Screw Retained Implant Supported Zirconia Anterior Fixed Dental Prosthesis with Different Abutment Angulations: Evaluation of Fracture Resistance and Failure Modes

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Abstract:

Objective: To evaluate the effect of different implant-abutment angulations on the fracture resistance of anterior three-unit implant-supported zirconia fixed dental prosthesis. **Materials and Methods:** Five groups (n=10) were fabricated to represent maxillary anterior three-unit zirconia fixed dental prosthesis supported by two implants with different implant-abutment angulations including group 0^o-0^o, group 0^o-17.5^o, group 0^o-35^o, group 17.5^o-17.5^o and group 35^o-35^o. Zirconia FDPs were cemented by self-adhesive resin cement. All specimens were subjected to thermocycling (5000 X $5^oC/55^oC$) and mechanical loading (50 N X 120,000 cycles /1.6Hz). Static loading was applied using the universal testing machine at a crosshead speed of 1 mm/min. One-way ANOVA and Post hoc Tukey test were applied and statistical significance was set at P value < 0.05. **Results:** All specimens subjected to TCML survived without mechanical failure. Group 0°-35°, group 17.5°-17.5° and group 35°-35° (654.24 ± 81.66 N; 551.34 ± 87.79 N; 382.42 ± 52.07 N, respectively) showed a significant decrease in fracture resistance compared to that in group 0°-0° which showed the highest fracture resistance (759.72 ± 88.33 N) (P=0.04, <0.001, <0.001 respectively). There was no significant difference between group 0°-17.5° (746.04 ± 85.02 N) (P=0.99) compared to that in group 0°-0°. **Conclusions:** The fracture resistance of zirconia FDPs decreased as implant-abutment angulation increased. Angled abutments of 0^o, 17.5^o, and 35^o could be used as a suitable option for restoration of nonideally placed implants but within limitations, because there was a significant decrease in fracture resistance in group 17.5°-17.5° and group 35°-35°.

Introduction:

Dental implants are most commonly used for rehabilitation of the partially or completely edentulous cases.[1] It is known that missing teeth in the esthetically anterior maxillary area leads to alveolar bone resorption from the labial aspect which compromised the positioning of the implant making it difficult for the clinician to restore with conventional abutments and influencing the final esthetics of prosthesis.[2]

The use of angled abutments was recommended to facilitate prosthesis fabrication. The clinician used angled abutments to avoid anatomical structures when placing the implants.[3] In a study performed by Tian et al.[4], they concluded that stress distribution decreased in the peri-implant bone of angulated abutments under certain conditions. This result suggested the use of angled abutments as a suitable option for the restoration of implants placed in nonideal locations.

Zirconia was widely used for implant-supported restoration because of its mechanical and esthetic properties.[5]Tetragonal crystalline structure of zirconia enabled it to undergo a transformation toughening under critical load that enhanced its mechanical resistance against microcracks propagation.[6] In a study performed by Traini et al.[7], they evaluated the fracture resistance of single implant-supported crowns fabricated from different restorative materials. They concluded that the implant-supported zirconia core group showed a significantly higher fracture strength value (1638 ± 662 N).

Using yttrium-stabilized zirconium dioxide in the esthetic anterior area was highly useful. However, their mechanical behavior upon loading was still critical because unfavorable forces could be transmitted to the implant or the restoration by the angulated abutments, thereby compromising the treatment prognosis.[8]

Despite the high mechanical properties of zirconia-based restorations, clinical failures still occur, usually at the connector area. Similarly, Saker et al.[9] evaluated the resistance to fracture of prefabricated straight and angulated zirconia implant-abutment-supported anterior three-unit lithium-disilicate prostheses. The fracture was located between the loading point and one of the connectors. The occlusogingival dimension of all-ceramic implant-supported fixed dental prosthesis should be maximized at the connector area.

The present study aimed to evaluate the fracture resistance of implant-supported anterior three-unit zirconia fixed dental prosthesis with different abutment angulations. The null hypothesis was to test that there was no difference in the fracture resistance of anterior three-unit zirconia FDP supported by two implants with different abutment angulations.The sample size was calculated by G*Power (3.1) with effect size

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(0.5739725), α level (0.05), minimum power (0.80)and maximum power (0.99). The calculated total sample size was 25 (minimum) and 65 maximum). Thus, the total sample size in the present study was determined to be (50) which was equally distributed in five groups (n=10 for each group). Five groups (n=10) of different abutment angulations were designed. Group (0^o-0^o) represented the ideal implant position which made it possible to use straight prefabricated titanium abutments. The other test groups represented compromised implant positions that required angled abutments 17.5^o and 35^o.[10] To create an edentulous area, maxillary right central, lateral, and canine teeth were removed from a typodont model (Pro2001-UL-sp-FEM-32, Nissin, Japan) of the maxilla. After this, the sockets of teeth were sealed with wax. The duplicating silicon material was used to accurately replicate the typodont and created a silicon mold. In turn, the mold was poured with an epoxy resin material to obtain a maxillary model with an anterior edentulous area. Two implants were drilled in each model in the position of maxillary right central and canine at different angulations (0^o, 17.5^o, and 35^o) with the aid of the surgical stent. Abutments were attached to their implant fixtures at torque 25 Ncm according to manufacturer recommendations. Group (0^o -0 ^{o}) consisted of two implants attached to straight abutments, group (0^o -17.5^o) consisted of two implants attached to straight and 17.5^o angled abutments while group (0^o-35^o) consisted of two implants with straight and 35^o angled abutments. Group (17.5^o-17.5^o) consisted of two implants with 17.5^o angled abutments and group (35^o-35^o) consisted of two implants with 35^o angled abutments. Anterior three-unit fixed dental prostheses were designed by using CAD/CAM software (Dental CAD 3.0 Galway, Exocad GmbH, Germany) with minimum wall thickness (0.6 mm), connector dimensions 9 mm^2 and screw channel diameter (2.3 mm). Anterior three-unit fixed dental prostheses were fabricated from super translucent multilayered zirconia by CAD/CAM system. The outer surface of the titanium prosthesis cap and the fitting surface of zirconia were treated with (50 μm) aluminum oxide powder (cobra aluminum oxide, Renefert, USA) at 4- pressure and 6- pressure, respectively at a distance of 10 mm. FDPs were cleaned and dried, then one coat of zirconia primer was applied (MKZ Primer, Bredent, Germany) for 60 seconds and dried gently for 3-5 seconds according to the manufacturer's recommendations. Zirconia-fixed dental prostheses were cemented to their corresponding abutments by self-adhesive dual-cure resin cement under constant load. Excess cement was removed then light curing was applied for 20 seconds for each side according to the manufacturer's recommendations. Zirconia FDPS were subjected to thermocycling (5000 cycles 5 ^{o}C to 55 ^{o}C; dwell time: 20 seconds; transfer time: 5 seconds) and then mechanical cycling was applied with a cycling device with 1.6 mm diameter that induced 50 N loads for 120,000 times with a frequency of 1.6 Hz. Static load to fracture test was applied to all survived specimens using a computer-controlled universal testing machine (Instron universal testing machine, Model 3345, Instron, USA). The upper compartment consists of a metallic rod with a spherical tip of 5 mm diameter. A 0.5 mm tin foil sheet was positioned in between to ensure even stress distribution. The force was applied by a load cell of 5 kN at a crosshead speed of 1 mm/min.[20] The load was transferred to the palatal surface of the pontic 2 mm below the incisal edge at an angle of 135-degree angle from the horizontal plane.[10] The failure load data were recorded in Newton using the machine's software

Figure. Specimen fixed to the customized lower compartment of computer-controlled universal testing machine.

(BlueHill 3 software version 3.3, Instron, USA), Figure1.

Statistical Analysis: Data normality was detected by using Shapiro–Wilk test which revealed that all data were in a normal distribution. Statistical analysis and data interpretation were performed using the computer program IBM SPSS (Statistical package for social science). One-way ANOVA (analysis of variance) was used to compare more than two groups of numerical (parametric) data followed by the Post Hoc Tukey test. Statistical significance was set at *P* value < 0.05.

Results:

The fracture resistance values for all groups were presented in Table . All tested specimens subjected to artificial aging survived with no fractures of FDPS or abutments. Group 0°-35°, group 17.5°-17.5° and group 35°-35° (654.24 ± 81.66; 551.34 ± 87.79; 382.42 ± 52.07 N, respectively) showed a significant decrease compared to that in group 0°-0° (759.72 ± 88.33 N) (P=0.04, <0.001, <0.001, respectively) which showed the highest fracture resistance value. Group 0°-17.5° (746.04 ± 85.02 N) (P=0.99) showed non-significance compared to that in group 0°-0°. Group 17.5°-17.5° and group 35°-35° (551.34 ± 87.79 N; 382.42 ± 52.07, respectively) showed a significant decrease compared to that in group 0°-17.5° (746.04 ± 85.02 N) (P=<0.001, <0.00, respectively) while group 0°-35° (654.24 ± 81.66 N) (P=0.095) showed non-significance compared to that in group 0°-17.5°. Group 17.5°-17.5° and group 35°-35° (551.34 ± 87.79 N; 382.42 ± 52.07 N, respectively) showed a significant decrease compared to that in group 0°-35° (654.24 ± 81.66 N) (P=0.047, <0.001, respectively). Group 35°-35° (382.42 ± 52.07 N) (P=<0.001) showed a significant

Table: Comparison of fracture resistance (N) between group 0°-0°, group 0°-17.5°, group 0°-35°, group 17.5°-17.5° and group 35°-35°

	Group 0°-0°	Group 0°-17.5°	Group 0°-35°	Group 17.5°-17.5°	Group 35°-35°	P
Fracture Resistance (N)	759.72 ± 88.33	746.04 ± 85.02	654.24 ± 81.66	551.34 ± 87.79	382.42 ± 52.07	<0.001*
Post-hoc		P1=0.99	P1=0.04* P2=0.095	P1=<0.001* P2=<0.001* P3=0.047*	P1=<0.001* P2=<0.001* P3=<0.001* P4=<0.001*	

Data expressed as mean ± SD
SD: standard deviation P: Probability *: significance <0.05
The test used: One-way ANOVA followed by post-hoc Tukey

P1: significance relative to Group 0°-0°
P2: significance relative to Group 0°-17°
P3: significance relative to Group 0°-35°
P4: significance relative to Group 17.5°-17.5°

decrease compared to that in group 0°-35° (654.24 ± 81.66 N) (P=0.047, <0.001, respectively). Group 35°-35° (382.42 ± 52.07 N) (P=<0.001) showed a significant decrease compared to that in group 17.5°-17.5°.

Discussion:

The present in vitro study evaluated the influence of different implant-abutment angulations on the resistance to fracture of zirconia anterior fixed dental prosthesis. The null hypothesis of the current study was rejected as implant-abutment angulation was found to be a statistically significant variable on the fracture resistance of the zirconia anterior fixed dental prosthesis.

To simulate clinical conditions, bar-like specimens were not used, instead of that the specimens in the current study were designed as three-unit fixed dental prostheses with normal anatomic shapes. It was known that the elastic modulus of epoxy resin material was detected as the elastic modulus of cancellous bone and dentin.[11] Epoxy resin material was selected as the material that supports all specimens. In this study, all tested groups had the same implant diameter (4 mm) to avoid the potential influence of diameter changes on results.[12]

The morphology of existing bone in the premaxilla often required that implants are placed at angles that are difficult to restore with conventional abutments.[13] Angulated abutments were used to correct this condition and make prosthesis fabrication easier. In the present study, the static load was applied with a labial apical direction near the cingulum area of mandibular incisors to simulate centric occlusion.[14]

Yttrium-stabilized zirconium dioxide showed the best mechanical properties of all dental ceramics.[15] In the present study, monolithic zirconia restorations were used due to the improved behavior of monolithic restorations compared to bi-layered restorations, when used for crowns and FPDs. The interface between the core and veneer layers was detected as the weakest part in a veneered system, but it was eliminated in a monolithic restoration, thus the chipping problem was overcomed.[16]

From the results of the current study, group 0°-35°, group 17.5°-17.5°, and group 35°-35° showed a significant decrease in fracture resistance (654.24 ± 81.66; 551.34 ± 87.79; 382.42 ± 52.07 N, respectively) compared to that in group 0°-0° that showed the highest fracture resistance among all groups (759.72 ± 88.33 N) (P=0.04, <0.001). The results of the present study showed that as angulation increased, the greater off-axis force induced more stress and strain in implant components. These results come in agreement with a study performed by EL-Sheikh et al. [17] in which they concluded that there was a statistically significant increase in stress and strain when abutment angulation increased. Similar findings are observed by Bholla et al. [18] that showed a 26% increase in stress in the 25° angulated abutment than in the straight abutment.

Opposite to the results of the present study, Katsavochristou et al.[19] investigated the fracture resistance of screw-retained implant-supported monolithic zirconia custom abutments with different angulations (0^{o}, 15^{o}, and 25^{o}). They concluded that the abutments with 15^{o} angulation showed the highest resistance to fracture (962.37 ± 93.81 N) compared to 25^{o} and 0^{o}angled zirconia abutments. Fracture resistance significantly increased as angulation of the custom zirconia abutment increased. This result could be due to different abutment thicknesses at the cervical region of the zirconia abutments fabricated for each group.According to the results of the current study, group 0°-17.5° (746.04 ± 85.02 N) showed a non-significant difference in fracture resistance compared to that in group 0°-0° (759.72 ± 88.33 N) (P=0.99). The results of the present study come in agreement with a study performed by Shende et al.[3] in which they studied stresses patterns within bone surrounding a dental implant when abutments with different angulations 0°, 15°, and 20° were used in the anterior maxillary region.

They concluded that only an 11% increase in shear stress was detected when the abutment angulations were increased from 0° to 25°.

On analysis of the results of the present study, it was detected that group 0°-35° (654.24 ± 81.66 N) showed a non-significant difference in fracture resistance compared to that in group 0°-17.5° (746.04 ± 85.02 N) (P=0.095). Similar findings were shown by Wu et al.[20] detected a decrease in the magnitude of stress with oblique loading in angulated abutments up to 27°. The results of this study could be explained that as the direction of load is opposite to the direction of the angled abutment, the stress on the surrounding bone and the implant decreased.

The current study showed that group 17.5°-17.5° and group 35°-35° (551.34 ± 87.79; 382.42 ± 52.07 N, respectively) showed a significant decrease in fracture resistance compared to that in group 0°-17.5° (746.04 ± 85.02 N) (P=<0.001, <0.001 respectively). Similar findings were observed in a study by Kapoor et al.[13] in which they evaluated the stress distribution in an anterior maxillary implant-supported prosthesis with 0°, 15°, and 25° angulated titanium and zirconia abutments. They concluded that stress was shown to increase with an increase in angulation. This result could be because when angled abutments are used, the stress is distributed asymmetrically with an increase in stress in the area opposite the direction of the abutment.

On assessing the results, it was observed that group 17.5°-17.5° and group 35°-35° (551.34 ± 87.79; 382.42 ± 52.07 N, respectively) showed a significant decrease in fracture resistance compared to that in group 0°-35° (654.24 ± 81.66 N) (P=0.047, <0.001, respectively). Similar to the results of the current study, Anitua et al.[21] assessed the effect of implant length and tilting on bone stresses in single-unit implant restorations. The implant titling of 0, 17◦, 30◦, and 45◦ was analyzed. Finite element analysis indicated that tilting the implant by 17◦ doubled the stress received by the bone. The highest increase was in the case of implant tilting at 45◦.

The purpose of restoration is to maintain strength while resisting the forces of occlusion. Saker et al.[9] reported that maximum masticatory forces varied greatly, from 190 to 290 N, in the anterior region and could reach up to 360 N in the molar region, depending on facial morphology and age. The results of the present study showed that all tested specimens have the potential to withstand anterior physiologic forces. Thus, the current study suggested that angled abutments of 0^o, 17.5^o, and 35^o could be a suitable option for restoration of implants placed in nonideal locations but within limitations, because there was a significant decrease in fracture resistance observed when both implants received angled abutments as group 17.5°-17.5° and group 35°-35°.

The limitations of this study included being an in vitro study. In vitro studies cannot reproduce all clinical parameters. The tests were performed only in the maxillary anterior region and the results may vary in posterior teeth due to morphological differences**.**

Conclusions:

Within the limitation of this in vitro study, the following conclusions were drawn: The fracture resistance of implant-supported zirconia FDPs was significantly decreased as implant-abutment angulations increased.

Although all tested specimens have the potential to withstand physiologic forces applied in the anterior region there was a significant decrease in fracture resistance observed when both implants received angled abutments as group 17.5°-17.5° and group 35°-35°.

Angled abutments (17.5^o and 35^o) could be used clinically as a suitable option for restoration of implant placed in a nonideal location.

References

1. G Guguloth H, Duggineni C, Chitturi R, Sujesh M, Ravvali T, Amiti R. Correlation between abutment angulation and off-axial stresses on biomechanical behavior of titanium and zirconium implants in the anterior maxilla: A three-dimensional finite element analysis study. J Indian Prosthodont Soc. 2019;19(4):353-361.
2. Bahuguna R, Anand B, Kumar D, Aeran H, Anand V, Gulati M. Evaluation of stress patterns in bone around dental implant for different abutment angulations under axial and oblique loading: A finite element analysis. Natl J Maxillofac Surg. 2013;4(1):46-51.
3. Shende S, Jadhav A, Edake D, Patil A, Patil H, Agrawal N. Analysis of stress distribution on the bone around an implant placed in the anterior maxilla using three different abutment angulations by means of finite element analysis. J Pharm Bioallied Sci. 2021;13(2):1591-1596.
4. Tian K, Chen J, Han L, Yang J, Huang W, Wu D. Angled abutments result in increased or decreased stress on surrounding bone of single-unit dental implants: a finite element analysis. Medical Engineering & Physics. 2012;34(10):1526-1557.
5. Geckili E, Geckili O, Bilhan H, Kutay O, Bilgin T. Clinical comparison of screw-retained and screwless morse taper implant-abutment connections: one-year postloading results. Int J Oral Maxillofac Implants. 2017;32(5):1123-1131.
6. Brizuela-Velasco A, Diéguez-Pereira M, Álvarez-Arenal Á, Chávarri-Prado D, Solaberrieta E, Fernández-González F, et al.. Fracture resistance of monolithic high translucency zirconia implant-supported crowns. Implant Dent. 2016;25(5):624-632.

7. Traini T, Sorrentino R, Gherlone E, Perfetti F, Bollero P, Zarone F. Fracture strength of zirconia and alumina ceramic crowns supported by implants. J Oral Implantol. 2015;41(S1):352-361.
8. ArunKumar G, Mahesh B, George D. Three-dimensional finite element analysis of stress distribution around implant with straight and angled abutments in different bone qualities. J Indian Prosthodont Soc. 2013;13(4):466-538.
9. Saker S, El-Shahat S, Ghazy M. Fracture resistance of straight and angulated zirconia implant abutments supporting anterior three-unit lithium disilicate fixed dental prostheses. Int J Oral Maxillofac Implants. 2016; 31(6): 1240-1246.
10. Al-Zordk W, Al-Dobaisi T, Ghazy M. Torque maintenance of screw-retained implant-supported anterior fixed dental prosthesis with different abutment angulations after aging. Int J Oral Maxillofac Implants. 2021;36(4):723-729.
11. Edelhoff D, Schweiger J, Prandtner O, Stimmelmayr M, Güth J. Metal-free implant-supported single-tooth restorations. Part I: Abutments and cemented crowns. Quintessence Int J. 2019;50(3):176-184.
12. Prado R, Pereira G, Bottino M, Melo R, Valandro L. Effect of ceramic thickness, grinding, and aging on the mechanical behavior of a polycrystalline zirconia. Braz Oral Res. 2017;31(S1):82.
13. Kapoor S, Rodrigues S, Mahesh M, Shetty T, Pai U, Saldanha S, et al.. Evaluation of stress generated with different abutment materials and angulations under axial and oblique loading in the anterior maxilla: three-dimensional finite element analysis. Int J Dent. 2021;2021(S1):9205930.
14. Lugas A, Terzini M, Zanetti E, Schierano G, Manzella C, Baldi D, et al.. In vitro simulation of dental implant bridges removal: influence of luting agent and abutments geometry on retrievability. Dent Mater J. 2020;13(12):2797.
15. Alqahtani F and Al Homidhi M. Evaluation of the mode of failure of abutments supporting implant-supported fixed partial dentures via different retention techniques. Niger J Clin Pract. 2021;24(2):220-224.
16. Park C, Phark J, Chee W. Evaluation of fracture resistance of varying thicknesses of zirconia around implant abutment cylinders. J Oral Implantol. 2017;43(5):328-332.
17. El-Sheikh M, Mostafa T. Effect of different angulations and collar lengths of conical hybrid implant abutment on screw loosening after dynamic cyclic loading. Int J Implant Dent. 2018;4(1):39.
18. Bholla P, Jacob J, Vamsi K, Ariga P. Influence of occlusal loading on stress patterns at the bone-implant interface by angulated abutments in the anterior maxilla: a three-dimensional finite-element study. J dent impl. 2014;4(1):93-97.
19. Katsavochristou A, Sierraalta M, Saglik B, Koumoulis D, George F, Razzoog M. Implant angulation effect on the fracture resistance of monolithic zirconia custom abutments: an in vitro study. J Prosthodont. 2020;29(5):394-400.
20. Wu D, Tian K, Chen J, Jin H, Huang W, Liu Y. A further finite element stress analysis of angled abutments for an implant placed in the anterior maxilla. Comput Math Methods Med. 2015;4(1):295-395.
21. Anitua E, Alkhraist M, Piñas L, Begoña L, Orive G. Implant survival and crestal bone loss around extra-short implants supporting a fixed denture: the effect of crown height space, crown-to-implant ratio, and offset placement of the prosthesis. Int J Oral Maxillofac Implants. 2014;29(3):682-689