Effect of thickness of zirconia framework on fracture strength and fracture mode of ceria-stabilized tetragonal zirconia polycrystals/alumina ceramic restoration on resin tooth abutment

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Purpose: This study aimed to evaluate the fracture strength and fracture mode of ceria-stabilized tetragonal zirconia polycrystals/alumina (Al_2O_3) nanocomposites (Ce-TZP/A) and yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) ceramic restorations in different thicknesses of frameworks on resin tooth abutments and to assess the usability of Ce-TZP/A ceramic restoration with thin zirconia frameworks.
Materials and Methods: Artificial maxillary second premolars were prepared for all-ceramic and metal-ceramic restoration. Then resin tooth abutments were duplicated. Four groups of zirconia-ceramic restoration framework were fabricated (n = 10): standard 0.5 mm thickness frameworks (Y-TZPs, Ce-TZP/As) for all-ceramic restoration preparation, and modified 0.3 mm thickness with palatal support frameworks (Y-TZPm, Ce-TZP/Am) for metal-ceramic restoration preparation. Porcelains were pressed. The restorations were fixed to resin abutment teeth and loaded vertically until fracture. The maximum fracture loads were recorded as fracture strengths. One-way ANOVA and post hoc test (Tukey's HSD) were performed. The fracture modes were observed and statistically analyzed with Fisher's exact test. All tests were used at a significant level of 0.05.
Results: The fracture strength of Ce-TZP/Am (2,824.1 ± 320.8 N) was significantly higher than Y-TZPm (2,399.7 ± 188.8 N) but was not significantly different from Ce-TZP/As (3,056.4 ± 337.1 N). There was no significant difference in fracture mode between groups.
Conclusion: Within the limitations of this study, Ce-TZP/A can be use with the thin modified design framework. Ce-TZP/Am provided good fracture strength and sufficiency for clinical use.
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Key Words: Ce-TZP/A, fracture strength, framework thickness, zirconia-ceramic restoration

Introduction

Nowadays, esthetic dentistry has become popular. All-ceramic restorations or metal-free restorations are being used increasingly instead of metal-ceramic restorations for many reasons such as esthetic capability [1,2], color stability, low thermal conductivity [3], low risk of metal allergy, and low plaque accumulation [4]. Metal-ceramic restorations were used and recommended for more than 50 years due to their durability and fit to the abutment, but their esthetics were not satisfied as compared to all-ceramic restorations (metal-free restorations). It is difficult to cover metal and create natural tooth color, due to its dark color. In addition, metals may cause bluish appearance of the surrounding soft tissues [5,6].

Recently, all-ceramic restorations are often preferred to metal-ceramic restorations. The increasing esthetic demand has driven the development and enhancement of dental ceramics [2,3]. One of the most recent dental ceramics is zirconia [3], which is a high strength ceramic. In the past, due to its high strength and limited manufacturing technology, dental zirconia was fabricated with difficulty, and milling machines could not attain satisfied accuracy and marginal adaptation. Hence, dental zirconia has rarely been acceptable. However, recent advancements in the CAD-CAM technology have made dental zirconia affordable for restorations such as fixed partial dentures (FPDs) [7], removable partial dentures, and complete dentures [8].

Zirconia has been played an important role in all-ceramic restorations due to its superior mechanical properties including high fracture strength, high fracture toughness, and high biocompatibility [6]. Zirconia can be used as frameworks of restorations and FPDs instead of metal framework, while maintaining their sufficient strength, but without metallic colored appearance. In addition, the use of zirconia-ceramic restorations can provide better esthetic appearance from outer porcelain and high strength from inner zirconia framework [6].

Currently, yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) are used widely in clinics due to their good flexural strength (1,000 MPa), but they have moderate fracture toughness (7 MPa) [9]. While ceria-stabilized tetragonal zirconia polycrystals (Ce-TZP) are very high fracture toughness zirconia (23 MPa), they have some disadvantages such as lower flexural strength (450 MPa) when compared to Y-TZP [9], and they are not available for use in the dental field. Therefore, Ce-TZP was developed into ceria-stabilized tetragonal zirconia polycrystals/alumina (Al_2O_3) nanocomposites (Ce-TZP/A) that have both high flexural strength and fracture toughness (1,000 MPa and 18 MPa) [9] to improve the low strength of Ce-TZP [10].

Ce-TZP/A was developed by integrating nanometer-sized Al_2O_3 and Ce-TZP particles in grains of the other component. Al_2O_3 particles were dispersed within the Ce-TZP grains and grain boundaries, and Ce-TZP particles were dispersed within the Al_2O_3 grains and grain boundaries. This homogeneous dispersion of Al_2O_3 particles in the Ce-TZP matrix resulted in increased hardness, flexural strength, hydrothermal stability, and suppressed grain growth of tetragonal zirconia while preserving its toughness [10,11].

The strength of zirconia comes from stress-induced transformation toughening that the tetragonal phase transforms into monoclinic phase. This transformation is associated with an increase in volume (3-5%) and local compressive stress fields are made and tend to stop crack propagation [12]. However, some zirconia such as Y-TZP have a few problems concerning low temperature aging degradation (LTAD) [10,13-16]. The LTAD is caused by unintentional phase transformation induced by fatigue at low-temperatures and exposure to moist environments such as water or saliva in the oral cavity [14,16,17], which may decrease the strength in the long-term and may lead to catastrophic failure of zirconia [18]. On the other hand, Ce-TZP/A has total resistance to LTAD [8,15,16,19], and can thus maintain its strength for a longer period. From the many excellent properties described above, Ce-TZP/A has an advantage over Y-TZP, but usability needs to be studied further.

Tooth preparation design of all-ceramic restorations requires more spaces than metal-ceramic restorations, which limits usability and is a significant disadvantage. Due to superior mechanical properties of Ce-TZP/A, it may be possible to reduce the thickness of Ce-TZP/A ceramic restoration framework from the usual standard of Y-TZP ceramic restoration framework, which is commonly used in many restorations. Thinner zirconia framework would require less tooth reduction, which follows the concept of minimal intervention [20]. This would lead to better preservation of pulp vitality, especially in young age patients who have large pulp cavities [21,22]. From these improved mechanical properties, the clinical applications of zirconia-ceramic restorations were supposed to expand. We have already reported that thin Ce-TZP/A frameworks gave a good result [23], but the effect of thickness of Ce-TZP/A ceramic restoration framework combined with pressed porcelain has not been studied in detail.

The aims of this study were to evaluate the fracture strength and fracture mode of Ce-TZP/A and Y-TZP ceramic restorations in different thicknesses of zirconia frameworks on resin tooth abutments and to assess the usability of Ce-TZP/A ceramic restorations with thin Ce-TZP/A frameworks.

Materials and Methods

Abutment tooth preparations

Artificial maxillary second premolar teeth (Simple Root Tooth Model A5A-500 #15, Nissin Dental Product Inc., Kyoto, Japan) were prepared for two types of preparations: metal-ceramic restoration preparation and all-ceramic restoration preparation. The metal-ceramic restoration abutment was prepared with a 1.0 mm heavy chamfer finish line at buccal margin, 0.5 mm chamfer finish line at palatal margin, 1.3 mm occlusal reduction of buccal cusp (non-functional cusp), and 1.8 mm occlusal reduction of palatal cusp (functional cusp). The all-ceramic restoration abutment was prepared with a 1.0 mm overall heavy chamfer finish line, 1.5 mm occlusal reduction of buccal cusp (non-functional cusp), and 2.0 mm occlusal reduction of palatal cusp (functional cusp). Both types of preparations had an axial convergence angle of approximately 6-degrees, and the palatal surfaces of the functional cusp were reduced in two planes. (Fig. 1)

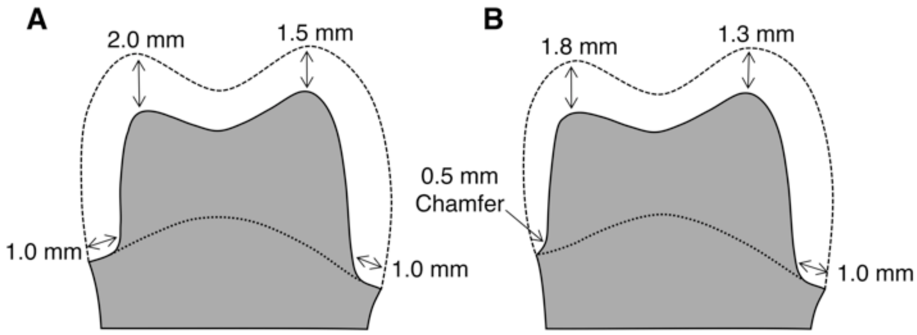

Fig. 1
Proximal view of abutment tooth preparations
(A) all-ceramic restoration preparation,
(B) metal-ceramic restoration preparation

Fabrication of resin tooth abutments

After preparing both the artificial teeth, their impressions were made with transparent vinyl polysiloxane impression material (Memosil 2, Heraeus Kulzer GmbH, Hanau, Germany). The impressions were used as duplicating molds for resin tooth abutments. After that, an auto-mixed composite resin (Clearfil DC core automix, Kuraray Noritake Dental Inc., Tokyo, Japan) was injected into the transparent duplicating molds. The composite resin paste was cured using a light curing unit (Optilux 501, Sybron Dental Specialties Japan Inc., Tokyo, Japan) for 15 s on each side (buccal, palatal, mesial, and distal). After the resin tooth abutments were cured, they were removed from the molds. After 30 minutes, the procedure was repeated for the next resin abutment. Twenty resin tooth abutments for metal-ceramic restoration preparation and twenty resin tooth abutments for all-ceramic restoration preparation were fabricated.

Fabrication of dies

The impressions of the prepared teeth were made with hydrophilic vinyl polysiloxane impression material (Exafine, GC Corp., Tokyo, Japan). The impressions were poured with type IV die stone (New Fujirock, GC Corp.). The metal-ceramic restoration preparation die and all-ceramic restoration preparation die were thus fabricated.

Fabrication of zirconia-ceramic restoration frameworks

In this study, two zirconia materials were used for fabricating zirconia-ceramic restoration frameworks, which were Y-TZP (Cercon base, DeguDent, Hanau, Germany) and Ce-TZP/A (NANOZR, Panasonic Healthcare, Tokyo, Japan). Moreover, two different framework designs were used. First one was standard zirconia-ceramic restoration framework design, which was 0.5 mm overall wall thickness framework used for all-ceramic restoration preparation. The other was modified zirconia-ceramic restoration framework design, consisting of 0.3 mm wall thickness framework with additional palatal support (1.0 mm thick and 2.0 mm high) at palatal margin extending to the proximal surfaces, used for metal-ceramic restoration preparation (Fig. 2).

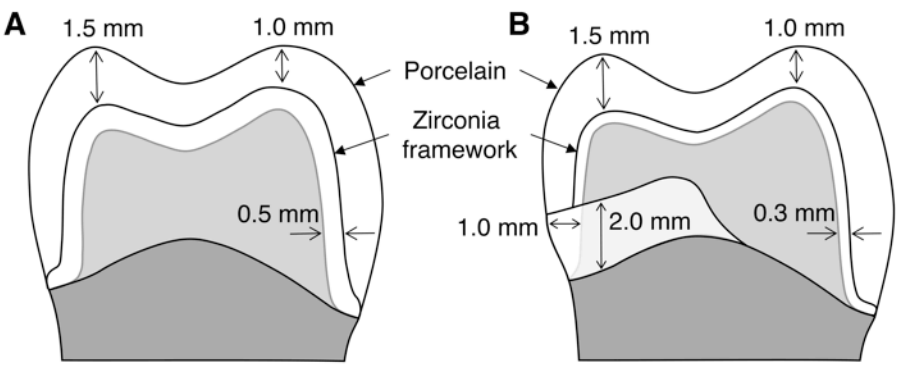

Fig. 2 Proximal view of framework designs and restoration thicknesses
(A) Standard design framework zirconia-ceramic restoration (Y-TZPs, Ce-TZP/As); 0.5 mm overall thickness framework
(B) Modified design framework zirconia-ceramic restoration (Y-TZPm, Ce-TZP/Am); 0.3 mm overall thickness framework with additional palatal support (1.0 mm thick and 2.0 mm high) at palatal margin extending to the proximal surfaces
(A), (B) Pressed-over porcelain 1.0 mm thickness on the occlusal surface of non-functional cusp and 1.5 mm thickness on the occlusal surface of functional cusp

Stone dies from the previous step were used as master dies for making four groups of zirconia-ceramic restoration frameworks as follows; 1 Standard Y-TZP framework (Y-TZPs), 2 Standard Ce-TZP/A framework (Ce-TZP/As), 3 Modified Y-TZP framework (Y-TZPm), and 4 Modified Ce-TZP/A framework (Ce-TZP/Am). Ten frameworks were fabricated for each group (total = 40). Y-TZPs and Y-TZPm were fabricated by using CAD-CAM system (Cercon smart ceramics, DreguDent). The dies were scanned (Cercon eye, DeguDent), frameworks were designed (Cercon art, DeguDent), milled (Cercon brain, DeguDent), and sintered (Cercon heat, DeguDent) according to the manufacturer's recommendations. Ce-TZP/As and Ce-TZP/Am were fabricated by using another CAD-CAM system (C-Pro system, Panasonic Healthcare). The dies were scanned, designed, milled, and sintered according to the manufacturer's recommendations. All frameworks were checked and adjusted for internal fit with resin tooth abutment by using fit checking vinyl polysiloxane material (Fit checker, GC Corp.) for ensuring acceptable internal fit and no difference within each group.

Fabrication of restorations

For all zirconia-ceramic restoration frameworks, outer surfaces of the frameworks were treated using air-abrasion with 70 μm alumina particles (Hi Aluminas, Shofu Inc., Kyoto, Japan) at 0.2 MPa for 10 s at a distance of 10 mm. Then, the frameworks were cleaned by using ultrasonic cleaner in an acetone solution for 10 minutes, followed by cleaning in deionized water for 5 minutes twice, and drying with air. Shade base stain (Cerabian ZR Press shade base stain SSA3, Kuraray Noritake Dental Inc.) was applied twice.

Maxillary second premolar restorations were formed with wax-up (Inlay wax Medium, GC Corp.). The wax patterns of all frameworks were made 1.0 mm thick on the occlusal surface of non-functional cusp and 1.5 mm thick on the occlusal surface of functional cusp by using a silicone jig of the anatomical form. The thickness was verified by periodic caliper measurement at several areas.

After that, wax patterns of the frameworks were invested using pressable ceramic investment (Ceravety press and cast, Shofu Inc.). Pressable ceramics (Cerabian ZR press A3, Kuraray Noritake Dental Inc.) were pressed on the zirconia frameworks. Zirconia-ceramic restorations were fabricated, adjusted, and polished.

Cementation

All zirconia-ceramic restorations were cemented to resin tooth abutments using an adhesive technique. Pre-treatment was performed on both inner surfaces of restorations and resin abutments. Inner surfaces of zirconia-ceramic restorations were treated using air-abrasion with 70 μm alumina particles at 0.2 MPa for 10 s at a distance of 10 mm, cleaned with ultrasonic cleaner in deionized water for 5 minutes, and dried with air. Then, silane-coupling agent (Clearfil ceramic primer, Kuraray Noritake Dental Inc.) was applied, followed by drying with air. The resin abutment tooth surfaces were cleaned with 40% phosphoric acid (K-etchant gel, Kuraray Noritake Dental Inc.) for 5 s, rinsed with water for 10 s, and air-dried. The silane-coupling agent (Clearfil ceramic primer, Kuraray Noritake Dental Inc.) was applied, and dried with air. Next, the zirconia-ceramic restorations were luted to the resin tooth abutments with adhesive resin cement (Panavia F2.0, Kuraray Noritake Dental Inc.) according to the manufacturer's recommendations. The restorations were pressed with firm hand pressure on resin tooth abutment until the restoration seated properly. Excess cement was removed before curing with a light curing unit (Optilux 501, Sybron Dental Specialties Japan Inc.) for 5 s on each buccal and palatal side. One hour after cementation, the specimens were stored in deionized water at 37˚C for 24 hours in darkness. After that, the specimens were embedded into stainless steel rings (20 mm length, 20 mm diameter) using acrylic resin (Palapress Vario, Heraeus Kulzer GmbH) at the position where the restorations' marginal line were placed 0.2 mm above the resin to mimic the biological width. The fracture loads were tested after polymerization of the resin.

Measurement of fracture load

Fracture loads of all specimens were tested using a universal testing machine (Autograph AGS-H, Shimadzu Corp., Kyoto, Japan). The specimens were tested with a 4.0 mm diameter ball-ended stainless steel rod at cross-head speed of 1.0 mm/min, loading along the axis at the central fossa until fracture. The maximum fracture loads were recorded as fracture strengths.

Fracture modes

After the fracture load test, all specimens were observed for the fracture modes and classified into two groups: Type A, fracture of zirconia-ceramic restoration limited to the pressing porcelain; and Type B, fracture of zirconia-ceramic restoration extending to zirconia framework and resin abutment.

Statistical analyses

The results of fracture load of zirconia-ceramic restorations were statistically analyzed with one-way analysis of variance (ANOVA) at a significant level of 0.05. After that, multiple comparison post hoc test was performed with Tukey's HSD test at a significant difference probability level of 0.05. The results of the fracture mode were statistically analyzed with Fisher's exact test at a significant level of 0.05.

Results

The means and standard deviations of fracture strength for each group are presented in Table 1. The one-way analysis of variance (ANOVA) showed statistically significant differences among groups ($p < 0.05$). The post hoc test (Tukey's HSD) revealed that the fracture strength of Ce-TZP/Am (2,824.1 ± 320.8 N) was significantly higher than Y-TZPm (2,399.7 ± 188.8 N), but was not significantly different from Ce-TZP/As (3,056.4 ± 337.1 N). No significant difference between Y-TZPs (3,338.8 ± 359.3 N) and Ce-TZP/As was observed. The fracture modes for all groups are presented in Table 2. The Fisher's exact test showed no significant difference between groups. The representative fracture modes of all groups are shown in Fig. 3.

Table 1 Fracture strength (N) of zirconia-ceramic restorations

Experimental group	Framework material	Framework design, thickness (mm)	Mean (SD) of fracture strength
Y-TZPs	Y-TZP	Standard (0.5)	3,338.80 (359.38)[a]
Ce-TZP/As	Ce-TZP/A		3,056.40 (337.13)[a,c]
Y-TZPm	Y-TZP	Modified with palatal support (0.3)	2,399.70 (188.86)[b]
Ce-TZP/Am	Ce-TZP/A		2,824.10 (320.83)[c]

The different superscript letter showed statistical difference ($p < 0.05$).

Table 2 Fracture mode of zirconia-ceramic restorations (n = 40)

Experimental group	Fracture mode	
	Type A	Type B
Y-TZPs[d]	1	9
Ce-TZP/As[d]	0	10
Y-TZPm[d]	1	9
Ce-TZP/Am[d]	3	7

Type A, Fracture of zirconia-ceramic restoration limited to the pressing porcelain
Type B, Fracture of zirconia-ceramic restoration extending to zirconia framework and resin abutment
The different superscript letter showed statistical difference ($p < 0.05$).

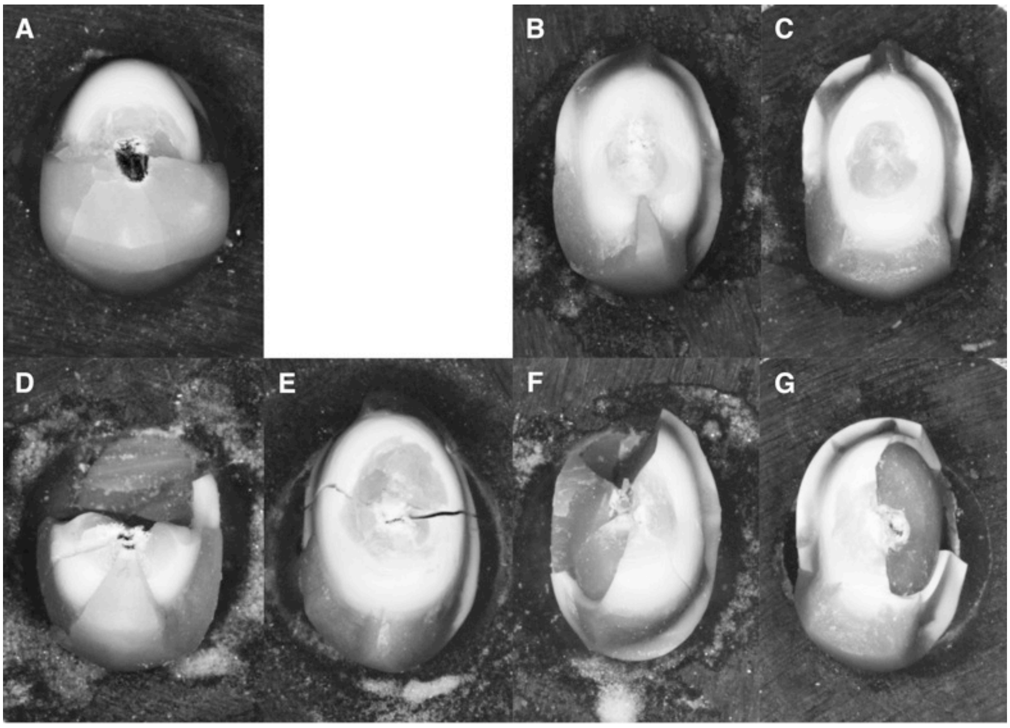

Fig. 3 Occlusal view of representative fracture modes of zirconia-ceramic restorations
Type A: Facture of zirconia-ceramic restoration limited to the pressing porcelain;
(A) Y-TZPs, (B) Y-TZPm, (C) Ce-TZP/Am
Type B: Fracture of zirconia-ceramic restoration extending to zirconia framework and resin abutment:
(D) Y-TZPs, (E) Ce-TZP/As, (F) Y-TZPm, (G) Ce-TZP/Am

Discussion

In this study, the aims were to evaluate the fracture strength and fracture mode of Ce-TZP/A and Y-TZP ceramic restorations in different thicknesses of zirconia frameworks on resin tooth abutments and to assess the usability of thin Ce-TZP/A framework with palatal support.

According to the conventional guidelines, minimum thickness of the metal framework of porcelain fused to metal restoration should be 0.3 mm [24]. However, nowadays, when the patients' demands have shifted towards metal-free restorations, the zirconia-ceramic restoration is one of the alternative choices and Y-TZP is the most commonly used zirconia for this restoration [25]. The minimum thickness of Y-TZP framework of zirconia-ceramic restoration in the posterior region is 0.5 mm [23,26]. Increase in this thickness requires greater tooth preparation. However, Ce-TZP/A has superior mechanical properties than Y-TZP, and can potentially reduce the thickness of the framework. In this study, 0.3 mm thick Ce-TZP/A framework was used to assess the usability of Ce-TZP/A ceramic restoration frameworks. This 0.3 mm thickness was based on the standard minimum thickness of metal framework of porcelain fused to metal restoration which has long term reliability history [6].

A modified framework design with palatal or lingual support on the porcelain fused to metal restoration has been suggested to improve the strength of veneered porcelain by creating support and providing good esthetic appearance without compromising on strength. Besides, the modified framework of zirconia-ceramic restoration is becoming more popular in clinical use [27]. Moreover, this modification also provides porcelain support, good esthetic appearance, and improves the characteristic strength of zirconia-ceramic restoration as well [28-30]. Therefore, the modified zirconia-ceramic restoration framework with palatal support was selected for this study.

In the previous study, modified Ce-TZP/A ceramic restoration framework was evaluated the fracture strength [23]. However, modified Ce-TZP/A ceramic restoration framework with pressed-over porcelain has not been studied in detail. Thus, for this study, modified Ce-TZP/A ceramic restoration framework with pressed-over porcelain was used in an attempt to be examined in actual restorations.

Fracture strength of Ce-TZP/Am was significantly higher than Y-TZPm. This implies that the strength of Ce-TZP/A ceramic restoration with modified framework makes it a better alternative choice for use with thinner zirconia frameworks, and reduce tooth preparation for zirconia-ceramic restorations. Although Y-TZPs showed higher fracture strength than Ce-TZP/Am, Y-TZPs ceramic restoration framework was thicker than Ce-TZP/Am ceramic restoration framework and would require more tooth reduction. Ce-TZP/Am and Ce-TZP/As showed no significant differences when tested for fracture strength. These results assume that Ce-TZP/A ceramic restoration framework can maintain its strength when reduced its thickness to 0.3 mm.

In general, the strength of zirconia comes from the transformation of the tetragonal phase to monoclinic phase, when external stresses are applied. This is called stress-induced transformation toughening. Consequently, 3-5% volume expansion occurs and induces local compressive stresses around the micro crack areas. As a result, the opening of the crack is stopped and crack propagation is resisted [12]. The tetragonal phase can spontaneously transform to monoclinic phase when exposed to humid environment, which is known as low temperature aging degradation (LTAD) [14,16,17]. For this reason, some zirconia materials have reduced strength and durability. Y-TZP materials are susceptible to LTAD [10,13-16]. On the other hand, Ce-TZP/A materials are completely resistance to LTAD [8,15,16,19]. Complete resistance to LTAD of Ce-TZP/A would be one of requirement property for use with modified frameworks with palatal or lingual support, as this palatal or lingual support is exposed to the moist environment of the oral cavity, which leads to creation of LTAD [8]. LTAD may shorten the durability in long-term evaluation of zirconia material. This phenomenon is a weakness and undesired property of zirconia.

Practically, tooth preparation for the conventional Y-TZP ceramic restoration requires shoulder finish line with rounded internal angles [23]. When compared to porcelain fused to metal restoration, the amount of tooth reduction is considereble. Therefore, the conventional Y-TZP ceramic restoration may have some difficulties in use in cases of vital teeth, especially in young patients, who have relatively large pulp cavities [21,22]. The use of Ce-TZP/A framework in case of zirconia-ceramic restorations would require less tooth reduction, because preparation can result in a chamfer finish line from proximal to palatal side, and reduced occlusal reduction [31]. This preparation would preserve tooth structure, minimize chances of damaging the pulp tissue, and would be preferable as per the minimal intervention concept.

Even though zirconia can provide tooth-color simulation, but it is still highly opaque [32]. This property may limit the esthetic outcomes of zirconia restorations. Therefore, veneering porcelain on zirconia-ceramic restorations would provide the enhancement of translucency to fulfill the esthetic outcomes [32] when compared to monolithic zirconia restorations. Both monolithic zirconia restorations and zirconia-ceramic restorations have their own advantages. Monolithic zirconia restorations have no chipping problem of veneering porcelain, but their esthetic outcomes are limited due to lack of translucency. In case of zirconia-ceramic restorations, esthetic capability is achieved by using esthetic veneering porcelain to cover the high strength zirconia framework. Therefore, monolithic zirconia restorations may be suitable for non-esthetic areas such as molar region, while porcelain veneered zirconia restorations can be used in esthetic areas such as anterior and premolar regions [3,33].

Maximum bite force can reach approximately 650 N in males and 540 N in females [34,35]. Thus, the fracture strength of Ce-TZP/Am would be high enough for clinical use. Numerous studies suggest that the chipping problems of veneering porcelain can be reduced by using an anatomically designed [18,36,37] modified framework with palatal or lingual support [29,30]. Moreover, porcelain pressing technique, which has a higher survival rate and better clinical outcomes than conventional layering technique can also be useful [18]. In a short-term clinical study, the porcelain veneer chipping rate of zirconia-ceramic restorations was not found to be significantly higher than metal-ceramic restorations [38]. Thus, zirconia-ceramic restorations may become an acceptable alternative choice of treatment [18].

The fracture mode of Ce-TZP/Am showed three specimens that fracture limited to the pressing porcelain, but Y-TZPm showed only one specimen. The fracture limited to the pressing porcelain and was not extending to zirconia framework and resin abutment referring to prevent a catastrophic failure of the abutment and can be re-treated with conventional treatment procedure.

Due to all the above stated advantages of Ce-TZP/A including high fracture strength, it can be fabricated as a thin framework while maintaining its strength, reduced tooth reduction, and complete resistance to LTAD. These suggest that Ce-TZP/A would be one of the most recommended alternative choices for frameworks in zirconia-ceramic restorations.

Resin cement was used in this study due to its many advantages when used with zirconia restorations such as its high compressive strength, high tensile strength, high bonding strength, sufficient marginal adaptation, low stress concentration in cement layer, and low solubility [39,40]. In addition, resin cement is preferred and is gaining popularity for use in zirconia restorations [40]. The abutment used in this study was created from resin composite material as its Young’s modulus is similar to dentin, making it widely used in clinics [41]. Therefore, resin cement and resin abutments were used in this study, in an attempt to simulate a practical clinical treatment for zirconia-ceramic restorations.

Within the limitations of this *in vitro* study, it can be concluded that Ce-TZP/A can be use with the thin modified design framework (0.3 mm thickness with palatal support) in zirconia-ceramic restorations. For this reason, the amount of tooth reduction can be reduced. Ce-TZP/A ceramic restorations with thin modified framework had higher fracture strength than Y-TZP ceramic restorations with thin modified framework. In addition, they provide sufficient strength for use in cases of vital or non-vital abutment teeth restored by resin composite material.

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References

1. Raptis NV, Michalakis KX, Hirayama H. Optical behavior of current ceramic systems. Int J Periodontics Restorative Dent 2006; 26: 31-41.
2. Studart AR, Filser F, Kocher P, Gauckler LJ. In vitro lifetime of dental ceramics under cyclic loading in water. Biomaterials 2007; 28: 2695-705.
3. Al-Amleh B, Lyons K, Swain M. Clinical trials in zirconia: a systematic review. J Oral Rehabil 2010; 37: 641-52.
4. Scarano A, Piattelli M, Caputi S, Favero GA, Piattelli A. Bacterial adhesion on commercially pure titanium and zirconium oxide disks: an in vivo human study. J Periodontol 2004; 75: 292-6.
5. Pjetursson BE, Sailer I, Zwahlen M, Hammerle CH. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: Single crowns. Clin Oral Implants Res 2007; 18 Suppl 3: 73-85.
6. Takeichi T, Katsoulis J, Blatz MB. Clinical outcome of single porcelain-fused-to-zirconium dioxide crowns: a systematic review. J Prosthet Dent 2013; 110: 455-61.
7. Nemoto R, Nozaki K, Fukui Y, Yamashita K, Miura H. Effect of framework design on the surface strain of zirconia fixed partial dentures. Dent Mater J 2013; 32: 289-95.
8. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. J Prosthodont Res 2013; 57: 236-61.
9. Uchida M, Kim HM, Kokubo T, Nawa M, Asano T, Tanaka K, et al. Apatite-forming ability of a zirconia/alumina nano-composite induced by chemical treatment. J Biomed Mater Res 2002; 60: 277-82.
10. Nawa M, Nakamoto S, Sekino T, Niihara K. Tough and strong Ce-TZP/alumina nanocomposites doped with titania. Ceram Int 1998; 24: 497-506.
11. Nawa M, Bamba N, Sekino T, Niihara K. The effect of TiO_2 addition on strengthening and toughening in intragranular type of 12Ce-TZP/Al_2O_3 nanocomposites. J Eur Ceram Soc 1998; 18: 209-19.
12. Mochales C, Maerten A, Rack A, Cloetens P, Mueller WD, Zaslansky P, et al. Monoclinic phase transformations of zirconia-based dental prostheses, induced by clinically practised surface manipulations. Acta Biomater 2011; 7: 2994-3002.
13. Yoshimura M, Noma T, Kawabata K, Somiya S. Role of H2O on the degradation process of Y-TZP. J Mater Sci Lett 1987; 6: 465-7.
14. Chevalier J, Cales B, Drouin JM. Low-temperature aging of Y-TZP ceramics. J Am Ceram Soc 1999; 82: 2150-4.
15. Ban SJ, Suehiro Y, Nakanishi H, Nawa M. Fracture toughness of dental zirconia before and after autoclaving. J Ceram Soc Jpn 2010; 118: 406-9.
16. Kohorst P, Borchers L, Strempel J, Stiesch M, Hassel T, Bach FW, et al. Low-temperature degradation of different zirconia ceramics for dental applications. Acta Biomater 2012; 8: 1213-20.
17. Pereira GK, Venturini AB, Silvestri T, Dapieve KS, Montagner AF, Soares FZ, et al. Low-temperature degradation of Y-TZP ceramics: A systematic review and meta-analysis. J Mech Behav Biomed Mater 2015; 55: 151-63.
18. Raigrodski AJ, Hillstead MB, Meng GK, Chung KH. Survival and complications of zirconia-based fixed dental prostheses: a systematic review. J Prosthet Dent 2012; 107: 170-7.
19. Kim JE, Kim JH, Shim JS, Roh BD, Shin Y. Effect of surface treatment on shear bond strength between resin cement and Ce-TZP/Al_2O_3. Biomed Res Int 2016; 2016: 7576942.
20. Tyas MJ, Anusavice KJ, Frencken JE, Mount GJ. Minimal intervention dentistry--a review. FDI Commission Project 1-97. Int Dent J 2000; 50: 1-12.
21. Hebling J, Giro EM, Costa CA. Human pulp response after an adhesive system application in deep cavities. J Dent 1999; 27: 557-64.
22. Murray PE, Smith AJ, Windsor LJ, Mjor IA. Remaining dentine thickness and human pulp responses. Int Endod J 2003; 36: 33-43.
23. Omori S, Komada W, Yoshida K, Miura H. Effect of thickness of zirconia-ceramic crown frameworks on strength and fracture pattern. Dent Mater J 2013; 32: 189-94.
24. Anusavice KJ, Hojjatie B, Dehoff PH. Influence of metal thickness on stress distribution in metal-ceramic crowns. J Dent Res 1986; 65: 1173-8.
25. Johansson C, Kmet G, Rivera J, Larsson C, Vult Von Steyern P. Fracture strength of monolithic all-ceramic crowns made of high translucent yttrium oxide-stabilized zirconium dioxide compared to porcelain-veneered crowns and lithium disilicate crowns. Acta Odontol Scand 2014; 72: 145-53.
26. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater 2008; 24: 299-307.
27. Marchack BW, Futatsuki Y, Marchack CB, White SN. Customization of milled zirconia copings for all-ceramic crowns: a clinical report. J Prosthet Dent 2008; 99: 169-73.
28. Bonfante EA, da Silva NR, Coelho PG, Bayardo-Gonzalez DE, Thompson VP, Bonfante G. Effect of framework design on crown failure. Eur J Oral Sci 2009; 117: 194-9.

29. Lorenzoni FC, Martins LM, Silva NR, Coelho PG, Guess PC, Bonfante EA, et al. Fatigue life and failure modes of crowns systems with a modified framework design. J Dent 2010; 38: 626-34.
30. Silva NR, Bonfante EA, Rafferty BT, Zavanelli RA, Rekow ED, Thompson VP, et al. Modified Y-TZP core design improves all-ceramic crown reliability. J Dent Res 2011; 90: 104-8.
31. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. Int J Periodontics Restorative Dent 2002; 22: 241-9.
32. Manicone PF, Rossi Iommetti P, Raffaelli L. An overview of zirconia ceramics: basic properties and clinical applications. J Dent 2007; 35: 819-26.
33. Bomicke W, Rammelsberg P, Stober T, Schmitter M. Short-term prospective clinical evaluation of monolithic and partially veneered zirconia single crowns. J Esthet Restor Dent 2017; 29: 22-30.
34. Pizolato RA, Gaviao MB, Berretin-Felix G, Sampaio AC, Trindade Junior AS. Maximal bite force in young adults with temporomandibular disorders and bruxism. Braz Oral Res 2007; 21: 278-83.
35. Al-Zarea BK. Maximum bite force following unilateral fixed prosthetic treatment: a within-subject comparison to the dentate side. Med Princ Pract 2015; 24: 142-6.
36. Rosentritt M, Steiger D, Behr M, Handel G, Kolbeck C. Influence of substructure design and spacer settings on the in vitro performance of molar zirconia crowns. J Dent 2009; 37: 978-83.
37. Preis V, Letsch C, Handel G, Behr M, Schneider-Feyrer S, Rosentritt M. Influence of substructure design, veneer application technique, and firing regime on the in vitro performance of molar zirconia crowns. Dent Mater 2013; 29: e113-21.
38. Sailer I, Gottnerb J, Kanelb S, Hammerle CH. Randomized controlled clinical trial of zirconia-ceramic and metal-ceramic posterior fixed dental prostheses: a 3-year follow-up. Int J Prosthodont 2009; 22: 553-60.
39. Oba Y, Koizumi H, Nakayama D, Ishii T, Akazawa N, Matsumura H. Effect of silane and phosphate primers on the adhesive performance of a tri-n-butylborane initiated luting agent bonded to zirconia. Dent Mater J 2014; 33: 226-32.
40. Ha SR. Biomechanical three-dimensional finite element analysis of monolithic zirconia crown with different cement type. J Adv Prosthodont 2015; 7: 475-83.
41. Chiba A, Hatayama T, Kainose K, Nakajima M, Pashley DH, Wakabayashi N, et al. The influence of elastic moduli of core materials on shear stress distributions at the adhesive interface in resin built-up teeth. Dent Mater J 2017; 36: 95-102.

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