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Fracture Resistance of 3-Unit Monolithic Zirconia Fixed Restorations Supported by three different substrates: A Comparative Study

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Abstract:
Objectives: To evaluate the fracture resistance of monolithic zirconia fixed dental prostheses (FDPs) supported byimplants, combined tooth-implant and teeth.
Materials and methods: Thirty partially edentulous mandibular epoxy resin castswere prepared at their posterior regionsand divided in to three equal groups (n=10) as the following: (group I) casts received two implants at second premolar and molar regions, group (TI) casts received one implant at second molar region, and (group T) casts with missing lower first molar. All the restorations were constructed from monolithic zirconia. All the samples were underwent thermomechanical loading (TCML) (5,000 x5°/55°, 3 x10^5 x 98 N). Then subsequently loaded until fracture using universal testing machine. Fracture sites were evaluated macroscopically.
Results: Fracture strength for group I (1893.5±315.3N) significantly differed from group TI (1297.29±222.3N), (*P* 0.034) with no significantly difference from group T (1640.56±587.8N), (*p = 0.488*). Fracture strength of group T was higher than those of group TI with no statistically significant difference (*p* =0.279).
Conclusion: The type of supportive abutmentsignificantlyaffect the fracture resistance of monolithic zirconia FDPs.Connecting implants rigidly to teeth gives a comparable fracture strength results with those of teeth connected. Monolithic zirconia FDPs have the potential to withstand the occlusal loads applied in the posterior area.
Keywords: Fracture resistance, fixed prostheses, implant, tooth implant, monolithic zirconia.

Introduction

Yttrium-stabilized zirconia (Y-TZP) display outstanding mechanical properties together with high fracture strength as well as fracture toughness due to its transformation toughening phenomenon, it has a flexural strength that mainly varies from 900 to 1200 MPa and a fracture toughness of 5to10MPa. Furthermore, zirconia is regarded as more biocompatible than other materials; ceramics, titanium, or metal alloys, which may enable a healthy as well as esthetic soft tissue response.[1]Y-TZP has been commonly used as a substitute to other materials for dental applications for instance bilayered crowns, FPDs supported either by natural teeth or dental implants or even a combination of implants and natural teeth, full anatomic monolithic zirconia crowns and FPDs, implant abutments, and screw-retained implant infrastructures.[1, 2]
Numerous studies have presented that zirconia has adequate strength to function as framework for posterior FPDs.[3,4]
This polycrystalline ceramic exhibits superior mechanical properties, biocompatibility, and simplicity of manufacture using CAD/CAM technology. Nevertheless, an early subject takes place was a chipping of the veneering ceramic which was stated in a various researches. [5, 6,7,8,9,10] it was manifest in the literature that, the zirconia framework infrequently underwent any fracture due to its high strength, its 'transformation toughening' phenomenon in addition to its relatively high fracture toughness and flexural strength making zirconia the strongest among all dental ceramics obtainable nowadays.
To evade the problem of ceramic veneer chipping and gaining the benefits of zirconia's strength, the idea of constructing a prosthesis made of completely zirconia (monolithic zirconia reconstructions) material was approached eliminating the veneering ceramic and depending on stains and glaze layering in different colors for achievement of esthetic appearance.[8,11,12]Full contour zirconia applications have been immense in the dental arena, involving single as well as multiple unit restorations, abutments and full arch implant retained restorations.[13]
Among the general methods that commonly used to evaluate the mechanical properties of dental ceramic involve; flexural strength, fracture toughness, Vickers hardness and fracture resistance utilizing a universal testing machine.
many in vitro studies were performed to evaluate the fracture resistance of monolithic zirconia single crown.[14,15,16]A few data regarding fracture resistance of monolithic zirconia fixed restorations has been reported yet Thus, this study aimed to evaluate the fracture resistance of implant-supported, tooth implant supported and comparing them with tooth supported fixed monolithic zirconia restorations. The null hypothesis to be tested was that in terms of fracture resistance thereare no differences between the treatment options either using implant-supported, tooth-implant supported or teeth-supported fixed monolithic zirconia restorations.

Material and methods

I. Preparation of the models:

For the construction of the laboratory models, Nissan typodent cast (Kilgore Nissin Dental Typodent Model India) was used, additional silicon and vacuum formed template indies were taken as a references for the amount of tooth reduction. Then, the teeth were manually prepared using low speed dental hand piece (DMY SKI-301 A, China) according to manufactures guiding principle with chamfer preparation of 1 mm, axial reduction of 1-1.5 mm and occlusal reduction of 2 mm and verified with previously mentioned indices. and from which 30 an epoxy resin cast (Exit 50- Egyptian Swiss For Manufacturing And

Trading 6 October Egyp)were duplicated using additional silicon impression material[17] (Betasil, (heavy-body and light-body) Muller-Omicron GmbH & Co KG Gemany) and then prepared to simulate clinical conditions for a three unit FPDs as follows:

Group I: Ten epoxy resin cast with twenty implants of 10mm length and 4mm width (Neo Biotech Co., Ltd Korea) were embedded at a distance of I I mm in both the premolar and molar regions.

Group TI: Ten epoxy resins cast with prepared mandibular second premolars and an implant in the molar region at a distance of I I mm

Group T: Ten epoxy resin cast with prepared mandibular second premolars and second molars at a distance of 11 mmin an attempt to create 10 clinical models representing a missing mandibular first molar. For (group I) and (groupTI) acrylic surgical stents were constructed on the Nissan typodent cast, then used on the epoxy resin cast to guide the implant placement. Surgical drilling was started by a pilot drill of 2.2 mm diameter that inserted to its full length till the drill stopper touches the cast ridge, followed by paralleling pin placement for paralleling conformation, and the drilling process was then continued with the other succeeding drill till the predetermined diameter was obtained using NeoBiotech surgical kit (IS Full KIT, Neo Biotech Co., Ltd Korea).Implantswere then inserted and finally cementable titanium abutments were screwed into the implants fixtures with a system specific ratchet and prepared to 6mm length.

Il. Fabrication FPDs

CAD/ CAM processing

The cast models of all groups were scanned using a 3D scanner(Cera Map400 Amanngirrbach, Germany) to enable full anatomical design using CAD software. The design settings for all groups were standardized as follows: the axial wall thickness was 1.5 mm and the occlusal thickness of 2 mm with minimal connector cross-section 9 mm^2 In order to ensure an even. Just before final prosthesis fabrication, CAD CAM wax mockup restorations were constructed using ceramill motion2 machine (Ceramill motion2 Amanngirrbach, Germany) and then placed on the epoxy resin casts for further verification. Finally the prosthesis is constructed from zolied high translucent zirconia (Zolid High Translucent White Amanngirrbach GmbH, Germany) and cemented to an epoxy resin casts using glass ionomer cement (Medicem (Glass Ionomer Luting Cement), PROMEDICA Dental Material GmbH, Germany).

Testing of the samples:

1. **Artificial ageing process**

Mechanical aging was performed using a programmable logic controlled equipment; the newly developed four stations multimodal ROBOTA chewing simulator integrated with thermo-cyclic protocol operated on servo-motor (Model ACH-09075DC-T, AD-TECH TECHNOLOGY CO., LTD., GERMANY).

The specimens were embedded in Teflon housing and fixed to the lower sample holder. A load of 10 kg, which is equivalent to 98 N of chewing force was exerted. The test was repeated 300000 times for clinical simulation of 2.6 years chewing condition.[18]all samples wereunderwent simultaneous thermal cycling between 5and 55 C° for 60 s each, with a dwell time of 12 s.

Fracture resistance testing:

After the artificial ageing process has been finished. All samples were individually mounted on a computer controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a loadcell of 5 kN and data were recorded using computer software (Instron® Bluehill Lite Software). Fracture test was done by compressive mode of load applied occlusally using a metallic rod with spherical tip (5.6 mm diameter) attached to the upper movable compartment of testing machine traveling at cross-head speed of 1mm/min. with tin foil sheet in-between to achieve homogenous stress distribution and minimization of the transmission of local force peaks. (Fig.1) The load at failure manifested by an audible crack and confirmed by a sharp drop at load-deflection curve recorded using computer software (Bluehill Lite Software Instron Instruments). The load required to fracture was recorded in Newton

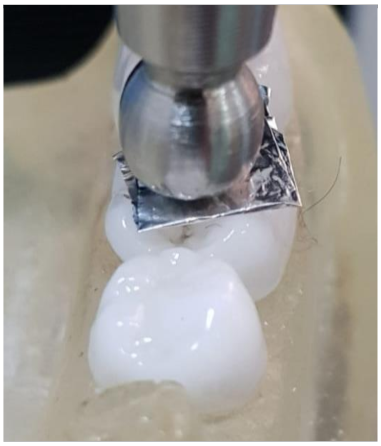

Figure 1: Tin foil sheet placed between the loading applicator and the

Statistical analysis

By using SPSS software (version 23 SPSS Inc., Chicago, Ill., USA); the normality of the distribution was assessed by Kolmogorov-Smirnov test. One way analysis of variance (ANOVA) was used for comparing between the groups. When a statistical difference was found, Post Hoc (Tukey HSD) Tests were used for multiple comparisons between study groups each one to another. The level of significant was set at ≤ 0.05 for all statistical analysis and confidence interval at 95% (95% CI).

Results

All the aged FDPs were survived without any observable defects. The data were collected, tabulated and then analyzed.The mean values and standard deviations of fracture resistance for each group were recorded. One way ANOVA test for fracture resistance between study groups represented statistical significant difference (*P* 0.042).(Table.1)

Post Hoc (Tukey HSD) test for checking the individual variation between FDPs supported by different supportive abutment represented that, implant supported FDPs group display high fracture strength with statistical significant difference (*P* 0.034) than tooth- implant supported FDPs group and high fracture strength with no statistical significant difference (*P* 0.488) than teeth supported FDPs group, teeth supported FDPs group display high fracture strength with no statistical significant difference (*P* 0.279) than tooth- implant supported FDPs group.

Table 1: One way ANOVA test for fracture resistance between study groups

	Sum of Squares	df	Mean Square	F	*P* value
Between Groups	1253447.3	2	626723.7	3.8	.042
Within Groups	2965532.8	18	164751.8		
Total	4218980.1	20			

***P* significant at ≤ 0.05**

Fracture mode of the tested FDPs

Most damages occurred near the point of loading and the fracture lines ran buccal or basal to across one of the connectors in all the samples of study groups.

Discussion

In-vitro studies were carried out mostly to overcome the limitations of clinical short term evaluation, difficult of repeatability and standardization of the clinical study.

In this study, the cast models were constructed from an epoxy resin material and the teeth were prepared as this material has an appropriate modulus of elasticity close to the bone analog material (approximately 20 GPa).[19]

The space between the abutments in the cast model was 11mm as previous study by **Chaar et al**[20]who declare that, span length of clinical models representative a missing first molar equal to 11 mm length .

Posterior edentulous region represent one of the frequent indications for the dental treatment in mandible as well as maxilla.[21]

Though implant retained FDPs are one of the treatment option for posterior free distal extension area, lack of the space or implant failure to integrate may lead to the using of tooth-implant connection.[22,23]

Monolithic zirconia FDPs were used in this study as they have markedly superior fracture resistance, superior chipping and flexural fracture resistance relative to their veneered counterparts.[24] From both radial cracking and chipping manners, Zirconia-based ceramic monoliths have the greater resistance to failure than those of lithium disilicate glass–ceramics, but still less esthetic.[25,15]

The thickness of the fabricated monolithic zirconia FDPs was 1-1.5mm as recommended by manufacturer in addition to study by**Lan et al**[14] who reported that; for clinical use, a zirconia prosthesis with a minimum thickness of 0.8 mm is recommended to allow for operative deviation and error in occlusal adjustment. All the restorations were permanently cemented by glass ionomer cement according to several previous studies.[24,47,48 ,49,50]

In the present study, for oral environment simulation all the samples were subjected to an artificial aging process. Studies reported that average of the masticatory loads range from 50 to 250 N.[20,21,18]

In this study a cyclic loading force of 98 N with a total number of 300000 cycles were applied to simulate clinical situation for 2.5 years. [18] thermocycling conventionally used to simulate the thermal changes occurring in the oral cavity during eating, drinking, or breathing. It was performed between5 and 55°C. This range has already been applied in other studies.[20,26,27,28,29]

In our study, after the artificial aging process, all tested groups exhibited minimal fracture resistance greater than those of natural maximum biting forces in the posterior area. The fracture resistance that recorded was more than 500 N, which is measured to be the minor level of fracture strength that accepted for FPDs in the posterior area.[30,31]

When comparing the different supportive abutments with the same superstructure zirconia monolithic FDPs we have that the type of supportive abutments exposed a significant effect on the fracture resistance of the zirconia. The maximal fracture strength was recorded for the implants supported followed by teeth supported then interconnected tooth implant retained group.

The results of the current study were settled by **Kolbeck and co-workers**[32] who tested the impacts of different abutment support on the load-bearing capacity of 3-unit zirconia FPDs and concluded that interconnected tooth implant retained restorations display lower load-bearing capacity than those of tooth-retained prosthesis.

studies results that performed by **Vult von Steyern el al**[33] and

Sarafidou et al[30] were partially analogous to our current results as they presented that implant retained prosthesis showed the maximal load-bearing capacity, the differences in their studies were that, combined implant-tooth supported restorations exhibited the highest load-bearing capacity than teeth supported restorations. Though there were differences between our study and these two studies, they are in accordance that interconnected tooth implant retained FPDs endure higher loads than the average of biting forces and therefore possibly used for clinical applications.

The results of the current study were also in agreement with**Sarafidou et al**[2]whofound that, implant- supported restorations were exhibited the highest load-bearing capacity than teeth supported and tooth–implant supported fixed restorations. In addition, after ageing process implant-tooth-supported prosthesis display a sufficient load-bearing capacity to be used clinically.

results of the present study were also in accordance with **Kolbeck et al**[32] who demonstrated that, teeth-supported FPDs showed the higher fracture force than tooth–implant supported fixed restorations. However, Fracture strength of tooth–tooth- and implant–tooth retained all-ceramic FDPs showed sufficient fracture resistance for posterior regions.

The current study results were in agreement with **Alkharratet al**[34] who declared that, The fracture strength of implant-retained FPDs were however, higher than those of combined tooth–implant- retained FPDs, clinical use of their seems to be justified.

The results of this study were in contradiction with**Al-Wahadniet al**[35] who found that, the bridges supported by mixed implant-tooth abutments showed highest fracture loads than that supported by implant abutments only and than those supported entirely by natural teeth.

Our results were also in contradiction with **Nothdurft et a1**[28] who examined 3-unit bridge placed on a combined implant-tooth and free standing implant-supported FPDs with all ceramic abutments and presented that the higher of

failure strength was recorded for the combined implant-tooth retained FPDs than those for free standing implant-retained group.

Conclusions

Within the limitation of this study, the following conclusions could be drawn

1- Monolithic zirconia FPDs have the potential to resist the occlusal loads applied in the posterior area**.**
2- The fracture strength of monolithic zirconia FPDs was affected by the type of supportive abutment, through which the implants supported FDPs group display the highest fracture strength followed by teeth supported then interconnected tooth implant supported FDPs.

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