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Fracture Strength and Mechanism of Dental Ceramic Crown with Zirconia Thickness

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Abstract

As the development of zirconia crown using CAD/CAM technology, the usage of full zirconia crown is gradually increased. Compare to the layering technique which is fabricated with zirconia coping and veneering porcelain, full zirconia crown shows higher strength and easier laboratory procedure. To prevent mechanical fracture of the full zirconia crown, the thickness of zirconia crown and proper sintering process should be considered. The purpose of this study was to investigate the influence of zirconia thickness for full zirconia crowns on fracture resistance. Mandibular 1st molar resin teeth were prepared the various thickness; (i) group A: 0.5mm, (ii) group B: 1.0mm, (iii) group C: 1.5mm, (iv) group D: 2.0mm, (v) group E: 2.5mm. Different preparation shapes of resin die and full zirconia crowns with different occlusal thickness were fabricated using CAD/CAM system (CAD/CAM system 5-TEC, Zirkonzahn, Italy). Pre-sintered zirconia crowns were sintered for 12 hrs at 1600℃ and then glazed. The samples were cemented on the resin die using resin cement. All specimens were stored in distilled water at 37℃ for at least 24 hrs and then were tested with a universal testing machine. Single load-to-fracture was applied on the lingual aspect of the disto-facial cusp at a rate of 1mm/min. The specimens were thoroughly evaluated for cracks and/or bulk fracture with SEM and fractography.

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Keywords: Zirconia crown, All ceramic, Fracture surface, Zirconia thickness, Fracture strength

1. Introduction

For last decades, increased demands for esthetic restoration have promoted great improvement of all-ceramic system. Because of their brittle properties, however, all ceramic systems are not used in posterior region which received high occlusal force. So, all ceramic restorations were used in region which received lower force and was important in esthetic. To improve brittle properties of all ceramic systems, porcelain-fused-to-metal (PFM) technique has been standard method. Because the strength of PFM restoration depends on coping material, a lot of studies have been done on finding of the better coping material. In recent years, zirconia was introduced in dental area and received attention as esthetic material.

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Zirconia is a crystalline dioxide of zirconium. Its mechanical properties are very similar to those of metals and its color is similar to tooth color. Fracture strength has progressively increased from glass ceramic (320MPa) to alumina (547MPa) to zirconia (900MPa) [1]. Zirconia has mechanical properties similar to those of stainless steel. Its resistance to traction can be as high as 900 ~ 1200MPa and its compression resistance is about 2000MPa. This material also tolerated well with cyclic stress [2].

Biocompatibility is also important to restorative materials. Since 1990, in vitro studies have been performed in order to obtain information about cellular behavior towards zirconia [3]. Evaluation of in vitro studies confirmed that ZrO_2 is not cytotoxic [4-6]. Moreover, zirconium oxide creates less flogistic reaction in tissue than other restorative materials such as titanium [7]. This result was also confirmed by another study. In the study on the peri-implant soft tissue around zirconia healing caps in comparison with that around titanium ones, inflammatory infiltrate and the level of bacterial products were found to be higher on titanium than on zirconium oxide[8].

There are many studies about zirconia used for coping material in porcelain veneering technique but not about full zirconia crown. Compare to the layering technique, full zirconia crown shows higher strength and easier laboratory procedure. To prevent mechanical fracture of the full zirconia crown, the thickness of zirconia crown and proper sintering process should be considered. The amount of tooth reduction also is important.

Therefore, the purpose of this study was to investigate the influence of zirconia thickness for full zirconia crowns on fracture resistance.

2. Materials and Methods

2.1. Tooth preparation

An anatomically correct model of a mandibular first molar was scanned by 3D optical scanner (S600, Zirkonzahn, Italy). Then, the tooth preparation was generated to fabricate resin die using CAD software (Modellier, Zirkonzahn, Italy). The tooth preparation was modeled by reducing proximal walls by 1.2mm with 6 degrees of convergence angle. And reduction amount of occlusal surface was various from 0.5~2.5mm (Group I: 0.5mm, Group II: 1.0mm, Group III: 1.5mm, Group IV: 2.0mm, Group V: 2.5mm). The crown margin design was 0.8~1.0mm deep chamfer and all line angles were rounded. The CAD file of prepared tooth was imported to a milling machine (CAD-CAM M5, Zirkonzahn, Italy) and acrylic resin block (PMMA) was milled to fabricate the resin die (Fig. 1.).

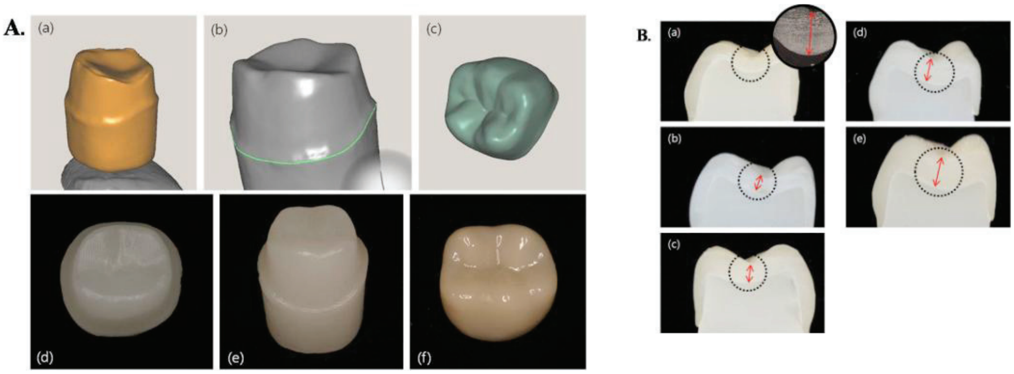

Fig.1. Resin die (A-a, b) and zirconia crown (A-c) design in CAD software (Modellier, Zirkonzahn, Italy). Manufactured resin die (A-d, e) and zirconia crown (A-f). The surface of bucco-lingual section shows different occlusal thickness of crowns (B-a-d).

2.2. Crown fabrication

Based on the data of plastic models in CAD software, crowns were designed fitting into each resin die. Specimens were classified into five groups by occlusal thickness. Zirconia blocks (Prettau zirkon CAD-CAM

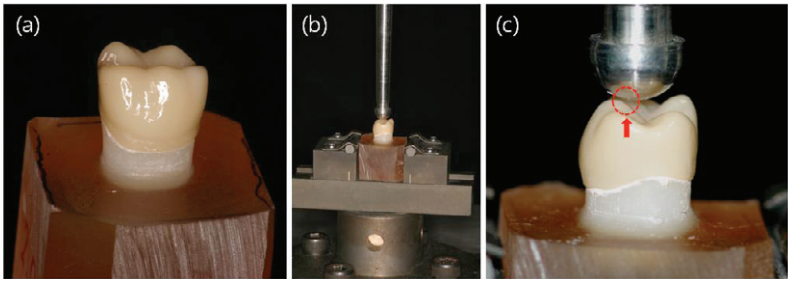

Fig.2. (a) Crown-tooth assembly embedded in acylic resin (EPOVIA® RF-9000, Cray valley Korea, Korea). (b and c) Apply single load-to-fracture to lingual aspect of disto-facial cusp of crown (arrow).

95H22, Zirkonzahn, Italy) were milled in partially sintered stage considering of 20% shrinkage and fully sintered for 12 hrs at 1600℃ thereafter. Sandblasting with 50 ㎛ aluminium oxide at 3 bars was employed and then outer surface of crown was glazed.

2.3. Crown cementation

The crowns were cemented using resin cement (RelyX Unicem, 3M/ESPE, USA) onto the each resin teeth following the manufacturer's instruction. The crown-tooth assembly was embedded in 25.4mm internal diameter PVC tubes using acrylic resin (EPOVIA® RF-9000, Cray valley Korea, Korea) as the potting material. The crown buccal margin was placed 2mm above the surface of the resin with the long axis of the crown-tooth assembly and tube aligned. Prior to mechanical testing, the specimens were stored in distilled water at 37℃ for at least 24 hrs to assure hydration and eliminate effect of water uptake dimensional expansion after crown cementation [9].

2.4. Fracture testing

The 5 crowns were subjected to single load-to-fracture each groups. For single load-to fracture, the specimens were mounted on the universal testing machine (AGS-1000D, Shimadzu, Japan). And load-to-fracture was applied through a 9mm stainless steel indenter on the lingual aspect of the disto-facial cusp at a rate of 1mm/min (Fig. 2). The load was applied until crowns broken. For fracto-graphic analysis using a field-emission scanning electron microscope(FE-SEM; S-4800, Hitachi, Japan), representative fractured samples were gold sputtered.

3. Results and Discussion

Table 1. shows fracture strength of zirconia crowns. According to the results, fracture strength increased with occlusal thickness of crown. Six specimens of each group were tested, and then mean fracture strength was calculated except values which was maximum, minimum and without the normal range. The mean fracture strength was calculated from group I, II and III. But in the group IV and V, measurement of fracture strength was impossible

Table.1. The mean fracture strength of zirconia crown.(specimens impossible to be measured were marked with **)

	Group I	Group II	Group III	Group IV	Group V
1	1730.87	**	1929.46	**	**
2	3184.71	3020.45	4589.51	2755.67	2865.99
3	2427.15	2949.35	**	**	**
4	2402.15	3405.36	4055.05	3199.42	**
5	2248.63	3353.87	4018.27	**	4488.99
6	3277.87	3275.42	3623.56	3574.52	4111.44
mean	2359.31	3216.58	3898.96	**	**

because potting materials were broken before zirconia crown fractured (specimens impossible to be measured were marked with **). In group IV and V, values were not measured or showed get out of the normal range. These could be improved using metal die instead of resin die. But using resin die which has modulus similar to the natural tooth was expected to present clinically significant results.

In ceramic restoration, porcelain fused to metal (PFM) technique has been used widely. The PFM crown consists of metal coping and porcelain veneered on the coping. For mechanical properties of crown, thickness of coping is required over 0.5mm and veneering porcelain 1.0~2.0mm, so aggressive preparation design is required. PFM is not used at region receive occlusal force due to its brittle properties. Allergy reaction could be caused by coping metal and final restoration could have color different with natural tooth due to metal color. So, in recent, to improve these disadvantages, zirconia which has strength similar to metal and esthetically good appearance is used widely. Compared with other ceramic restorations, it is possible to form thinner margin likely metal for zirconia coping. And color of restorations is more stable than of PFM. The biocompatibility is also good. Therefore, many studies about zirconia-ceramic restoration have been performed lively. Contrary to metal coping that go through the cast procedure, zirconia coping using CAD/CAM technology shows better margin fitting and has a little errors. As the development of CAD/CAM technology, crown is fabricated with only zirconia. Zirconia crown can be fabricated similar to the natural teeth and laboratory process reduced, so that error during laboratory process can be reduced. Compare to existing ceramic restoration requesting much tooth reduction, full zirconia crown needs less amount of reduction. In a result, the crown having 0.5mm occlusal thickness showed similar strength to PFM. This is considered to be useful for patients who have little inter-occlusal space.

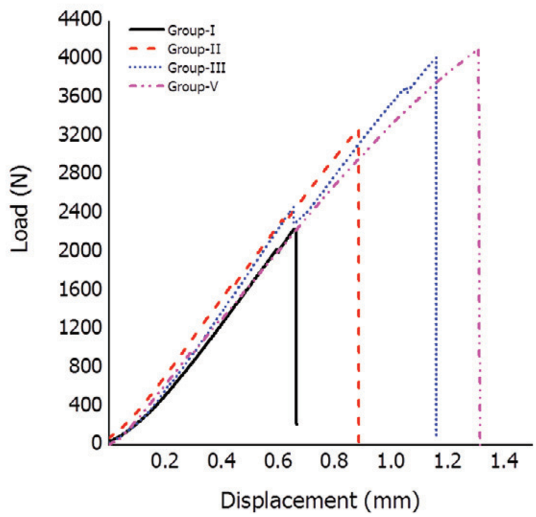

Fig.3. Load-displacement curve with thickness of crown.

Based on data of Table.1, load-displacement graph was drawn at Fig. 3. Slightly falling points of each graph were drawn when potting material deformed. And point when zirconia crown was broken out was where the graph sharply fallen down.

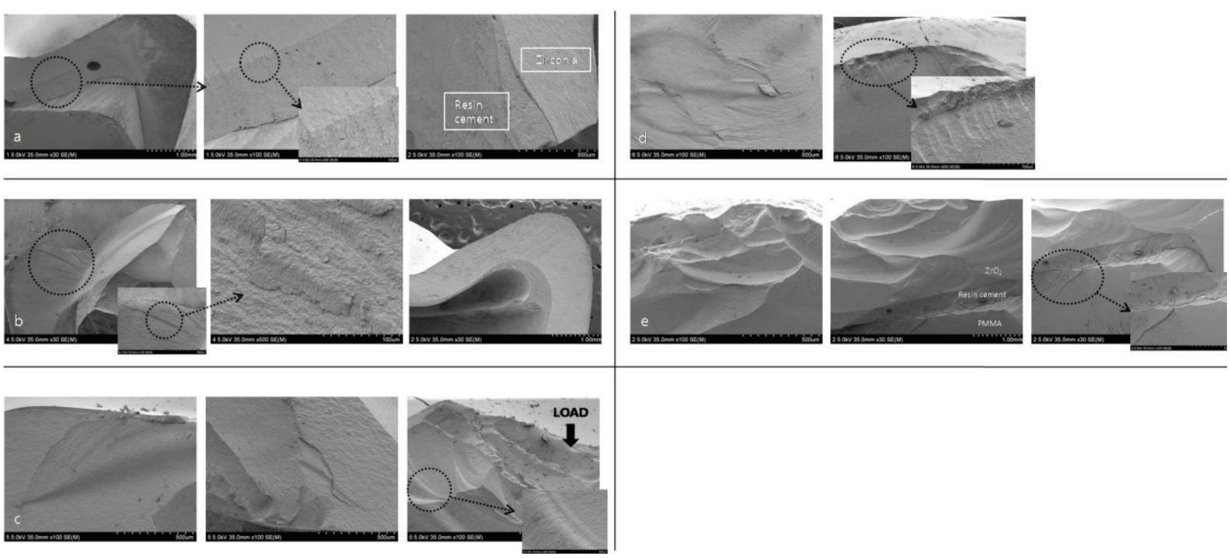

Fig.4. FE-SEM images of fracture surface. Bonding between crown and cement was maintained tightly (a). Occlusal fracture surfaces of crown from initial loading site. (a; Group A, b; Group B, c; Group C, d; Group D, e; Group E)

In fractography, it was observed crack propagation around the region received single load with radial shape. Image of group D and E were taken after specimens broken by an excessive load over the potting material fractured. All groups showed alike aspect of crack propagation. Compared to PFM failure mode which was chipping of veneering porcelain, full zirconia crown showed not chipping but bulk fracture. In crown segment, zirconia area was very dense and there were no cracks initiating from spherical pores as porcelain fracture [10]. Bonding between crown and cement was maintained with close combination and other fracture surface of crown appeared when received occlusal load (Fig. 4). From the Fig. 4, in the case of thin thickness of zirconia crown, fracture behavior was abruptly failed with cleavage surface, whereas in the case of over 2.0mm thickness of zirconia crown, fracture behavior was crack propagation with several steps. It is confirmed that over 2.0mm thickness of zirconia crown has the fracture strength that endures the occlusal force inhibited the crack growth and propagation.

4. Conclusions

The esthetic restoration would be received more attention and also zirconia would occupy a large part of restorative material. Within the limitations of this in vitro study, zirconia has shown favorable mechanical properties. According to this study, fracture strength of zirconia crown increased with occlusal thickness. Although fracture testing about Group D and E were not performed exactly, crowns have below 2.0mm occlusal thickness showed the strength that could be clinically useful. In particular, zirconia crown could be used for patients who have a little inter-occlusal space. The crown with 0.5mm occlusal thickness had fracture strength that endures the occlusal force. This means that aggressive preparation is not required for patient with a little inter-occlusal space. Later, possibility of hypersensitivity would be reduced and restorative tooth would be well preserved.

By using zirconia with CAD/CAM technology, it could be reduced that laboratory procedures make errors such as impression, wax up, casting etc. Also full zirconia crown technique could save the time to deliver restoration or adjust occlusal relationship. In total, full zirconia crown could save the time and patient's teeth.

If zirconia crown used widely, it would need the study about influence on opposing dentition. As porcelain could wear the opposing natural tooth, occlusal adjustment is significant in ceramic restoration. Zirconia has higher mechanical properties than glass ceramics so it is more important for full zirconia crown restoration.

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