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INFLUENCE OF THE MARGIN DESIGN ON THE FRACTURE RESISTANCE OF IMPLANT SUPPORTED MONOLITHIC ZIRCONIA CROWNS : AN *IN VITRO* STUDY

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Introduction: The purpose of this in vitro study was to test the influence of the margin design of implant supported monolithic zirconia crowns and test if monolithic zirconia crowns with extra fine finish line thickness cemented on zirconia implant abutments can bare the maximum masticatory forces on molars and hence be used in the posterior region.

Methods: Fourteen identical monolithic zirconia crowns cemented on zirconia implant abutments mounted on titanium bases and fixed on implant replicas embedded in PMMA resin were divided into two groups: group I designed with a 0.5 mm CFL (CFL) and group II with a feather-edge finish line (FEFL) of 0.3 mm. All specimens underwent static load until fracture in order to determine the break force. Break forces in N were recorded for each group.

Results: The CFL group exhibited slightly higher fracture resistance (1879.14 ± 322.28 N) compared to the feather-edge finish line group (1685.00 ± 362.18 N). However, statistical analysis revealed that the observed difference between the two groups (194.14 ± 183.24; $p = 0.310$) was not significant.

Conclusions: Within the limitations of this study, both monolithic zirconia crowns with 0.5 mm chamfer and 0.3 mm feather edge margins cemented on zirconia implant abutments can be used in the posterior region as their resistance to fracture is similar and surpasses the maximum masticatory force applied on molars.

Keywords: zirconia, crowns, ceramics, prosthodontics, cementation

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Conflicts of interest:
The authors declare no conflicts of interest.

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INFLUENCE DE LA CONCEPTION DE LA LIMITE SUR LA RÉSISTANCE À LA FRACTURE DES COURONNES MONOLITHIQUES EN ZIRCONE SUR IMPLANT : UNE ÉTUDE IN VITRO

Introduction: L'objectif de cette étude in vitro est d'évaluer l'influence de la forme de la limite cervicale des couronnes en zircone monolithique scellées sur pilier implantaire en zircone sur leur résistance à la fracture et de tester si les couronnes en zircone monolithique avec des limites cervicales extra fines implanto-supportées peuvent résister aux forces masticatoires en région postérieure.

Matériels: Quatorze couronnes en zircone monolithique scellées sur des piliers implantaires en zircone eux même scellés sur des bases en titane vissées sur des répliques d'implants incrustés dans de la résine PMMA ont été divisées en deux groupes : groupe I avec des limites de 0.5 millimètres d'épaisseur en congé et groupe II avec des limites de 0.3 millimètres d'épaisseur en lame de couteau. Tous les spécimens ont subi un test de charge statique jusqu'à la fracture afin d'évaluer la force à laquelle la fracture a lieu. La force en N responsable de la fracture pour chaque spécimen a été enregistrée.

Résultats: Le groupe avec les limites en congé a montré une résistance à la fracture légèrement supérieure (1879.14 ± 322.28 N) par rapport au groupe avec les limites en lame de couteau (1685.00 ± 362.18 N). Cependant, l'analyse statistique des données a prouvé que la différence observée entre les deux groupes (194.14 ± 183.24; $p = 0.310$) est non significative.

Conclusions: Dans les limites de cette étude, il est possible de conclure qu'il est acceptable d'utiliser des couronnes en zircone monolithique avec des limites en congé de 0.5 millimètre d'épaisseur ou des limites en lame de couteau de 0.3 millimètres d'épaisseur scellées sur piliers implantaires en zircone dans les régions postérieures puisque leur résistance à la fracture est similaire et dépasse les forces masticatoires maximales appliquées sur les molaires.

Mots clés : Zircone, Couronnes, Céramiques, Prothèse dentaire, Cémentation

Introduction

Failures in fixed implant prosthodontics are numerous and are related to many factors [1]. We can mainly describe failures related to prosthetic components which will affect resistance and retention of the restoration, however other types of failures should also be taken into consideration especially regarding the biological integration of implant supported restorations. These failures include discoloration of the gingiva due to the choice of the material of the abutment or the framework, but also recession of the tissues surrounding the implants [2] and poor gingival support.

A better conception and fabrication of prosthetic components would ensure a proper prevention of the aforementioned challenges. In order to achieve this, a new design for implant abutments was introduced [3], based on the principle of a preparation technique for natural teeth introduced and developed by Ignazio Loi in 2008 [4]. This technique, called BOPT (biologically oriented preparation technique) aims for a better integration of fixed prosthesis to the surrounding tissues by modifying the configuration of the prosthetic finish line of the abutment tooth. Indeed, traditional finish lines, mainly chamfer and shoulder, are described as "horizontal", whereas Loi's technique does not require a defined finish line, but rather a zone where the prosthesis would end, hence the name vertical preparation technique. The most notable difference between these two protocols is the fact that in the traditional preparation, the clinician chooses where the prosthesis ends and transfers this information to the laboratory technician via an impression where the horizontal finish line is well defined. In the BOPT, the end of the prosthesis is chosen by the laboratory technician depending on the information the clinician gives on surrounding tissues. This technique offers many advantages whether on the biological or mechanical aspect. Among them, a better preservation of dental tissues, thickening of surrounding soft tissues [5], a better control over the emergence profile, and a better stability of the gingival level over time [6-8]. Another important advantage of this technique over the regular preparation protocol is a better fit of the crown to the abutment leading to less bacterial infiltration and less exposure of luting cement. Thus, the BOPT offers numerous advantages when applied to the preparation of natural teeth.

However, it is possible to apply the principles of BOPT in fixed implant prosthodontics through the choice of a certain implant abutment [4]. In this case, the chosen abutment must not have a prosthetic finish line or must have a feather edge margin granting it a vertical geometry. This abutment is very useful in the esthetic zone where creating a correct emergence profile remains a prominent challenge [9]. Furthermore, the stability of soft tissues around the implant is a determining factor for success in the esthetic sector giving another advantage to the marginless abutment as it ensures great gingival stability [2]. As demonstrated, it is reasonable to say that the application of BOPT principles in fixed implant prosthodontics leads to good prosthetic management for implants in the esthetic zone.

Other than the type of the abutment, the fabrication method and the material of the prosthetic crown [10] have considerable influence on the mechanical behavior of the restoration on the one hand, and on yielding proper esthetics on the other hand. CAD/CAM is a well-known and established technique that results in the manufacturing of resistant, esthetic, durable and precise prosthetic elements [11]. In addition to that, CAD/CAM helped the emergence of new materials, namely zirconia [12] that has good mechanical properties [13] such as a low thermal conductivity, a low potential of corrosion, good radio opacity and great resistance to flexion and fracture. Moreover, zirconia restorations offer proper esthetics which makes this biomaterial a good fit for prosthetic rehabilitations. However, monolithic zirconia prosthodontic components are generally preferred due to the high rate of chipping of bilayer zirconia [14]. Feather edge monolithic zirconia crowns also offer good fracture resistance and adequate strength [15].

Therefore, it would be interesting to compare the fracture resistance of zirconia crowns with different margin designs over zirconia implant abutments to assess whether implant supported monolithic zirconia crowns with extra thin feather edge margins can be used in daily practice.

Materials and methods

Sample size

To determine the sample size, a power analysis was conducted for independent Student's t test using G*Power software 3.1.9.7 for Windows (Heinrich Heine, Universitat Düsseldorf, Düsseldorf, Germany), and considering a power of 95%, an alpha level of 5%, and an effect size of 2.14 calculated based on a previous study (Agustín-Panadero et al.). The total sample size required for this study was 14 crowns in total (7 per group).

Design of the study

Fourteen samples were tested. They were divided into two groups according to the geometry of the finish lines. Group I consisted of seven first lower right molar zirconia crowns with a 0.5 mm chamfer finish line (CFL) cemented on zirconia abutments using GC G-Cem One™ (GC America Inc.). Group II consisted of seven first lower right molar zirconia crowns with a 0.3 mm feather-edge finish line (FEFL) (fig. 1) cemented on zirconia abutments also using GC G-Cem One™ (GC America Inc.). All specimens underwent a static load until fracture test.

Abutment design

The overall abutment height was 7 mm (1 mm more than the height of the titanium base). A standard gingival height of 1 mm was used for both groups. Abutment wall thickness was 1 mm for all abutments used. Abutments were cemented on Titanium bases with Panavia V5 paste (Kuraray Noritake Dental Inc. - Okayama, JAPAN)

Crown design

The same crown design was used for all specimens. Only the finish line was different between group I and group II, all specimens had a minimum of 0.8 mm occlusal thickness[16] to ensure a proper resistance to fracture. The overall height of the crown was 7.8 mm and the spacing used for both groups was 40 microns in the occlusal region and 60 microns at the margins.

Closing torque and cementation

Following the manufacturer's recommendations, the closing torque used for the Titanium bases over the implant analogs was 20 N (fig. 2). Finally, crowns were cemented using GC G-Cem One™ (GC America Inc.). Cement was light-cured for 2 seconds before excess removal then crowns were held in place with digital pressure for final light-curing (20 seconds). The specimens were then incubated for a period of 48 hours at room temperature following the cementation.

Standardization

All abutments were cemented on BT Link KR titanium bases (Biotec S.r.l - Via Industria 53 - 36031 Povalaro di Dueville - Italy) with a 4.1 mm diameter and a height of 6 mm with an internal hexagonal connection screwed on BTK® Analog DR (Biotec S.r.l - Via Industria 53 - 36031 Povalaro di Dueville - Italy) implant replicas with an internal hexagon connection. All crowns and abutments were milled using GC Initial™ (GC America Inc.- 3737 west 127th street Alsip - IL 60803 - U.S.A) zirconia disks and sintered according to the manufacturer's recommendations at a temperature of 1500ºC. All crowns and abutments were designed on DentalCAD 3.1 Rijeka software (Exocad® GmbH). In order to ensure a correct and reproducible position of the crowns during the testing, all implant replicas were embedded in PMMA resin. PMMA blocks were designed using a CAD software with a designated space that matched the lab analogs in order to get the same position and axis for all specimens tested.

Fig 1. measuring the marginal thickness of one FEFL crown

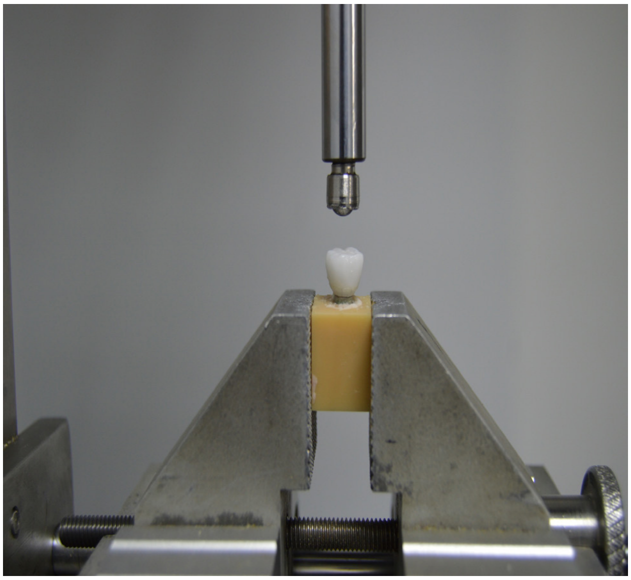

Fig 2. Specimen placed on the YLE® universal testing machine

Static load test

The static load until fracture test was performed on the universal testing machine (YLE® GmbH Waldstraße Bad König, Germany), with a spherical tip applying an increasing pressure on the center of the occlusal surface of the crowns (fig. 3) at a crosshead speed of 1 mm/min [17]. All the data was analyzed and collected on the YLE® software with the compression module. Progressive force was applied until fracture of the crowns and the break force was registered for each specimen.

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY, USA). Descriptive statistics of the fracture resistance (N) for feather-edge finish line and CFL groups were calculated and presented as means ± standard deviations and minimum/maximum values. The Shapiro-Wilk test was used to evaluate the normality of distribution of the quantitative variable. And since the fracture resistance was normally distributed, the independent Student's t test was used to compare means between the two groups. The level of significance was set at 5% and the test was two-tailed.

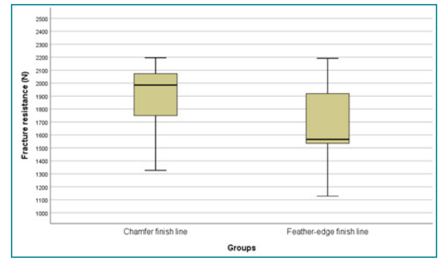

Fig 3. Box-plots of the fracture resistance among groups

Results

Table 1 and Fig. 4 present a summary and comparison of the fracture resistance results across groups.

The CFL group exhibited slightly higher fracture resistance (1879.14 ± 322.28 N) compared to the feather-edge finish line group (1685.00 ± 362.18 N). However, statistical analysis revealed that the observed difference between the two groups (194.14 ± 183.24; p = 0.310) was not significant.

Table II and Table III show the fracture type for each specimen from each group. The most reported fracture type for group I was type D, while the type B was predominant in group II.

Table 1. Comparison of fracture resistance (N) between groups

Groups	Fracture resistance (N) Mean ± SD	Minimum value (N)	Maximum value (N)	*p*-value
Chamfer finish line (N=7)	1879.14 ± 322.28	1327	2196	
Feather edge finish line (N=7)	1685.00 ± 362.18	1128	2191	0.310¶

SD = standard deviation; SE = Standard Error ¶: Independent Student's t test.

Table 2. Break force and fracture type for the specimens of group I

Specimen	***Fracture type***
Group I 1	D
Group I 2	B
Group I 3	D
Group I 4	D
Group I 5	D
Group I 6	B
Group I 7	A

Table 3. Break force and fracture type for the specimens of group II

Specimen	***Fracture type***
Group II 1	B
Group II 2	B
Group II 3	B
Group II 4	A
Group II 5	C
Group II 6	A
Group II 7	D

Four types of fractures were observed for both groups as follows (fig. 4):

- Type A: Complete fracture of the crown along the midline
- Type B: Complete fracture of the crown with only the abutment remaining
- Type C: Complete fracture of the crown and the abutment with only the titan base remaining
- Type D: Small fractures in the crown with the crown/abutment/implant analog complex bending in the PMMA die

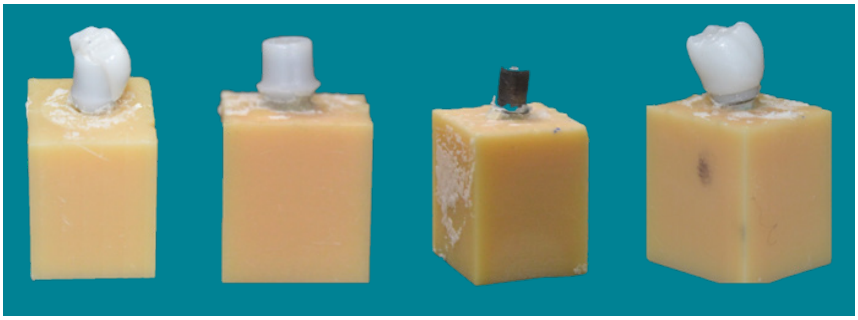

Fig 4. The different types of fractures (from left to right: type A, type B, Type C and Type D)

Discussion

It is well established in the literature that the use of feather edge margins offer great advantages compared to CFLs whether on natural teeth or implant abutments. Indeed, feather edge margins help for a better adaptation of soft tissue to the emergence profile of the restoration [18], granting better esthetics and periodontal health [19]. Moreover, feather edge margins result in lesser gingival recession hence better esthetics than chamfer margins [20]. As a matter of fact, marginless implant abutments lead to a greater volume of soft [5] and hard [21] tissue around the restoration, which creates a greater barrier to bacteria, thus a better hygiene. For all the reasons mentioned earlier, this study is of great clinical significance as it helps to determine whether vertical preparation technique principles can assure proper resistance to fracture when it comes to monolithic zirconia crowns on zirconia abutments. The particularity of this study is the use of monolithic zirconia crowns with a novel extra thin marginal thickness of 0.3 mm.

Within the limitations of this study, it seems that implant supported FEFL crowns over zirconia abutments have similar resistance to fracture than CFL crowns. Both groups gave high mean break forces, 1879.14N ± 322.28N for CFL and 1685.00 ± 362.18N for FEFL, that are both above the average maximal masticatory force for men which is 847N according to Waltimo et al [22]. This means that both CFL crowns with a marginal thickness of 0.5 mm and FEFL crowns with 0.3 mm marginal thickness can be used in the molar region on zirconia implant abutments. Both finish lines can be used interchangeably since no statistically significant difference in break force was found between the two groups, although CFL crowns had slightly greater resistance to fracture.

The findings in the present study first contradict the results of Haddad et al [15]. In this study, the authors claimed that the minimal acceptable marginal thickness for feather edge crowns in the posterior region was 0.5 mm, yet the results demonstrate that 0.3 mm thickness on the margin can bare forces higher than the maximal masticatory forces on molars. This is due first of all to the use of zirconia abutments which surely played a role in supporting and dissipating some of the stress applied on the crown's surface. But it could also be linked to some design considerations regarding the crown itself. In this study, the occlusal thickness used was 0.8 mm, which is optimal for clinical use according to Lan et al [16] although another study conducted by Sorrentino et al. showed that 0.5mm occlusal thickness can also be used in the molar region [23].

Second, studies suggest that zirconia implant abutments can only be safely used in the anterior region. Adatia et al [24] found that the average maximum force that a zirconia implant abutment with 0.5 mm margins can tolerate is 576N ± 120N, which is above the maximum incisal force (283N) [25] but lower than masticatory forces on molars (847N) [22]. Another study by Foong et al [26] revealed that zirconia abutments have lower resistance than titanium abutments. What is important to note however is that these studies used single piece zirconia abutments whereas in the present study, titan bases were used as an interface between the milled zirconia part of the abutments and the implant analogs adding to the resistance of the abutments [27] which explains why the abutments were able to withstand such high forces before fracture with such thin margins. Such were the findings of Moilanen et al [28] as they showed that monolithic zirconia crowns on prefabricated titan bases show greater resistance to fracture than those in direct contact with the implant surface.

Third, a study by Agustín-Panadero et al [29] had contradicting results while sharing a similar study design. Indeed, the study used zirconia abutments connected on titanium prosthetic platforms just like the present study however found significantly greater fracture resistance for CFL abutments. The difference between this study and the present one was that it used zirconia cores for the crowns with injected IPS emax ceramic as a veneering ceramic on top whereas the present study used monolithic zirconia crowns. This study also focused on the connection between the abutments and the implant and the transepithelial part of the abutment rather than the abutment/crown complex. The failures and fractures happened either at the abutment level or the screw that retains the titanium platforms unlike the present study where the fractures happened mainly on the level of the monolithic zirconia crowns. This is mainly due to the direction in which the loading was done. It was conducted at an angle of 30º in the study by Agustín-Panadero et al and not perpendicular to the occlusal like the present study. Other studies [29,30] used screw retained crowns and thus cannot be compared to the present one. Yet the use of cemented crowns is essential to get better resistance to fracture as demonstrated by Rosa et al [31]. According to the authors, cemented implant supported crowns have a significantly higher resistance to fracture than screw retained implant supported crowns.

As for the types of fractures that occurred, a study conducted on extracted natural teeth [32] showed similar results in that fractures in the feather edge group also happened mostly along the midline, just like the present study where this kind of fracture was described as type A fracture and was also predominant in the FEFL crown group however the limited fracture types observed might be due to the small sample size which is a limitation of the present study.

The use of resin cement also helped with the greater fracture resistance for both groups in this present study since according to Rohr et al [33], the use of resin cement for the cementation of monolithic zirconia crowns improves both flexural strength and resistance to fracture. However, a limit for this study resides in the cementation procedure. Indeed, it was impossible to apply the same constant force on all crowns during cementation as the crowns were held in place with digital pressure. It is advised in the literature to apply a pressure of 60N for a few seconds followed by a constant force of 20 to 30N [34]. This was not achieved in the current study and thus represents the first limit for our results.

The second and most important limit to the present study is the lack of artificial aging of the specimens. According to Iijima et al [35], fatiguing can lead to a loss of 54 to 64% of the resistance to fracture of zirconia prosthodontic components. The lack of artificial ageing might have affected the results of the present study.

Conclusion

Within the limitations of the present study, comparison of fracture resistance of cemented implant supported monolithic zirconia crowns with CFL and FEFL over zirconia implant abutments cemented on titanium bases reveal the following:

- Both CFL and FEFL monolithic zirconia crowns can be cemented on zirconia abutments over titanium bases in the posterior region as they were able to withstand the maximum masticatory force on molars.
- The newly proposed marginal thickness of 0.3 mm for extra thin feather edge monolithic zirconia implant supported crowns can bear the maximum occlusal forces and can thus be used in the posterior region.

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