ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 10 (2011) 1561–1566
Engineering Procedia

ICM11

Fracture Characteristics of Dental Ceramic Crown according to Zirconia Coping Design

H.Y.Cho[a], H.Y.Won[a], H.C.Choe[b], M.K.Son[c]*

[a]*School of Dentistry, Chosun University, Gwanju 501-759, Korea*
[b]*Department of Dental Materials, School of Dentistry, Chosun University, Gwangju 501-759, Korea*
[c]*Department of Prosthodontics, School of Dentistry, Chosun University, Gwangju 501-759, Korea*

Abstract

Fracture characteristics of the ceramic crown according to the zirconia coping design have been researched using various experimental methods. The 3D contour dimension of a mandibular first molar acrylic model tooth was scanned with Optical scanner (S600, Zirkonzahn, Italy), and then a classic crown preparation was created in CAD software (Zirkonzahn.Modellier, Zirkonzahn, Italy). The CAD file of the prepared tooth was imported into a milling machine, and acrylic resin (PMMA) dies were generated. Four different coping designs based on the thickness of zirconia marginal collar were used: 0.0mm zirconia collar (Group1), 0.5mm (Group2), 1.0mm (Group3), and 2.0mm (Group4). Copings were fabricated with CAD/CAM System (CAD CAM M5, Zirkonzahn, Italy) and veneering porcelain (IPS e.max Ceram) was build-up with layering technique. All the samples were cemented (RelyX Unicem, 3M/ESPE) onto corresponding dies. All specimens were tested in 4 groups (n=10 for each group) based on the thickness of zirconia collar. Fracture load test was performed on eight crowns from each group, and the remaining crowns (n=2) were subjected to fatigue test. Fracture strength was tested with a universal testing machine at a crosshead speed of 1.0mm/min to the vertical axis of the tooth 0.5mm lingually down the mesio-distal cusp. For the testing of fatigue failure, specimens were subjected to 50,000 cycles of cyclic loading 200 N, at a rate of 15Hz and then loaded dynamically at a crosshead speed of 1.0mm/min, until failure. Fracture location and fracture surface of failed crowns were observed with a field emission scanning electron microscope (FE-SEM S-4800, Hitachi, Japan).

Mean of fracture strength values of veneering porcelain were: 1411N for Group1, 1428N for Group2, 1596N for Group3 and 1621N for Group4. And according to increasing of thickness on zirconia collar, zirconia coping showed more fracture strength value with increasing of fracture strength of porcelain veneered it up. And examined using FE-SEM, two interesting features were shown from the fracture surface, sudden fracture and gradual fracture. And failure of specimens was mainly occurred by crack growth initiated from porosities within the veneering porcelain. In conclusion, according to the fracture test, the more thickness of zirconia collar, the higher fracture strength of veneering porcelain. Thus, zirconia coping design with 2.0mm marginal collar width is recommended for both functional longevity and esthetics of zirconia-ceramic restoration.

Selection and peer-review under responsibility of ICM11

Keywords: Crown; All-ceramic; Zirconia coping; Zirconia collar; Fracture strength; Chipping

* Corresponding author. Tel.: +82-62-220-3825; fax: +82-62-227-2363.
E-mail address: son0513@chosun.ac.kr.

Selection and peer-review under responsibility of ICM11 doi:10.1016/j.proeng.2011.04.261

1. Introduction

There are various restorative materials commercially available for replacement of single and multiple teeth [1]. With the increasing demand for esthetics, several all-ceramic materials and processing techniques have been introduced in the past decade [2]. All-ceramic restorations have several advantages, including life-like appearance [3], biocompatibility [4], wear resistance, and color stability [5, 6]. Disadvantages include less-than-ideal marginal adaptation, excessive wear of the opposing dentition, aggressive preparation design [3], technique sensitivity [7], and susceptibility to fracture [6]. Despite the biocompatibility and esthetic appeal of all-ceramic crowns, fracture of the veneer or the core material remains the major clinical reason for technical complications in the posterior region [8]. Especially, interproximal fracture of veneering porcelain is one mode of fracture [9] and makes clinical problem such as food impaction, loss of interdental papillae and esthetic problem etc.

Porcelain has low tensile strength around 35MPa (5,000 psi) and high compressive strength of 517 MPa (75,000 psi). Because of these physical properties, coping is important for functional longevity of the restoration [11]. Copings are designed to provide fracture resistance of the porcelain, and the porcelain is supported by the coping so that tensile or shear fractures can be minimized [11].

Zirconia can be used as a support material (especially in the posterior region) for esthetic restorations because of its biocompatibility [12], esthetic appeal as compared to visible metal [13] and high flexural strength [14]. The mechanical properties of zirconia are the highest ever reported for any dental ceramic [15]. The flexural strength of zirconia ranges from 800 to 1,000 MPa [15], and the shear strength of zirconia ceramics has been shown to be similar to that of metal ceramics [16]. Pogoncheff et al. [9] reported that extending zirconia collar to the interproximal area was useful to preventing interproximal porcelain fracture.

However, although some solutions with coping design have been provided for the metal ceramic crown, remarkably little scientific data on optimal zirconia coping design of dental ceramic crown has been studied. Therefore, the objective of this study was to investigate fracture characteristics of the ceramic crown according to the zirconia coping design using zirconia-ceramic molar crowns manufactured with CAD/CAM technology.

2. Materials and methods

2.1. Tooth preparation and master die fabrication

The 3D contour dimensions of a mandibular first molar acrylic model tooth was scanned with Optical scanner (S600, Zirkonzahn, Italy), then a classic crown preparation was created in CAD software (Zirkonzahn.Modellier, Zirkonzahn, Italy) into a 6 degree total convergence angle (3 degree on each side), a deep chamfer of 1.0mm, preparation height of 5mm, and 1.5-2.0mm occlusal reduction (Fig.1-a). The CAD file of the prepared tooth was imported into a milling machine (CAD/CAM M5, Zirkonzahn, Italy), and acrylic resin (PMMA) dies were generated, which were then used as a master die to fabricate all-ceramic crowns.

2.2. Specimens fabrication

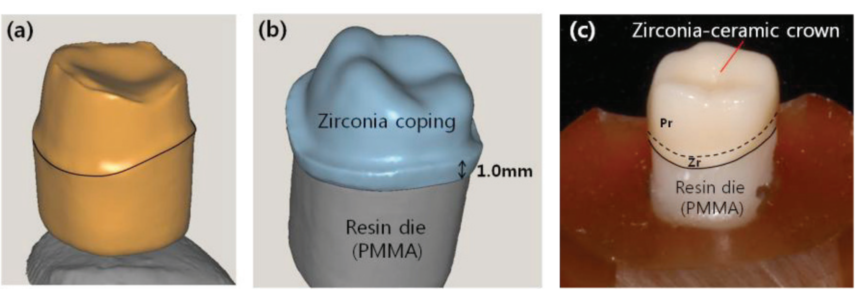

Fig. 1. (a) Preparation dimensions of the master die. (b) Zirconia coping design with 1mm marginal collar width (Group3). (c) Specimen fabricated for this study (Pr = Porcelain; Zr = Zirconia collar)

2.2.1. Zirconia coping design and fabrication

Four different coping design based on the thickness of zirconia marginal collar were used: 0.0mm zirconia collar (control), 0.5mm, 1.0mm and 2.0mm (Fig. 1-b), and the remaining surface, occlusal surface and axial walls, was designed to have thickness of 0.5mm. Total twenty-eight copings (n=7 for each group) were fabricated from zirconia blocks (Zirconia Translucent 95H10, Zirkonzahn, Italy) with CAD/CAM System (CAD/CAM M5, Zirkonzahn, Italy). All the copings were then placed on a firing tray and sintered in a furnace (Zirkonofen 600/V2, Zirkonzahn, Italy) for 12 hours at 1500 ℃. The inner surface of the copings was sandblasted with 50 ㎛ aluminum oxide at 3 bar pressure, rinsed and dried.

2.2.2. Porcelain build-up

The sintered copings were veneered with porcelain (IPS e.max Ceram) by a skilled dental technician following manufacturer's instruction. Then the specimens were fired in a vacuum furnace (Programat P300; Ivoclar Vivadent AG, Schaan, Liechtenstein) for 30 min. at 720℃.

2.2.3. Cementation

All the samples were cemented (RelyX Unicem, 3M/ESPE) onto the corresponding dies. Mixing and cementing procedures were performed at room temperature according to the manufacturer's instructions. The crowns were initially seated on their respective dies using finger pressure and the excess cement was removed.

After cementation, the specimens were embedded in acrylic resin (Epovia, Cray valley) in a 1 inch diameter PVC tube. The crown buccal margin was placed 2mm above the surface of the resin, with the long axis of the crown-tooth replica and tube aligned (Fig. 1-c). The specimens were stored for 24 hours in distilled water at 37℃.

2.3. Fatigue and fracture tests

All specimens were tested in 4 groups (n=10 for each group) based on the thickness of zirconia collar: 0.0mm (group1), 0.5mm (group2), 1.0mm (group3) and 2.0mm (group4). Fracture load test was performed on eight crowns from each group, and the remaining crowns (n=2) were subjected to fatigue test.

For fracture load test, the samples were mounted in a universal testing machine (AGS-1000D, Shimadzu, Japan), and a stainless steel ball 9.0mm in diameter was placed on the lingual aspect of the distobuccal cusp (0.5mm lingual to the cusp tip) with a crosshead-speed of 1.0mm/min. And for the testing of fatigue failure (subgroup2), the samples were positioned in a Fatigue testing machine (ADT-AV01K1N, Shimadzu, Japan), and a tungsten carbide (WC) indenter 6.25mm in diameter was placed at the same area of the crowns. The cyclic load was set at 200N to simulate a clinical posterior occlusal biting force [17], at a rate of 15Hz. A previously performed pilot study has shown that the rapid rate of decline in strength leveled off after 50,000 cycles of loading [18]; hence, this number of cycles was selected for the fatigue test. Fatigue testing was followed by dynamic loading, at a crosshead speed of 1.0 mm/min until catastrophic failure occurred.

Fractured surface of failed crowns were observed with a field emission scanning electron microscope (FE-SEM S-4800, Hitachi, Japan).

3. Results and Discussion

Clinically, all-ceramic restorations commonly fail through slow crack growth resulting from fatigue cased by masticatory stresses [9]. Veneering porcelain is weaker compared to the core material, so it fails at low loads when it is placed under tension [19] resulting in marginal chipping or fracture. Based on concepts found in literature about metal-ceramic restoration, the use of a zirconia collar may provide support for veneering porcelain. However, management of the facial marginal area with zirconia can be an esthetic problem because the translucency

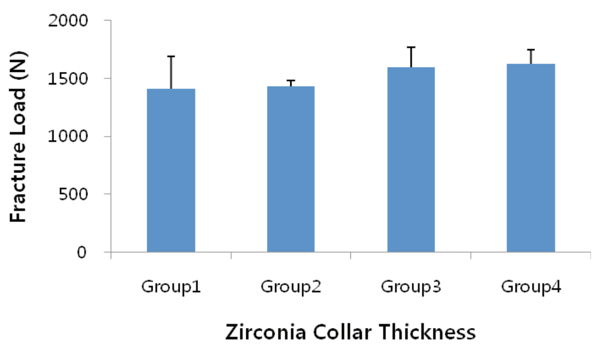

Fig.2. Mean values of fracture strength (N)of veneering porcelain with collar thickness. Lines at top of bars represent standard error.

of zirconia is poor compared to that of porcelain or natural teeth. Therefore, the present study was undertaken to investigate fracture characteristics of the ceramic crown according to the design of zirconia marginal collar and provide the clinician with data for dental applications.

Table 1. The values of upper yield strength and maximum strength of Fig. 3.

	Group1 (0mm)	Group2 (0.5mm)	Group3 (1.0mm)	Group4 (2.0mm)
Upper yield strength	1301.83	1473.45	1836.30	1777.46
Maximum load	1341.06	1505.32	1841.20	2299.66

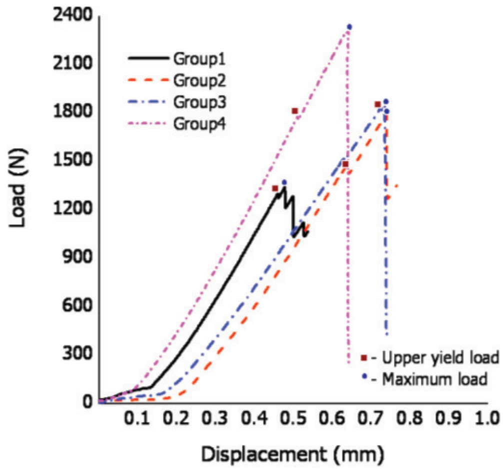

Fig. 3. Load-displacement curves of veneering porcelain with collar thickness.

3.1. Fatigue and fracture tests

Fracture strength of veneering porcelain for the 4 zirconia-ceramic crowns are presented in Fig. 2. Group1 (0.0mm zirconia collar) had the lowest mean strength value, 1411N, and Group4 (2.0mm) had the highest strength value, 1621N. The other mean strength values were: 1428N for Group2 (0.5mm) and 1596N for Group3 (1.5mm). The results of the present study revealed that the more thickness of zirconia collar, the higher fracture strength of veneering porcelain. When static or cyclic load is applied to occlusal surface of the crown, the stresses are transferred to the marginal area of veneering porcelain. Although porcelain is brittle material which is prone to chip-off, zirconia collar has supporting function and plays an important role in preventing the fracture or chipping of the veneering porcelain.

Load-displacement curves of the representative of each group are described in Fig. 3 and the values of upper yield load and maximum load are shown in Table 1. Upper yield point is the point in the load-displacement curve at which the fracture of veneering porcelain occurred. Generally, porcelain strength depended on zirconia coping and collar thickness. From the load-displacement curves, upper yielding strength increased as collar thickness of zirconia coping. It is confirmed that stress is transferred to collar and then, shielded at collar. Therefore, in the case of high thickness of collar, fractured strength was higher than that of lower thickness of collar. And maximum strength is the point when the catastrophic fracture of zirconia coping occurred. Based on those facts, zirconia coping,

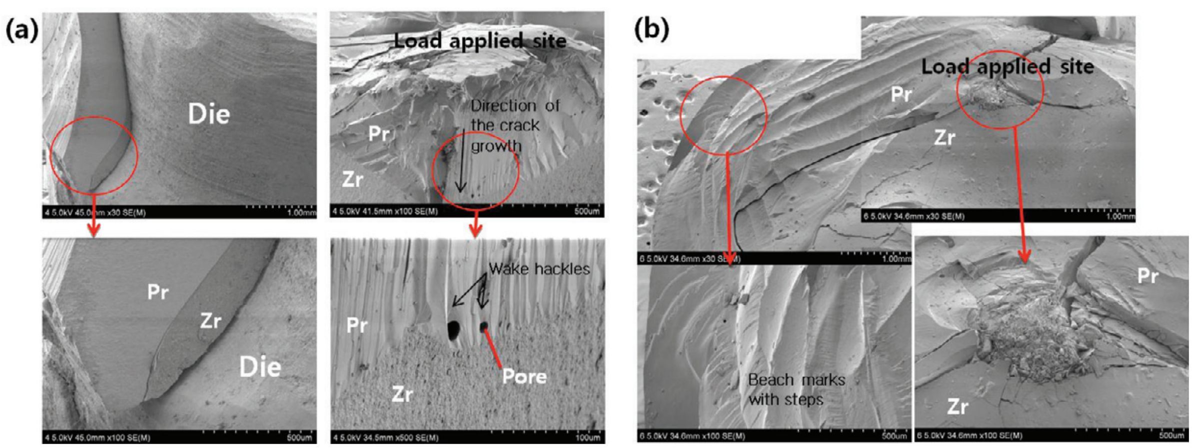

Fig. 4. FE-SEM image showing the fracture surface of Group 1(a); sudden fracture and Group 2(b); gradual fracture (Pr = Porcelain; Zr = Zirconia)

according to increasing of thickness on zirconia collar, showed more fracture strength value with increasing of fracture strength of porcelain veneered it up.

3.2. Microscopic analysis

Examined using FE-SEM, two interesting features were shown from the fracture surface, sudden fracture and gradual fracture (Fig. 4). When static load was applied through outer surface of the veneering porcelain, cracks initiated from the point of load application by the indenter and from porosity within the veneering porcelain. Wake hackles were formed as the crack passes pores present inside of the ceramic, indicating the direction of the crack growth, and the cracks propagated toward the direction perpendicular to major stress axis, and sudden fracture finally occurred through the whole crown thickness (Fig. 4-a). There were no signs of major interfacial failure between the zirconia coping and the porcelain veneer. The other feature of fracture surface, a gradual fracture, are shown in figure 4-b. The fatigue failure was preceded by a combination of crack initiation and crack propagation. When cyclic loading was applied to the porcelain, micro-cracks were initially formed by fatigue stress. Delamination of veneering material was then occurred making special appearance, beach marks with steps and exposure of zirconia core material. From the Fig. 4, in the case of no collar of zirconia, fracture behavior was abruptly failed with cleavage surface, whereas in the case of high thickness of zirconia collar, fracture behavior was low crack propagation rate, gradually. It is confirmed that zirconia collar plays an important role in inhibiting the crack growth and propagation.

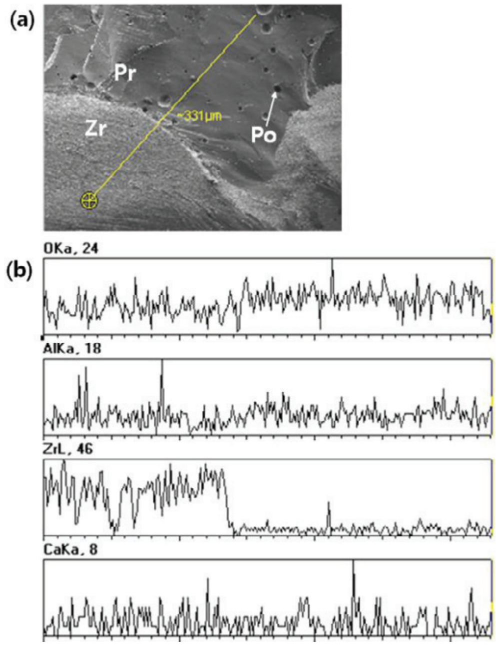

Fig. 5. SEM image and its line profile of fracture surface showing two layers of veneered porcelain and zirconia coping (Pr = Porcelain; Zr = Zirconia; Po = Pore)

Fracture of all-ceramic restoration is very complicated process which could be related to a combination of different reasons including the dimensions of core and veneer materials, inherent and processing defects within the porcelain and the preparation design [20]. The results from these microscopic analysis showed some fracture reasons in ceramic restorations. Processing-related porosities of porcelain are formed by loss of water when it is fired in furnace (Fig. 5-a), and cracks are initiated from these inherent flaws. Oram et al. [21] reported that occasional presence of pores inside the ceramic could account for the weakness and eventual fracture of ceramic at that site. And in an evaluation of internal defects of some porcelain, Oilo [22] also reported that porosities which are generated through firing schedule markedly increase the failures of restoration. Considering the porosities plays an important role in initiating crack growth, a technique which can minimize the formation of porosity is needed during porcelain build-up process.

4. Conclusions

- From the load-displacement curves, fracture strength of veneering porcelain showed 1411N for Group1, 1428N for Group2, 1596N for Group3 and 1621N for Group4. The more thickness of zirconia collar, the higher fracture strength of veneering porcelain. Upper yielding strength increased as collar thickness of zirconia coping. Thus, zirconia coping design with 2.0mm marginal collar width is recommended for both functional longevity and esthetics of zirconia-ceramic restoration. And maximum strength is the point when the catastrophic fracture of zirconia coping occurred.
- From the fractured surface, in the case of no collar of zirconia, fracture behavior was abruptly failed with cleavage surface, whereas in the case of high thickness of zirconia collar, fracture behavior was low crack propagation rate, gradually. Thus, zirconia collar plays an important role in inhibiting the crack growth and propagation.

- Fracture of all-ceramic restoration is related to a combination of different reasons including the dimensions of core and veneer materials, inherent and processing defects within the porcelain and the preparation design. Porosities acted to the site of crack initiation and growth from within the veneering porcelain. Therefore, a technique which can minimize the formation of pores is needed during porcelain build-up process.
-

References

[1] Shirakura A, Lee H, Geminiani A, Ercoli C, Feng C. The influence of veneering porcelain thickness of all-ceramic and metal ceramic crowns on failure resistance after cyclic loading. J Prosthet Dent 2009;101:119-127.

[2] Yilmaz H, Aydin C, Gul BE. Flexural strength and fracture toughness of dental core ceramics. J Prosthet Dent 2007;98:120-128.

[3] Mettam GR, Adams LB. How to prepare an electronic version of your article. In: Jones BS, Smith RZ, editors. Introduction to the electronic age, New York: E-Publishing Inc; 1999, p. 281–304

[4] Sjogren G, Sletten G, Dahl JE. Cytotoxicity of dental alloys, metals, and ceramics assessed by millipore filter, agar overlay, and MTT tests. J Prosthet Dent 2000;84:229-236.

[5] Siervo S, Pampalone A, Siervo P, et al. Where is the gap? Machinable ceramic systems and conventional laboratory restorations at a glance. Quintessence Int 1994;25:773-779.

[6] Zahran M, El-Mowafy O, Tam L, Watson PA, Finer Y. Fracture Strength and Fatigue Resistance of All-Ceramic Molar Crowns Manufactured with CAD/CAM Technology. Journal of Prosthodontics 17 (2008) 370–377.

[7] Blatz MB. Long-term clinical success of all-ceramic posterior restorations. Quintessence Int 2002;33:415-426.

[8] Pjetursson BE, Sailer I, Zwahlen M, Hammerle CH. A systematic review of the survival and complication rates of all-ceramic and metalceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. Clin Oral Impl Res 18(Suppl 3):73-85; erratum in Clin Oral Impl Res 19:326-328, 2008.

[9] Pogoncheff CM, Duff RE. Use of zirconia collar to prevent interproximal porcelain fracture: A clinical report. J Prosthet Dent 2010;104:77-79.

[10] O'Brien WJ. Dental materials and their selection. 4th ed.: Quintessence Pub Co;2009;pp.215.

[11] Hobo S, Shillingburg HT Jr. Porcelain fused to metal: tooth preparation and coping design. J Prosthet Dent 1973;30:28-36.

[12] Bianchi AE, Bosetti M, Dolci Jr G, Sberna MT, Sanfilippo F, Cannas M. In vitro and in vivo follow-up of titanium transmucosal implants with a zirconia collar. Journal of Applied Biomaterials & Biomechanic 2004;2:143–150.

[13] Tan PL, Dunne JT Jr. An esthetic comparison of a metal ceramic crown and cast metal abutment with an all-ceramic crown and zirconia abutment: a clinical report. J Prosthet Dent 2004;91:215-8.

[14] Kosmac T, Oblakb C, Jevnikarb P, Fundukb N, Marion L. The effect of surface grinding and sandblasting on flexural strength and reliability of Y-TZP zirconia ceramic. Dental materials 1999;15:426-433.

[15] Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater 2008;2:299–307.

[16] Al-Dohan HM, Yaman P, Dennison JB, Razzoog ME, Lang BR. Shear strength of core-veneer interface in bi-layered ceramics. J Prosthet Dent 2004;91:349-55.

[17] Proebster L. Compressive strength of two modern all-ceramic crowns. Int J Prosthodont 1992;5:409-14.

[18] Chen HY, Hickel R, Setcos JC, Kunzelmann KH. Effects of surface finish and fatigue testing on the fracture strength of CAD-CAM and pressed-ceramic crowns. J Prosthet Dent 1999;82(4):468–75.

[19] Kelly JR, Tesk JA, Sorensen JA. Failure of all-ceramic fixed partial dentures in vitro and in vivo: analysis and modelling. J Dent Res 1995;74(6):1253–8.

[20] Friedlander LD, Munoz CA, Goodacre CJ, Doyle MG, Moore BK. The effect of tooth preparation design on the breaking strength of Dicor crowns: part 1. Int J Prosthodont 1990;3(2):159–68.

[21] Oram DA Davies EH, Cruickshanks-Boyd DW. Fracture of ceramic and metalloceramic cylinders. J Prosthet Dent 1984;52(2):221-30.

[22] Oilo G. Flecural strength and interanal defects of some dental porcealins. Acta Odontol Scand 1988;46:313-22.