Fracture Resistance and Mode of Failure of Ceramic versus Titanium Implant Abutments and Single Implant-Supported Restorations

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ABSTRACT

Background: The material of choice for implant-supported restorations is affected by esthetic requirements and type of abutment.

Purpose: This study compares the fracture resistance of different types of implant abutments and implant-supported restorations and their mode of failure.

Materials and Methods: Forty-five Oraltronics Pitt-Easy implants (Oraltronics Dental Implant Technology GmbH, Bremen, Germany) (4 mm diameter, 10 mm length) were embedded in clear autopolymerizing acrylic resin. The implants were randomly divided into three groups, A, B and C, of 15 implants each. In group A, titanium abutments and metal-ceramic crowns were used. In group B, zirconia ceramic abutments and In-Ceram Alumina crowns were used. In group C, zirconia ceramic abutments and IPS Empress Esthetic crowns were used. Specimens were tested to failure by applying load at 130° from horizontal plane using an Instron Universal Testing Machine. Subsequently, the mode of failure of each specimen was identified.

Results: Fracture resistance was significantly different between groups ($p < .05$). The highest fracture loads were associated with metal-ceramic crowns supported by titanium abutments ($p = .000$). IPS Empress crowns supported by zirconia abutments had the lowest fracture loads ($p = .000$). Fracture modes of metal-ceramic crowns supported by titanium abutments included screw fracture and screw bending. Fracture of both crown and abutment was the dominant mode of failure of In-Ceram/IPS Empress crowns supported by zirconia abutments.

Conclusions: Metal-ceramic crowns supported by titanium abutments were more resistant to fracture than In-Ceram crowns supported by zirconia abutments, which in turn were more resistant to fracture than IPS Empress crowns supported by zirconia abutments. In addition, failure modes of restorations supported by zirconia abutments were more catastrophic than those for restorations supported by titanium abutments.

KEY WORDS: dental implant, fracture resistance, implant abutment, In-Ceram Alumina, IPS Empress Esthetic, zirconia

INTRODUCTION

Titanium and ceramics are associated with adequate soft tissue response and marginal bone stability and therefore are used for implant abutment fabrication.[1,2]

Titanium abutments could be visible and show metallic blue color through thin gingiva. On the other hand, all-ceramic abutments have high potential to satisfy esthetic demands in the aesthetic zone.[1,3,4]

The fracture resistance of ceramic abutments is higher than the maximum anterior occlusal loads reported in the literature.[4–6] Nevertheless, titanium abutments have higher fracture resistance than zirconia abutments.[1,7,8]

The type and design of the implant-abutment connection could impact the fracture resistance of implant/abutment/restoration assemblies.[9–13] In this regard, two-piece internal connection designs have better fracture resistance than one-piece internal connection or

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external connection designs.[11–13] Furthermore, some researchers have suggested that failure modes of zirconia abutments depend on the system design characteristics.[10,13] Systems with internal connections had more abutment fractures than screw fractures.[10,13]

Dental ceramics and high sintered alumina restorations have surface flaws such as voids and cracks that initiate crack propagation of ceramics under loading. The cracks will eventually grow and cause abutment failure.[14]

The material of choice for implant-supported restorations is affected by esthetic requirements and type of abutment. Metal-ceramic crowns are used over titanium abutments because all-ceramic crowns allow metal to show through. On the other hand, all-ceramic crowns are better to use over ceramic abutments, especially in the aesthetic zone, because they allow for better aesthetics.[3]

Metal-ceramic crowns are considered more resistant to fracture and endure greater stress than all-ceramic crowns.[4,6,15]

Zirconia crown restorations have been shown to be more resistant to fracture than In-Ceram Alumina, IPS Empress leucite, and IPS Empress lithium disilicate crowns.[16–18] However; Pallis and colleagues[19] found no significant difference in fracture resistance between different tested ceramic materials. They found that the failure loads were 771 to 1115 N for IPS Empress 2, 859 to 1086 N for Procera AllCeram and 998 to 1183 N for In-Ceram Zirconia.

Metal-ceramic crowns were reported to be stronger than IPS Empress and In-Ceram crowns.[20–22] Also, metal-ceramic fixed prostheses were reported to have significantly higher survival rates and fewer fractures than zirconia-based fixed dental prostheses.[23,24]

However; some researchers concluded that the survival rates and fracture strength of ceramic crowns were similar to those of metal-ceramic crowns.[25–28]

Furthermore, zirconia-based fixed dental prostheses were reported to have similar survival rates and material fractures to metal-ceramic fixed dental prostheses.[29] Wassermann and colleagues[30] concluded that In-Ceram Alumina and In-Ceram Spinell crowns had similar 5-year survival rates to metal-ceramic crowns.

The ability of single implant all-ceramic abutment restorations to withstand functional forces in the oral cavity is still questionable.[4,6]

This controversy provoked the conduct of this study to compare the fracture resistance of three types of single implant-supported restorations and to identify their mode of failure.

Hence, the aim of this study was to compare the fracture resistance of single implant-supported restorations, namely metal-ceramic crowns cemented to titanium abutments, In-Ceram Alumina crowns cemented to zirconia abutments, and IPS Empress Esthetic crowns cemented to zirconia abutments. Furthermore, the mode of fracture of the implant-supported restorations was identified.

The null hypothesis for this study was that fracture resistance and fracture modes of metal-ceramic crowns supported by titanium abutments are similar to those of IPS Empress/In-Ceram Alumina crowns supported by zirconia ceramic abutments.

MATERIALS AND METHODS

Forty-five implants (Oraltronics Dental Implant Technology GmbH, Bremen, Germany) with a diameter of 4 mm and length of 10 mm were randomly allocated to three groups: A, B, and C. Each group consisted of 15 implants. Each implant was inserted into a specimen holder made of a stainless steel cylinder and covered up to the first thread with clear autopolymerizing acrylic resin (poly(methyl methacrylate); Melliodent, Heraeus Kulzer, Hanau, Germany). The implants were aligned parallel to the outside of the specimen holder using a surveyor (Degussa AG, Frankfurt, Germany) to ensure standardized alignment of the implants within the acrylic resin.

Implants in group A received prefabricated standard titanium abutments (Oraltronics) and metal-ceramic crowns (metal: nickel-chromium alloy; Remanium G-Soft, Dentaurum J.P. Winkelstroeter KG, Ispringen, Germany; ceramic: VITA Zahnfabrik, Bad Sachingen, Germany). Meanwhile, implants in group B were restored with Zirconium abutments (Oraltronics) and In-Ceram Alumina crowns (VITA Zahnfabrik). Also, implants in group C were restored with Zirconium abutments and IPS Empress Esthetic crowns (Ivoclar Vivadent, Schaan, Liechtenstein). Figure 1 shows used abutments embedded in clear acrylic resin.

All abutments had internal connection with the implants, were straight, and had shoulders. The Zirconium abutments used consisted of two parts: a zirconia blank and a titanium base insert to which it was

Figure 1 Zirconia abutment embedded in clear acrylic resin.

bonded (Figure 1). The zirconia blank is made of Yttrium-stabilized tetragonal zirconium oxide polycrystals (TZP-A).

The abutments were torqued into the implants to 30 Ncm according to manufacturer's recommendations using a torque control system (Oraltronics). Then, abutment screws were tightened after 5 minutes, following the manufacturer instructions, before cementation of the restoration.

A metal-ceramic crown (0.3 mm metal thickness and 1.2 mm ceramic thickness) for the maxillary right central incisor (Figure 2) was fabricated with incisogingival dimensions of 11 mm, labiolingual dimensions of 7 mm, and mesiodistal width of 8 mm. Then, a silicone index of the fabricated crown was constructed and used as a guide in an attempt to fabricate all crowns to similar dimensions. Furthermore, grinding using a diamond finishing bur at reduced speed (<20,000 rpm) under copious cool-water irrigation was carried out in order to obtain the requested crown dimensions when necessary. For standardization, all crowns were fabricated by the same dental technician.

The In-Ceram crowns were fabricated of glass-infused alumina-based ceramic using the slip casting method according to manufacturer's recommendations. The In-Ceram crown consisted of a 0.5 mm thick In-Ceram core and 1 mm thick veneering porcelain (Vitadur Alpha/Vita VM7, VITA Zahnfabrik).

In addition, IPS Empress Esthetic crowns were fabricated of lithium disilicate-reinforced glass ceramic using the lost-wax technique and layering method according to the manufacturer's recommendations. The IPS Empress crown consisted of an 0.7 mm IPS Empress core and 0.8 mm veneering porcelain (Ivoclar Vivadent, Schaan, Liechtenstein). For further information on the composition of the materials used, please consult the manufacturers' catalogs.

The intaglio surfaces of the metal-ceramic and In-Ceram crowns were sandblasted (50 μm aluminum oxide powder for 15 seconds according to manufacturer guidelines), while the inner surfaces of IPS Empress crowns were acid-etched (9% hydrofluoric acid [Ultradent Products, South Jordan, UT, USA] for 1 minute, followed by copious water irrigation and then drying for 30 seconds). All crowns were cemented to abutments using glass ionomer cement (Super Dent, Westbury, NY, USA).

All specimens were stored in water at 37°C for 72 hours, then thermocycled for 3000 cycles between 5 and 55°C. Two water baths were used for thermocycling (temperature was 5°C for the first and 55°C for the

Figure 2 Ceramometal crown cemented over titanium abutments embedded in clear acrylic resin.

TABLE 1 Means, Standard Deviation, and Minimum and Maximum Fracture Loads among Tested Groups (n = 15 per Group)

	Group A (Metal-Ceramic Crowns)	Group B (In-Ceram Alumina Crowns)	Group C (IPS Empress Esthetic Crowns)
Mean fracture load	1012.00	498.00	274.00
Standard deviation	132.514	154.975	77.071
Minimum fracture load	820	320	150
Maximum fracture load	1250	870	400

second). The specimens were placed in a perforated tray and cycled between the baths. Each cycle lasted 30 seconds, with 10 seconds' dwelling time in each bath and 5 seconds' transfer time between baths.[31]

Each specimen was then mounted within an Instron Universal testing machine (Instron 1195; Instron Ltd, High Wycombe, UK) with a crosshead speed of 1 mm per minute. The load was applied at the midline of the lingual surface of the restoration, 4 mm from the incisal edge, and was set at 130 degrees from the horizontal. For each specimen, testing loads were applied onto a standard point at the middle of the lingual surface of the restoration.

The pattern of specimen fracture was recorded photographically at the start of the failure of each specimen.

Statistical Analysis

The data were analyzed using Statistical Package for the Social Sciences software (version 19.0; SPSS Inc., Chicago, IL, USA). Simple descriptive frequency tests for the study variables and groups were carried out and processed. Differences between groups were analyzed by means of least significant difference post hoc test. Statistical significance was based on probability values of $p \leq .05$.

RESULTS

A total of 45 crowns were tested. The labiolingual dimensions of fabricated crowns ranged from 6.9 to 7.4 mm (mean = 7.2 ± 0.2 mm), the incisogingival dimensions ranged from 10.8 to 11.1 mm (mean = 11 ± 0.15 mm), and the mesiodistal dimensions were 7.8 to 8.2 mm (mean = 8.1 ± 0.16 mm). There were no statistically significant differences between samples in labiolingual, incisogingival, or mesiodistal dimensions ($p > .05$).

Table 1 shows that metal-ceramic crowns on titanium abutments (group A) had a mean fracture load of 1012 ± 132.5 N (the highest fracture load was 1250 N); In-Ceram crowns on ceramic abutments (group B) had a mean fracture load of 498 ± 155 N (the highest fracture load was 870 N); and the mean fracture resistance of IPS Empress crowns on ceramic abutments (group C) was 274 ± 77.1 N (the highest fracture load was 400 N).

Table 2 shows that the mean loads required to fracture metal-ceramic crowns on titanium abutments were significantly higher than loads required to fracture In-Ceram or IPS Empress crowns on ceramic abutments ($p = .000$). Moreover, In-Ceram crowns on ceramic abutments were associated with significantly higher fracture loads than IPS Empress crowns on ceramic abutments ($p = .000$).

Table 3 demonstrates the distribution of mode of failure among the tested groups of specimens in this study. Fracture modes of metal-ceramic crowns supported by titanium abutments involved screw fracture (2 specimens) or bending (13 specimens). Five specimens showed chipping of the ceramic veneer, and 3 specimens

TABLE 2 Least Significant Difference Post Hoc Test of the Difference in Fracture Loads between Groups

Groups	Mean Difference	Standard Error	Significance ($p < .05$)	95% Confidence Interval	
				Lower Bound	Upper Bound
Metal-ceramic vs In-Ceram	538	51.5	.000	412.3	663.7
Metal-ceramic vs IPS Empress	762	51.5	.000	636.3	887.7
In-Ceram vs IPS Empress	224	46.1	.000	111.5	336.5

TABLE 3 Distribution of Study Specimens according to the Mode of Failure

Mode of Failure	Titanium Abutment/ Metal-Ceramic Crown	Ceramic Abutment/ In-Ceram Crown	Ceramic Abutment/ IPS Empress 2 Crown
Screw bending	13	0	0
Screw fracture	2	0	0
Crown and abutment fracture	0	13	15
Only abutment fracture	0	2	0
Total ($n = 45$)	15	15	15

showed deformation of the metal core of the crown. On the other hand, fracture of either the abutment alone or both crown and abutment affected In-Ceram crowns supported by ceramic abutments. Meanwhile, the mode of failure affecting IPS Empress crowns supported by ceramic abutments was crown and abutment fracture. No implant fracture, bending, or displacement was observed in any specimen in this study.

DISCUSSION

This study demonstrated that the fracture resistance and fracture modes of metal-ceramic crowns supported by titanium abutments were different from IPS Empress/In-Ceram Alumina crowns supported by zirconia ceramic abutments, and therefore the null hypothesis of this study was rejected.

The fracture resistance of single implant-supported all-ceramic restorations was previously tested using different ceramic abutment/crown assemblies.[5,17,21,25–27,32] However, the literature lacks studies that compare the fracture resistance and fracture mode of IPS Empress Esthetic and In-Ceram Alumina crowns supported with zirconia ceramic abutments to metal-ceramic crowns supported with titanium abutments. This study was conducted to tackle this area.

The selected implant diameter (4 mm) was similar for all tested groups in this study. The reason behind this was to avoid the potential influence of diameter changes on results.[10] The implant size in this study was similar to the size that was used by Butz and colleagues[25] However, some previous studies used smaller (3.75 mm)[21] or larger (4.3 mm)[26,27] sizes of implants, and this (among other factors) might explain the difference between the results.

Following previous studies and in order to mimic clinical situations; the specimens were inserted up to the first implant thread into autopolymerizing resin that has a modulus of elasticity close to human bone.[5,21,25–27,32,33]

Also, the maxillary right central incisor crowns were constructed with average dimensions following previous studies.[5,21,25–27,32]

Glass ionomer luting agent was used in this study because of its reduced film thickness in comparison to resin cements.[34]

The forces were applied on the palatal surface of crowns at a 130-degree angle from the horizontal plane. This angle is equivalent to the angle of clinical loading on the anterior teeth.[25–27,35] However, some researchers used different angles (e.g., 30 degrees[5] and 45 degrees[21]), and this could explain the difference between their findings and the results of this study.

This study demonstrated that assemblies of metal-ceramic crowns supported by titanium abutments were stronger than IPS Empress and In-Ceram Alumina crowns supported by zirconia ceramic abutments. This study finding is consistent with the results of other studies.[21,22] This could be attributed to the fact that ceramic surface flaws initiate crack propagation under loading and thus allow for abutment fracture under lower levels of stress.[16] Furthermore, ceramics demonstrate asymmetric strength distribution, as their strength distribution curve gradually increases from low strength value to high strength value and then suddenly drops at higher strength values.[19]

This study showed that titanium abutments were associated with the highest fracture resistance, as previously reported.[7,12,13,17,21,25–27] The highest mean fracture load of a metal-ceramic crown supported by titanium abutments reported in this study (1012 N) was larger than what was reported by Cho and colleagues[21] (333 N), Kohal and colleagues[36] (531 N), and Leutert and colleagues[13] (678.2 N). This may be due to applying the load at different angles, using different implant and restoration sizes, and lack of specimen thermocycling in these studies. Furthermore, Truninger and colleagues[12] reported lower levels of fracture loads for titanium abutments (714.1 ± 184.9 N), and this could be explained by the fact that they did not use prosthetic rehabilitations over the tested abutments.

On the other hand, the highest mean fracture load of a metal-ceramic crown supported by titanium abutments reported in this study was smaller than what was reported by other researchers[26,27] (1344.2 N[26] and 1251 N[27] in two studies by Att and colleagues). This may be the result of lack of thermocycling, using implant systems with different implant and abutment dimensions, Procera crowns being used on all tested abutments, and the use of adhesive cements in the previous studies.

Also, IPS Empress crowns cemented over ceramic abutments had the lowest mean fracture load (274 N). This finding is in agreement with those reported by other studies.[5,37] However, other studies reported a much higher fracture resistance (604 N[37] or 788.1 N[5]), which could be due to the different study settings and parameters, including thermocycling, abutment dimensions, materials, crown preparation, or force direction. On the other hand, the highest mean fracture load of ceramic crowns supported by ceramic abutments (498 N) reported in this study was slightly larger than what was reported by Att and colleagues (470 N[26] and 457 N[27] in two studies) or Truninger and colleagues[12] (429 N). The previous justification also applies here to explain the difference between studies.

The selected type of implant-abutment connection in this study was the two-piece internal connection design. This design was selected for this study, as it was proved to have better fracture resistance than one-piece internal connection or external connection designs.[11–13] In an in vivo study, Canullo[9] found that two-piece zirconia abutments were not associated with abutment fracture or screw loosening over 3 to 4 years.

Regarding the failure mode, assemblies of metal-ceramic crowns and titanium abutments were affected with screw fracture or bending. This could be due to the abutment screw being the weakest element in the tested metal-ceramic crown/titanium abutment assemblies and thus being fractured or bent under loading. This concurs with the findings of some researchers.[21,27,38] However, it disagrees with Att and colleagues[26], who reported crown fractures without screw fracture or bending. This could be explained by the fact that they used Procera crowns rather than metal-ceramic crowns in their study.

Also, ceramic crown/ceramic abutment assemblies were associated with crown and abutment fractures. Unfortunately, there is no other reported consistent mode of failure of ceramic assemblies in the literature.[5,7,27]

Nguyen and colleagues[10] tested different types of zirconia abutments using rotational load fatigue testing (without using a prosthetic rehabilitation over the abutments) and reported abutment fractures (18 samples) and screw fractures (16 samples). They concluded that failure modes of zirconia abutments depended on the system design characteristics. Systems with internal connections had more abutment fractures than screw fractures.[10] Similar results were reported by Leutert and colleagues.[13]

Some researchers still have concerns about the competence of ceramic implant abutment-supported single crowns to endure functional loads intraorally.[4,6]

In order for ceramic implant abutment-supported single crowns to be successful, they should be able to endure the reported values of clinical incisal loads, which reach 90 to 370 N.[4–6]

Finally, this study reported the fracture resistance levels of crown/abutment/implant assemblies that made them capable of enduring physiologic occlusal stress in the anterior area of the oral cavity regardless of the materials used. This concurs with the findings and conclusions of previous studies.[4–6,21,25–27,32,37] As anterior aesthetics is a chief concern for professionals and patients, the use of materials that have superior aesthetics but inferior strength (but can endure physiologic occlusal stress) is reasonable and professionally accepted.[1,4,6] This is further supported by the claims that in order to obtain superior aesthetics and avoid metal show, all-ceramic restoration should be supported with ceramic rather than titanium abutments.[3]

The limitations of this study include being an in vitro study. In vitro studies cannot reproduce all clinical parameters. However, they may provide an insight into material characteristics, use, function, and performance during a short time under reproduced and standardized conditions. Samples were stored in water and were thermocycled in an attempt to better approximate the clinical oral environment. Nevertheless, thermocycling has the potential to reduce material capability to resist fracture.

Further studies are still required on larger samples, on different implant-abutment connections, on different types of ceramic abutments and prosthetic rehabilitations, and using cyclic loading in artificial mouths.

CONCLUSIONS

This study demonstrated that metal-ceramic crowns supported by titanium abutments resisted failure to a greater degree than IPS Empress/In-Ceram Alumina crowns supported by zirconia ceramic abutments. Regardless of the materials, crown/abutment/implant assemblies were observed to withstand loads in excess of physiologic occlusal loads in the anterior area of the oral cavity.

Screw fracture or bending was the dominant failure mode that affected assemblies of metal-ceramic crowns and titanium abutments. Meanwhile, ceramic crown/ceramic abutment assemblies were associated with crown and abutment fractures.

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