Original Article

pISSN, eISSN 0125-5614
M Dent J 2017; 37 (1) : 7-14

Fracture resistance of implant supported all ceramic zirconia-lithium disilicate crowns

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Objectives: The objectives of this study were to evaluate the effects of different veneering methods and the effects of different sizes of abutment on the fracture resistance of the crowns, and to assess the mode of failure of these crowns.

Materials and methods: A hundred and eight implant abutments (Straight 3.5/4.0 TiDesignTM, AstraTech Dental) were fabricated into 3 groups with different sizes of abutments [Ø4.5 (s), Ø5.5 (m), and Ø6.5 (l)]. Each group of implant abutments contained 3 subgroups of 12 specimens each (n=12). Zirconia frameworks were fabricated on all implant abutments. Various veneering materials were then applied and processed on the zirconia frameworks. Fluorapatite veneering ceramics were used as the control group (ZAC). Lithium disilicate crowns were fabricated as the veneering layer on the zirconia frameworks with different procedures: group A bonded via fired Crystal/Connect glass ceramic (FCC) and group B bonded via resin cement (BRC). Resin cement was used for cementation. All specimens were placed in a thermocycling unit and tested with a universal testing machine. Statistical analyses were performed by using two-way ANOVA and Tukey B test.

Results: The mean of fracture resistance in the ZAC group was at the highest value (1787-3295N) of cohesive failure. The mean fracture resistance of the FCC group (1714-2809N) was higher than that of the BRC group (1565-1809N). The mean fracture resistance of the abutment diameter 5.5 mm (m) was at the highest value. The largest size of abutment (l) had a mean fracture resistance higher than the smallest size of abutment (s). The two main factors, veneering method and abutment size, had individual effects on fracture resistance. There were significant differences of fracture resistance in all groups with different veneering methods and different sizes of abutment. Adhesive failure was found in the BRC group. Meanwhile the FRC group was found to have both adhesive and combination failure.

Conclusion: The mean fracture resistance of crowns fused with Crystal/Connect was significantly higher than that of crowns bonded with resin cement, but all the crowns had adequate fracture resistance to be used as implant supported restorations in the posterior region.

Key words: fracture resistance, lithium disilicate, zirconia, veneering method, implant abutment

How to cite: Chitmongkolsuk S, Eiampangpaiboon T, Bunyasresth N, Kanchanavasita W. Fracture resistance of implant supported all ceramic zirconia-lithium disilicate crowns. M Dent J 2017; 37: 7-14.

Introduction

Nowadays dental implants have been widely used as implant therapy for replacing missing teeth. The assessment 10-year outcomes of titanium implants in retrospective study demonstrated a 10-year implant survival rate of 98.8% and a success rate of 97.0% [1]. A systematic review evaluated the incidence of technical complications that can be divided into the major level; such as implant fracture, loss of suprastructures, the medium level; such as abutment fracture, veneer or framework fractures, esthetic and phonetic complications and the minor level; such as

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Received : 16 December 2016 Accepted : 15 February 2017

abutment and screw loosening, loss of retention, loss of screw hole sealing, veneer chipping and occlusal adjustments. The most common technical complications by implant-supported reconstructions were fractures of veneer material (acrylic, ceramic and composite), abutment or occlusal screw loosening and loss of retention (fracture of the luting cement). Comparing the rate of ceramic fracture or ceramic chipping, the implant-supported fixed dental prostheses had a significantly higher than the tooth-supported fixed dental prostheses. Although framework fracture of the reconstruction was a rare complication. The implant-supported single crowns had high rate fracture of the crown framework (coping). This technical complication was significantly higher in all-ceramic crowns [2]. Further clinical investigations have shown the long-term outcomes with implant-supported restorations. Ceramic chipping was the most frequent complication and was higher rates of fractures in dentitions with attrition and in fixed dental prostheses when compared with single crowns [3].

In dentistry, the esthetic expectation has led to development of ceramics for esthetic capability, biocompatibility, color stability, wear resistance, and low thermal conductivity. During the past decade, limitations of ceramic properties are brittleness and less resistant to tensile forces, which has limited their use for long time. For all of these limitations of ceramic properties, ceramic is superior esthetic appearance but its mechanical properties are not as well as conventional metal material in posterior region. However, zirconia has been newly introduced for fabrication of restorations in prosthetic dentistry with CAD/CAM techniques. The fracture resistance of zirconia was about twice as high compared to alumina [4-7]. Zirconia showed better mechanical properties and superior resistance to fracture than other conventional dental ceramics but the use of monolithic zirconia fixed dental prostheses is the possible abrasiveness of the material toward enamel. Thus, it has been an alternative framework for fixed dental prostheses. Lithium disilicate was used to be veneering material with various methods to bond between veneer and zirconia framework [8,9]. Furthermore, Stimmelmayr et al. reported that the fracture strength of the implant abutment increased with the implant diameter [10]. The aim of this in vitro study were to evaluate the effect of different veneering method and the effect of different abutment size on the fracture resistance of the all ceramic zirconia-lithium disilicate crowns, and to assess the mode of failure of these crowns. It was hypothesized that there were no difference in fracture resistance and mode of failure of different veneering method and different abutment size of implant supported all ceramic zirconia-lithium disilicate crowns.

Materials and methods

Three implant abutments (Straight 3.5/4.0 TiDesignTM, Astra Tech Dental) with 3 emergence profiles (Ø = 4.5, 5.5 and 6.5 mm) were used as model to fabricate the replica abutments. Each implant abutment (Ø = 4.5, 5.5 and 6.5 mm) and implant analog was duplicated to construct the impression mold. Pattern resins (GC dental, Tokyo, Japan) were poured to impression mold and putty index was used to connect between abutment part and analog part. After that, all pattern resins were sent to dental laboratory for casting with cobalt-chromium alloy (Figure 1). A total of 108 implant abutments were fabricated with three different diameters of implant abutments.

All crowns were controlled in standardized dimensions of mandibular first molar (mesio-distal width = 11.9 mm, bucco-lingual width = 11.1 mm, occlusal thickness at central fossa = 1.5 mm). ZirCAD frameworks (IPS e.max ZirCAD, Ivoclar Vivadent, Liechtenstein) were fabricated on all implant abutments. Each group of implant abutments was divided into 3 subgroups of 12

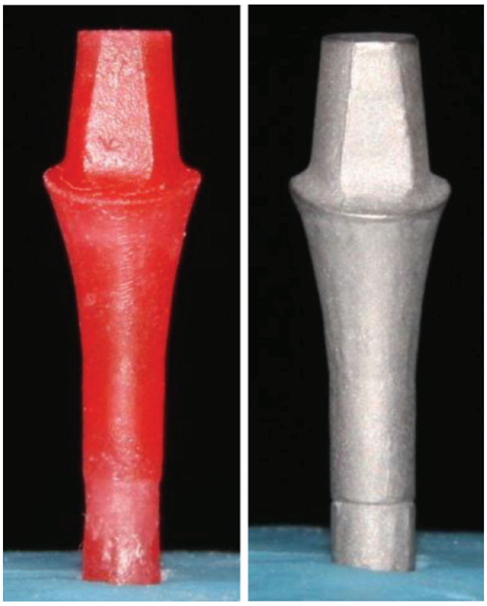

Figure 1 Pattern resin and casted replica abutment

specimens each (n=12). Various veneering materials were then applied and processed on the ZirCAD framework. Lithium disilicate crowns (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein) were fabricated as veneering layer on ZirCAD framework with different procedures; group A bonded via fired Crystal/Connect glass ceramic and group B bonded via resin cement. Fluorapatite veneering ceramics (IPS e.max Ceram, Ivoclar Vivadent, Liechtenstein) were used as the control group (group C).

Self-curing luting cement (Multilink N, Ivoclar Viradent, Liechtenstern) was used to bond the restorative crowns to the replica abutments. All specimens were embedded in a self-polymerizing resin block (PVC ring Ø = 18 mm, height 25 mm). After 24 hours of cementation, all specimens were exposed to 10,000 thermal cycles of 5ºC and 55ºC, with a 30 second dwell-time at each temperature. Then all specimens were tested with universal testing machine at a consistence crosshead speed of 1.0 mm/min. The maximum load was recorded when crown has fractured. Failure modes of all specimens were analyzed at the fracture sites under visual observation, optical light microscope, or scanning electron microscope (if necessary).

Statistical Analyses

The values of mean and standard deviation of fracture resistance were analyzed in each group of specimens. The effect of different veneering methods and the effect of different size of abutment on the fracture resistance of the crowns were analyzed by using TWO-WAY ANOVA and Tukey B tests. All statistical tests were performed at α = 0.05.

Results

After thermocycling 10,000 cycles, fracture resistance of all crowns was determined. Mean and standard deviation in each group are shown in Table 1.

To estimate means of fracture resistance in material types of 3 groups, fracture resistance of control group (Zirconia based All-Ceramic) was the highest values. In test group, fracture resistance of test group A (Fusion with Crystal/ Connect) was higher than fracture resistance of test group B (Bonding with Resin cement). There were significant differences in fracture resistance in 3 types of materials.

Table 1 Mean and standard deviation of fracture resistance (in Newton) of crowns with different designs (n=12)

	Ø 4.5 mm (s)	Ø 5.5 mm (m)	Ø 6.5 mm (l)
Fusion with Crystal/Connect (FCC)	1714 ± 508	2809 ± 1073	2293 ± 788
Bonding with Resin Cement (BRC)	1565 ± 229	1809 ± 22	1788 ± 93
Zirconia based All-Ceramic (ZAC)	1787 ± 292	3295 ± 986	2851 ± 733

To compare means of fracture resistance in abutment diameter, fracture resistance of abutment diameter 5.5 was the highest values when compare with larger size of abutment (6.5 mm) and smaller size of abutment (4.5 mm). However, the largest size of abutment (6.5 mm) had the means of fracture resistance higher than the smallest size of abutment (4.5 mm). There were significant differences of fracture resistance of crowns in different sizes of abutment.

Failure mode analyses

Failure types in each group were shown in Table 2.

In test group A (Fusion with Crystal/Connect - FCC), there were both types of failure mode. Twenty-four samples of group FCC were found adhesive failure at framework and veneering interface, and twelve samples of group A were found combination of adhesive and cohesive failure. On the other hand, all samples in test group B (Bonding with Resin cement - BRC) were found adhesive failure at framework and veneering interface. In control group (Zirconia based all ceramic - ZAC), most of failure mode was cohesive failure within veneering layer. Except in group 6.5 mm, they were found combination of adhesive and cohesive failure.

Discussion

All-ceramic crowns have been used popularly in both anterior and posterior area due to the esthetic property. However, the physical properties of all-ceramic crowns are weak and brittle [11-15]. To reinforce the fracture resistance of all-ceramic, zirconia has been used to fabricate the crown [12]. Some studies found veneer chipping was the most common complication in veneered zirconia crown [4,16]. The use of monolithic zirconia or lithium disilicate crown can reduce the incidence of veneering failure because of the superior mechanical properties than feldspatic ceramic [17-19]. The monolithic full anatomic design showed superior fracture resistance behavior when compared to bi-layered crowns. Moreover, adhesive failure was found in bi-layered restorations. Some cracks propagated parallel to the interface with a thin layer of porcelain remained between the cracks and the interface [18-19]. However, full contour of zirconia material has effect to wear of the opposing teeth due to the hardness of zirconia. In addition, surface of feldspathic ceramic was roughens after using, which caused the exposure of the crystalline structure and increased the rates of natural tooth

Table 2 Mode of failure of crowns with different designs

Material types	Abutment diameter	Mode of failure (%)		
		Adhesive	Cohesive	Combination
Fusion with Crystal/ Connect (FCC)	4.5 mm (s)	75%	-	25%
	5.5 mm (m)	58.33%	-	41.67%
	6.5 mm (l)	66.67%	-	33.33%
Bonding with Resin Cement (BRC)	4.5 mm (s)	100%	-	-
	5.5 mm (m)	100%	-	-
	6.5 mm (l)	100%	-	-
Zirconia based All-Ceramic (ZAC)	4.5 mm (s)	-	100%	-
	5.5 mm (m)	-	100%	-
	6.5 mm (l)	-	83.33%	16.67%

wear with time using [20]. To minimize abrasion of the natural opposing teeth and avoid initiation and progression of microcracks, smooth surface of ceramic was concerned by polishing and glazing [21]. Thus, lithium disilicate was appropriate restorative material to use as veneering layer on zirconia framework because mechanical properties of lithium disilicate were superior to those of feldspathic ceramics. It was approximately three times as strong as feldspathic ceramics. [17] Therefore, various techniques of CAD/CAM based fabrication of the framework and attachment of the veneering materials have been proposed. The accuracy of CAD/CAM production can reduce hand-layered veneer defects from human errors and increase the mechanical properties of the veneers [22-23]. In this in vitro study, lithium disilicate with glazing surface was used as veneer on zirconia framework. Substructures of 3 different abutment sizes were controlled with same thickness in anatomical shape. Various veneering layers of all crowns were controlled in standardized dimension from scanning model in the CAD process. The cement spaces (10-60 μm) were within the range of clinical acceptance [24]. There was no significant effect of variation of gap thickness [25]. The proper cement spaces in this in vitro study were 60 μm for framework gap and 40 μm for veneering gap. Nesse et al. reported that the milled group had better marginal fit than the cast group with no differences in seating within 2 groups [26].

The aims of this study were to assess the fracture resistance and the mode of failure of the implant supported all ceramic zirconia-lithium disilicate crowns. It was reported that the biting force of healthy and young adults in the posterior region was approximately 597 N for female and 847 N for male with a maximum of about 900 N [27-28]. Ferrario et al. reported an average posterior biting forces of 700N [29]. From the result of this study, the means of fracture resistance in 9 subgroups (>1,500N) were higher than the reported maximum of human biting force. However, the result might not represent the clinical situation for only a perpendicular force was applied. For better understanding of the fracture resistance of the tested materials, other impact factors, i.e. lateral force, thermocycling and emergency risks would be considered.

In this study, we found that there were significant differences of fracture resistance in 3 types of materials. Similarly, Schmitter et al. reported the higher value of fracture resistance in fused lithium disilicate veneer to zirconia frameworks group (1388 ± 190 N) when compared to luted veneer group (1211 ± 158 N) [30].

When compare the means of fracture resistance in abutment diameter, fracture resistance of group supported by abutment diameter 5.5 mm was the highest values. However, the group supported by the large size of abutment, 6.5 mm had the means of fracture resistance higher than those supported by the small size abutment, 4.5 mm. There were significant differences of fracture resistance of crowns in different sizes of the abutment. It might be explained that abutment size 5.5 mm would be the most suitable design of crown thickness. Larger abutment size had an effect in fracture resistance due to the reduction of crown thickness. As well as, smaller abutment size could reduce the fracture resistance of restorative crowns due to less support of implant abutment. Furthermore, the abutment size 4.5 mm had the step at inner surface of zirconia substructure. This is the technical error in limitation of milling bur that need to be polishing before sintering. So it might lead the weak point in group of abutment size 4.5 mm.

Regarding the mode of failure, we found in this study, the cohesive failure within veneering layer was mostly found in the control group (Zirconia based all ceramic). Kim et al. reported that fractures in veneered layer were occurred in veneered zirconia crowns as a posterior implant-supported restoration that using the hand layer technique same as the control group [31]. In a test group of our study, test group A (Fusion with Crystal/Connect) was found both types of failure modes, adhesive failure and combination failure. Whereas, test group B (Bonding with Resin cement) was found only adhesive failure at framework and veneering interface. Correspondingly, the previous paper found that a mixed failure mode was occurred with the fused crown, while adhesive failure between the veneer and Multilink Implant cement was occurred in the luted crown [30]. Zahran et al. showed zirconia bi-layered crowns fractured in the veneering layer, as the cracks reached the interface and arrested, extended laterally parallel to the interface, with the core exposed [32]. Likewise, spindle shaped voids, which were clearly evident under the central fossa, may be the crucial factor that weakens the bi-layered composite and leads to adhesive failure [33]. It might be explained that the interface became weak point when the void defects were present.

In the present study, the lithium disilicate veneer layers were cemented to zirconia core by either fusion technique (Fused with Crystal/ Connect) or luting technique (Bonding with resin cement). The fracture resistance of group with fusion technique were superior than group with luting technique. It might be the negative effect that occurred at the initial point of the fracture at the interface between resin cement and ceramic. However, the fusion technique had cost due to required additional specific materials. Also, this technique revealed the catastrophic fracture from veneered layer to zirconia framework. On the other hand, the luting technique requires the available material, resin cement. Furthermore, in case of veneer fracture, it occurred with still intact zirconia substructure. Thus, it would be possible to repair those crowns with this technique.

The limitation in this study would be that the software (inLab 3D software) had limitation to construct the multilayer design technique with anatomical shape of substructure due to characteristic of implant abutment. Subsequently, it needed to be constructed the substructure in each group of abutment size by manual. Furthermore, another human error was occurred while removing the large spur at outer surface of zirconia substructure. This might be increasing the cement gap between substructure and veneering layer.

In conclusion, the mean fracture resistance of crowns fused with Crystal/Connect was significantly higher than that of crowns bonded with resin cement, but all the crowns have adequate fracture resistance to be used as implant supported restorations in posterior region. There were significant differences of fracture resistance of crowns in different sizes of abutment. Abutment diameter 5.5 mm would be a suitable size as it showed the highest value of fracture resistance.

Acknowledgement: None
Funding: None
Competing interests: None
Ethical approval: None (Laboratory study)

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