groups(Table 2).

Ⅳ. DISCUSSION

The purpose of this study was to evaluate the fracture resistance of zirconia all ceramic restorations after continuous thermo and mechanical cycling. In this study, one control group(MC), four veneered zirconia all ceramic groups(EM, ZM, LA, and IC), and three full zirconia all ceramic groups(PR, CE and ZF) were used to perform fracture resistance test. The fracture resistance of the ZF(9670 N) and PR(9101 N) groups was significantly higher than that of other groups. From the results of the fracture resistance of experimental groups before and after thermo and mechanical cycling, only the EM and ZF groups showed significant reduction of fracture resistance after cycling. Among all experimental groups, only the EM group is composed of $Li_2Si_2O_5$ glass ceramics ; the other experimental groups are composed of zirconia, which generally has a high flexural strength(~900 MPa). Therefore, it is reason able that three full zirconia all ceramic groups showed higher fracture resistance than the other experimental groups due to difference sin the material sand their compositions. In addition, it is well known that the reason why the fracture resistance of the MC and LA groups were higher than those of other veneered all ceramic groups is due to the higher sintering temperature of veneering ceramics on metal and the LA zirconia core as compared to other veneered all ceramic systems.

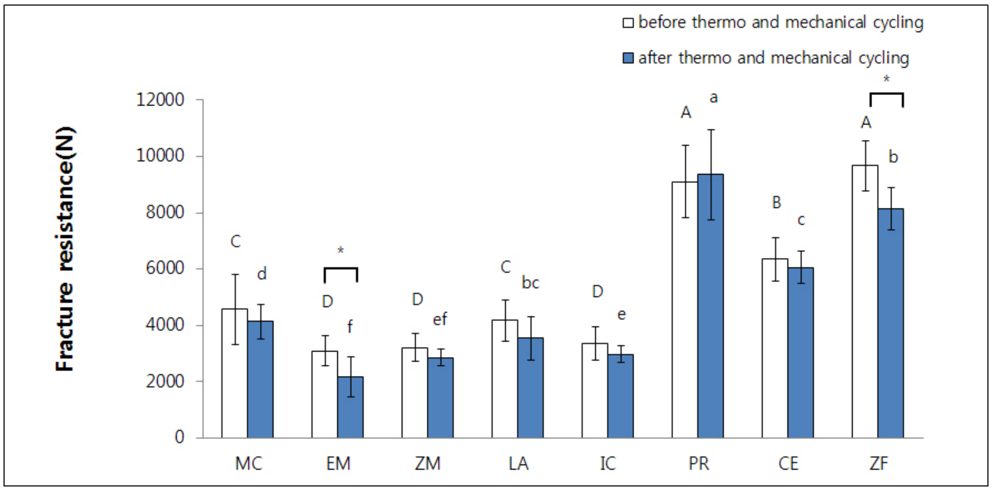


Figure 6. Fracture resistance of metal ceramic system and all ceramic system. The same uppercase letters were not significantly different among the groups before thermo and mechanical cycling. The same lowercase letters were not significantly different among the groups after thermal and mechanical cycling by one way ANOVA at α=0.05.

* means significant different between before and after thermo and mechanical cycling by t-test at α=0.05.

Table 2. Failure modes classified by the depth of propagation of the fracture line

		MC	EM	LA	IC	ZM	PR	CE	ZF
F1	Mixed	20	0	0	0	0	0	0	0
F2	Adhesive failure at the core/veneering interface	0	0	4	5	6	0	0	0
F3	Cohesive failure in core	0	18	16	15	14	20	20	20

Fracture resistance caused by thermo-cycling and fatigue did not show any significant differences between most of the experimental groups. However, the EM and ZF groups showed a significant reduction in fracture resistance, and all specimens of the EM group showed complete fracture of the core after 13,000 and 14,500 repetitions of the loading test. The complete fracture of the EM group is thought to be caused by the weak strength of the all ceramic core itself. In addition, the PR groups showed an increase of fracture resistance after thermo and mechanical cycling. This phenomenon is thought to be an intrinsic characteristic of the PR full zirconia block, compressive stress within itself to prevent the spread of cracks when crack initiation is stimulated from the outside. This is an innovative feature that offsets the weak fracture properties of ceramics(Shimizu et al., 1993; Luthardt et al., 2002).

The occlusal force is normally 40 N, and the maximum occlusal force against antagonistic teeth is thought to be from 245 N to 540 N on average(DeBoerer et al., 1978; Jager et al., 1989). However, because ceramics used as the material for teeth restoration are fragile and limited in tensile strength, high strength is required when the molar region is restored(Probster, 1992; Josephson et al., 1991). Recently developed ceramic crown material and way to prepare has enough strength and are esthetic and simple to prepare so that it shows good results in many clinical application(Probster, 1992). According to the results of this study, every ceramic crown used in the experiment showed an occlusal force of more than 2000 N, which is acceptable fracture resistance in clinics.

The reduction of mechanical strength of dental materials has been reported in several studies. This problem stems on the fact that oral conditions change these materials physiochemically. The presence of moisture and thermo changes with repetitive mechanical force during mastication creates conditions that lead to abrasion and fatigue. This is very important when ceramic materials are used for restorations because of the friability and low flexural strength of ceramics.

Ceramics are subject to fatigue, and the accumulation of micro structural defects might cause cracks during mastication(White, 1993; Myers et al., 1994). The endurance of ceramic restorations has sometimes been investigated by using a quantitative fragment test that shows the cracks on the internal surface of the occlusal region where the greatest stress is applied during mastication (Wiskott et al., 1995). The occurrence of an intermittent load at the same area can lead to fatigue of the ceramic material. Fairhurst(1993) and Wiskott(1995) have reported that failure of restorations from fatigue is explained by micro-porous cracks at a focused loading area. Cracks occurring by repetitive load will fuse with pre-existing cracks, weakening the whole material. Hence, cracks are thought to be the result of repetitive loading that exceeds the mechanical strength of the ceramic material.

The mechanical repetitive loading of the experimental ceramic material used in this study is considered a good imitation of the clinical environment. The mechanical repetitive loading was experimented in random in several previous studies. For example, Drummond(2000) applied mechanical stimulus 1000 times using a repetitive load of 4 kg. Sobering(1998) applied 20–30 N load conditions 1~10,000 times to three types of ceramic groups at 1 Hz. Kheradmandan(2001), on the other hand, reported that cracks occurred in ceramics when mechanical repetitive loads of 25 N at 1.3 Hz were applied 40,400~310,000 times. However, Ohyama(1999) reported that he applied 4.9 N at 20 Hz 100,000 times and found cracks after 1000~100,000 times, but he already found cracks after 100~10,000 times. Therefore, because the purpose of this study was to evaluate the effect of a mechanical repetitive load on the fracture resistance of flawless ceramics, it was decided to run the experiment 16,000 times at 20 N. Also, internal factors of the experimental conditions such as the properties of the materials, the number of times the load was applied, the presence of moisture, and the weight of the load are also important to the final results of the periodic fatigue test.

Therefore, the mechanical periodic treatment in this study was done in water maintained at a temperature of 37 ℃ and a frequency of 1 Hz to imitate the masticatory conditions(Kheradmandan et al., 2001).

It is widely known that oral conditions can lead to physiochemical changes of the dental material. Changes in temperature worsen the mechanical properties in moisture conditions, and mechanical fatigue occurs at the mechanical bonding interface of the materials and/or on the inside of the material by masticatory force(Kvam et al., 1995). Keeping ceramic materials in water reduces the physical properties(Scherrer et al., 2003; Teoh, 2000), which might be related to the solubility difference between oxides. Also, the binding strength between a metal and resin(ceramic) is eventually reduced when a thermo cycle load is applied(Morena et al., 1986). It was shown in the current study that every experimental group except for PR exhibited a reduction of fracture resistance after being subjected to thermo periodic conditions and in the after math of fatigue.

From observation of the failure mode, mixed fractures occurred among metal, opaque, and veneering ceramics in the MC group. However, most of the all ceramic restoration groups showed(1) adhesive fracture at the interface of the core and veneering and(2) cohesive fracture inside the core. Also, veneer coming off as thin layers from the zirconia core is common at the interface of the core and veneer of all ceramic restorations(Studart et al., 2007).

A limitation of this study is that the conditions related to the dental ligament and alveolar bone by occlusal force were not considered. Also, the thermo changes of dietary food, the temperature of the thermo-cycle, and the fact that the mechanical repetitive load was applied vertically, are additional limitations of this study. It is not possible to imitate clinical conditions exactly because of these factors, and more investigation is required. However, within the scope of this research, it is expected that the fracture resistance of ceramics that bind with a zirconia core after thermo- cycling and fatigue have enough strength to over come the occlusal force in oral conditions.

V. CONCLUSION

This study was result of the influence of thermo and mechanical cycling on the fracture resistance of all ceramic system.

1. The comparison between experimental groups on the condition of before and after thermo and mechanical cycling indicated that the full contour zirconia of PR and ZF groups were significantly higher than that of other experimental groups on the condition of pre-cycling($P < 0.05$).
2. The failure mode of fracture resistance test specimens showed IC, ZM, LA, and MC groups were adhesive failures between ceramic, metal coping and veneering ceramic, and EM, ZF, PR, and CE groups was only cohesive failure within the ceramic coping.

In conclusion, all zirconia core is thought to have potential for clinical usage on the basis of the results of fracture resistance test after thermo and/or mechanical cycling.

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