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ORIGINAL ARTICLE

Comparison of Fracture Toughness of All-Ceramic and Metal–Ceramic Cement Retained Implant Crowns: An In Vitro Study

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Abstract To evaluate the fracture toughness of cement-retained implant-supported metal–ceramic molar crown with that of all-ceramic crowns, fabricated using IPS Empress 2 and yttria-stabilized zirconia copings. An dental implant and abutment was embedded in a clear polymethyl methacrylate model. A wax pattern reproducing the anatomy and dimension of a mandibular molar was made using inlay wax. Copings were made from the manufacturers guidelines for zirconia, metal ceramic and empress crown, in total of 21 copings, which were built for the crowns with metal layering ceramics specified by the manufacturers. The polymethylmethacrylate block-implant abutment complex was mounted on universal testing machine, and a static continuos vertical compressive load with a crosshead speed of 0.5 mm/min was applied. The breaking load and the peak load (in kilo Newtons) were recorded. The fractures for group I (zirconia–ceramic) and group II (metal–ceramic) occurred on the mesio-buccal aspect of the crowns involving the veneered ceramic layer while the catastrophic/bulk fracture was not observed. The mean value of breaking load for zirconia–ceramic, metal–ceramic and IPS-empress 2 was 3.4335, 3.071 and 1.0673 kN respectively. The mean value of peak load for zirconia–ceramic, metal–ceramic and IPS-empress 2 was 4.7365, 3.2757 and 1.566 kN respectively. It can be concluded that the zirconia–ceramic crown with the fracture toughness of 4.7365 ± 2.2676 kN has sufficient strength to allow clinical testing of these crowns as an alternative for metal–ceramic crowns (3.2757 ± 0.4681 kN).

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Introduction

The success of osseointegrated dental implants has revolutionized dentistry over the last few decades [1]. With more than three decades of evidence to support the clinical use of osseointegrated dental implants made of pure titanium, it is possible to confidently confirm that these implants are predictable and provide patients with long-term functional tooth replacement [2, 3]. This is a remarkable accomplishment, considering the many challenges and stresses that the oral environment and forces of mastication present for dental implants.

Despite various restorative options available for crowns, metal–ceramic restorations are frequently used for prosthetic rehabilitation of osseointegrated implants [4]. Its been reported that metal–ceramic restorations during eccentric excursions do experience technical complications [5]. In a systematic review, when used as implant-supported restoration, the cumulative incidence of ceramic or veneer fractures was reported to be 4.5 % in 5 years and 14 % in 10 years [6, 7]. In comparison, tooth supported prostheses experience only 3.2 % of ceramic fracture in the period of 10 years [8, 9]. This difference can be attributed to increased occlusal loads due to lack of proprioception and resiliency of implant-supported prostheses [10].

As the expectations of the patients regarding esthetics is growing, the research in the field of all-ceramic materials for restoration of the natural dentition and dental implants has delivered accordingly [11]. Posterior teeth are subjected to greater masticatory and para-functional forces than anterior teeth, ceramic materials used for reconstruction of posterior teeth should have adequate mechanical properties to prevent failures [12].

During the past two decades numerous types of high strength ceramics (i.e. IPS-empress, Empress 2, In-Ceram Alumina, In-Ceram Spinell and In-Ceram zirconia, aluminum oxide, zirconium dioxide ceramic) [13] and novel processing methods have been introduced for the fabrication of crowns, bridges, inlays, onlays, and veneers as well as for the reconstruction of dental implants [14].

Its been documented that when used for posterior teeth, the survival rates at 5 years of densely sintered lithium disilicate crowns (94.9 %) and reinforced glass–ceramic crowns (93.7 %) were similar to those obtained for metal–ceramic crowns (95.6 %) [15]. However, molar titanium implant abutments have a perfectly circular diameter of maximum 7.5 mm at the shoulder, forming a small crown basis compared to the large rectangular gingival cross-section of a natural molar of approximately 10 × 10 mm [16]. Consequently fracture load data known from esthetic ceramic crowns on tooth preparations may not exactly apply to implant abutment crowns [17]. There is insufficient knowledge of the strength of posterior all-ceramic crowns cemented to implant-supported titanium abutments so that they can become an alternative to metal ceramic crown [18, 19].

Hence, the aim of the present study was to evaluate the fracture toughness and bond strength of cement-retained implant-supported metal–ceramic molar crown with that of all-ceramic crowns, fabricated using IPS Empress 2 and yttria-stabilized zirconia copings.

Materials and Methods

An internal hex titanium endosseous implant (Osstem, GS II Dummy Fixture, Seoul, Korea) with dimensions of 5.0 mm in diameter and 10 mm length was selected for the study. A prefabricated titanium straight abutment (Osstem Implant, Seoul, Korea) with platform diameter 6 mm, height 5.5 mm and circular shoulder width of 0.8 mm was connected to the implant with the connecting screw.

A block of 35 × 35 × 20 mm in dimension was acrylized, using clear heat-cure polymethylmethacrylate material (Paladur; Heraeus Kulzer, Dormagen, Germany). A central borehole of 10 mm in length and 5 mm in diameter was prepared simulating osteotomy in the block. The selected implant was placed in the borehole using self-cure polymethacrylate resin (DPI, India) (Fig. 1). A wax pattern reproducing the anatomy and dimension of a mandibular molar was made using inlay wax (S-U-Wax, Schuler Dental, Ulm, Germany) with a bucco-lingual width and mesio-distal width of occlusal surface of approximately 8 and 10 mm respectively (Fig. 1). After making an index of the wax pattern using vinylpolysiloxane (VPS) putty impression material (Exaflex, GC America, Japan), the index was sectioned. The wax pattern was then cut back anatomically to obtain a coping allowing for an uniform thickness of ceramic build-up space with the help of putty index [19]. Again an index was made of the wax pattern coping after the cutback, this wax coping was considered as master coping [19].

Fabrication of Zirconia Copings (Group I)

The wax pattern thus prepared on the implant abutment was sprayed with titanium dioxide reflective spray (Cercon scan spray, DeguDent, Germany) to create the white-opaque surface necessary for laser optical 3D scanning (Dental Wings 5 series scanner, Montreal-Quebec) and to reduce reflection and improve readability. For fabrication of zirconia copings, CAD/CAM system (DWOS software, Dental Wings, Yenadent milling machine) was used. After the dimensions of the coping were recorded, the wax coping was removed from the abutment and the abutment was sprayed and scanned similarly. The two images i.e. the implant abutment and wax coping were then superimposed and the margins of the coping was adjusted using the DWOS software (Dental wings, Montreal-Quebec). Cement space of 50 µm was created axially around the implant abutment surface by the software to provide the passive fit and from the scanned image [20]. Seven identical copings were milled (Yenadent D40 series, Yena Makina, Istanbul, Turkey) using the pre-sintered zirconia blocks (ICE Zirconia, Metaxit, 12 mm). The pre-sintered copings were 20 % larger in size to compensate for the shrinkage during sintering [21]. These pre-sintered copings were then sintered overnight for 6–8 h in the sintering machine (Zirkonofen 600, Zirkon zahn, Germany) to a temperature of 1,500 °C. The finishing of the copings was done with finishing stone (Cerapro, Edenta, Hauptstrasse, Switzerland) maintaining the standardized thickness of the copings. The copings were then verified on the implant abutment for a passive fit.

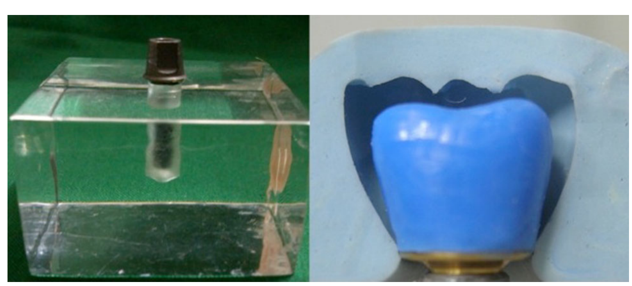

Fig. 1 Polymethylmethacrylate-implant abutment complex and the silicon' index used for cut back technique

Fabrication of Metal Copings (Group II)

Seven metal copings were prepared using the traditional lost-wax technique from the putty index as mentioned previously. Co–Cr–Mg base-metal alloy (Remanium GM 380, Dentaurum, Germany) was used for the casting of copings. The dimension of the copings was checked, to maintain the standard amongst the copings. The passivity of the copings was checked on the implant abutment.

Fabrication of IPS-Empress 2 Copings (Group III)

Seven Lithium disilicate press-fit IPS empress 2 (Ivoclar vivadent, Schaan, Lichtenstein) copings were also prepared using the traditional lost-wax technique. The wax patterns were invested with IPS Pressvest (Ivoclar-Vivadent, Schaan, Liechenstein) phosphate-bonded investment material and kept for 45 min for mould expansion. Once invested, the mold were transferred to the Variopress machine and IPS-empress 2 ingot (Ivoclar, Schaan, Switzerland) is pressed into the mold created. The copings were divested and fine trimming with finishing stone (Cerapro, Edenta, Hauptstrasse, Switzerland) was done maintaining the standardized thickness of the coping. The dimension of the copings was checked, to maintain the standard amongst the copings. The passive fits of the copings were checked on the implant abutment.

Ceramic Layering

Ceramic layering was then done on all the copings of metal–ceramic, IPS-empress 2 and zirconia. For zirconia and IPS-empress 2, IPS-e max (Ivoclar, Schaan, Switzerland) ceramic material was used (all-ceramic crowns) and for metal–ceramic, Duceram plus (Dentsply Ceramco, USA) ceramic veneering material was used. Different ceramic veneering materials were used for all-ceramic and metal–ceramic to prevent the thermal misfit between veneering ceramic and copings (zirconia, IPS-empress 2 and Co–Cr base metal) [22]. The ceramic build-up was done following the manufacturer's instructions by a same ceramist.

In all, 21 samples were fabricated and 1 sample of each group was cross-sectioned mesio-distally with diamond disc (MDT Microdiamond Technologies Limited, Israel) along an arbitrary line joining the mesio-buccal, disto-buccal and distal cusp tips (Fig. 2). Sectioning was done to verify the uniformity of ceramic build-up and also the marginal integrity, using the putty index of the mandibular molar previously prepared (Fig. 3).

Maxillary 1st molar antagonist with proper inter-cuspation with the mandibular molar sample was made in inlay wax (Carmel, Montreal-Quebec, Canada) and cast using Remanium GM 380 metal, to transfer uniform occlusal load to the study samples (Fig. 4).

Fig. 2 Crowns build up with ceramic for zirconia, metal and empress copings

Fig. 3 Section of crowns made with zirconia, metal and empress coping fitted on the implant abutment of the model

The samples were cemented using zinc polcarboxylate cement (Poly F, Denstply, USA) over the implant abutment and were subjected to vertical load applied through the apposing casted maxillary molar. The polymethylmethacrylate block-implant abutment complex was mounted on universal testing machine (UNITEK 9450 PC, Fuel Instruments and Engineers Pvt. Ltd., Kolhapur, India), and a static continuous vertical compressive load with a crosshead speed of 0.5 mm/min was applied. The breaking load and the peak load (in kilo Newtons) were recorded. The compressive load was applied at a crosshead speed of 0.5 mm/min. The initial breaking load and the peak load at which the sample fractured was recorded in kilo Newtons (kN). Breaking load was defined as the first sign of drop in load after the initial crack as detected by the testing machine and the peak load was defined as the load at which the testing machine stopped further application of load

Fig. 4 Vertical static loading applied on the crown cemented on the abutment

once complete fracture/separation of fragment occurred. The modes of failure were observed and evaluated with visual analysis (Fig. 5).

Results

The fracture toughness for group I (zirconia–ceramic) and group II (metal–ceramic) occurred on the mesio-buccal aspect of the crowns involving the veneered ceramic layer while the catastrophic/bulk fracture was not observed. The samples in group I showed both adhesive and cohesive failure of the veneering ceramic while the samples of group II showed predominantly adhesive failure. The fracture pattern in group III (IPS-empress 2) was not similar to group I and group II and catastrophic/bulk fractures was observed.

The mean value of fracturing load for zirconia–ceramic, metal–ceramic and IPS-empress 2 was 3.4335, 3.071 and 1.0673 kN respectively (Table 1). The mean value of peak load for zirconia–ceramic, metal–ceramic and IPS-empress 2 was 4.7365, 3.2757 and 1.566 kN respectively (Table 2).

These mean values were subjected to statistical analysis using a 1-way analysis of variance (ANOVA). It was concluded that the groups were statistically different at a significance level of $P < 0.05$.

The fracturing load and peak load of the groups were also subjected to Student's paired '*t*'-test and the differences between the groups were calculated (Table 3). It was concluded that there was statistical significant difference between metal–ceramic and IPS-empress 2 ($P < 0.05$). No statistical difference was found between the other groups.

Discussion

The emphasis on esthetics has increased dramatically not only in the anterior region but also in the posterior region resulting in increase in a number of all-ceramic crown systems. However, the brittle characteristics of dental porcelains used as monolithic crowns have traditionally limited the use of these materials in the posterior regions [23]. The advent of porcelain fused to metal crowns provided better mechanical properties due to the metal coping reinforcing the dental porcelain, but did so at the expense of esthetic properties like translucency and light transmission [24]. A number of new all-ceramic crown systems which is not reinforced with metal copings have been developed with the intent of providing good mechanical performance as well as superior esthetics. The clinical performance of these new all-ceramic systems on natural posterior teeth has been promising [25]. Various studies have been done on the performance of all-ceramic systems as implant-supported restorations. However, the comparison of fracture strength of the materials used for all-ceramic restorations has not been done [17].

A study has shown that there was no significant difference in the fracture toughness of the ceramic crowns on human mandibular first molars using mouth-motion fatigue loading technique as well as single cycle loading technique [26]. Since the aim of this study was to evaluate only the fracture toughness, single cycle loading technique was used. Fracture toughness tests of ceramic materials are important for the expected life-time with an acceptable low probability of failure [27]. One of the important factors affecting the fracture resistance of metal–ceramic and all-ceramic crowns is the core-veneer ratio [28]. Whereas the

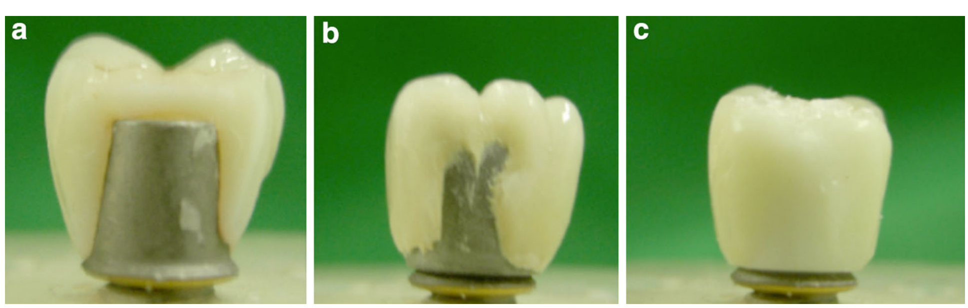

Fig. 5 Fractured crowns of zirconia, metal and empress copings

Table 1 Values for the breaking load for all the crowns

Sample	Zirconia–ceramic crowns (kN)	Metal–ceramic crowns (kN)	IPS-empress crown (kN)
1	2.695	3.743	0.955
2	3.480	3.365	1.788
3	2.165	3.363	1.295
4	2.840	3.100	1.123
5	9.318	2.565	0.328
6	0.103	2.293	0.915
Mean	3.4335	3.071	1.0673
SD	2.8351	0.4981	0.4391
F value	27.08		

Table 2 Mean values and standard deviation of peak load of all the samples

Sample	Zirconia–ceramic crowns (kN)	Metal–ceramic crowns (kN)	IPS-empress crown (kN)
1	3.040	4.023	1.593
2	4.475	3.403	2.080
3	2.198	3.413	1.378
4	4.690	3.100	1.350
5	9.368	3.270	0.730
6	4.648	2.445	2.265
Mean	4.7365	3.2757	1.566
SD	2.2676	0.4681	0.5057
F value	6.72		

Table 3 P- values for peak and breaking load

	Peak load (kN)		Breaking load (kN)			
Zirconia	–	0.81	–	–	0.16	–
IPS-empress 2	1.76	3.20	–	0.14	3.89	–

overall crown thickness (minimum 1.5 mm recommended) may be of primary importance in resisting fracture, the relative layer thickness influences strength, stress distribution and failure mode. It has been suggested that a 1:1 ratio of core to veneering porcelain thickness may provide reasonable strength, esthetics and fabrication tolerance [29]. In an in vivo study it was stated that the fracture resistance increases as the core thickness/veneer thickness ratio increases [30].

Coping design and crown geometry plays an important and underappreciated role in the fracture failure of all-ceramic crowns [31]. However, modern CAD/CAM systems are now able to provide a considerably better anatomically cut back coping design. Thus, future clinical long-term results may be more favourable [32]. The amount of chip fractures within the veneering ceramic in studies with anatomically shaped coping design was very low (0 % after 3 years and 3.3 % after 2 years) [33].

The fracture toughness of zirconia–ceramic crowns and metal–ceramic crowns was significantly greater ($P < 0.05$) than IPS empress 2 crowns. These results confirm the importance of the framework design of high-strength substructures/copings.

Generally, two types of veneer ceramic fractures are distinguished. Adhesive failure is diagnosed if ceramic fracture denudes supporting metal coping, and cohesive failure is identified when complications occur within veneering material, without involvement of the coping [33]. In the current study, all the samples of group I have showed adhesive and cohesive failure, while the samples in group II have shown failure at the metal–ceramic interface. Similar failure patterns with cohesive failure in zirconia–ceramic restorations limited to the veneer material and adhesive failures in metal–ceramic restorations were observed in other studies as well [33–35]. The large fractured chips observed for the zirconia–ceramic crown without exposure of the core/veneer interface strongly suggests high residual stresses within the veneer layer. This may be related to the very low thermal diffusivity of yttria-stabilized zirconia ($\sim$3 W m/K) [36], which may affect the rate of cooling of the veneering porcelain [37].

One of the factors responsible for fracture of the veneer material is the difference between coefficients of thermal expansion between the metal and the ceramic material [38]. The effect of the coefficient of thermal expansion (CTE) and the highly deleterious impact on metal coping and veneering ceramics caused by residual stresses has been frequently discussed in the dental literature [22, 39].

In the present study, veneer-core failure origins (catastrophic/bulk fractures) predominated only for the IPS Empress 2 crowns which were similar to a study conducted by Potiket et al. [40]. The high elastic modulus of the metal maxillary molar antagonist and the single-point contact may have induced a Hertzian stress distribution, which has been shown to cause catastrophic/bulk fractures. Catastrophic failure of the zirconia–ceramic crowns was not evident in the present study and is consistent with most clinical observations [41, 42]. The high crystalline content, flexural strength and fracture toughness of the yttria-stabilized zirconia based core material can be considered as reasons for the superior ability to resist crack propagation [36].

Conclusion

It can be concluded that the zirconia–ceramic crown with the fracture toughness of 4.7365 ± 2.2676 kN has sufficient strength to allow clinical testing of these crowns as an alternative for metal–ceramic crowns (3.2757 ± 0.4681 kN). However, IPS-empress 2 crowns with 1.566 ± 0.5057 kN fracture tough should be subjected to more laboratory tests simulating oral conditions before clinical trials.

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