eor.istanbul.edu.tr
Official Publication of Istanbul University Faculty of Dentistry
Eur Oral Res 2025; 59(1): 27-32
Original research

In vitro fracture resistance of implant-supported terminal zirconia cantilevered frameworks

Tabark Shihab Al Bayati[1], **Saja Ali Muhsin**[2]

Purpose
This study aims to investigate the in vitro fracture loads of three different terminal cantilever forms of implant-supported zirconia frameworks.

Materials and Methods
A total of 30 implant-supported zirconia frameworks (Aconia, China) were CAD/CAM-fabricated and divided into three groups, each with a distal abutment cantilever form design of 5mm: Group A had square cantilevers, Group B had oval cantilevers, and Group C had oval-square cantilevers. Universal testing machine was used to apply vertical loads to the samples, and the fracture loads were recorded. Variance analysis and Tukey's post-hoc tests were applied for statistical evaluation.

Results
There was no significant difference between the mean fracture loads of Group B (587.8±112.2 N) and Group C (591.3 ±81.3 N), but both of these groups exhibited significantly lower fracture loads compared to Group A (893.8±145 N, p<0.001 for each).

Conclusion
Within the scope of this experimental study, it can be concluded that implant-supported terminal square shaped cantilever zirconia frameworks, each measuring 5 mm from the distal abutment, are more likely to exhibit greater resistance to vertical loads compared to their oval and oval-square counterparts.

Keywords: *Fixed partial denture, zirconia, implant, fracture load, dental prosthesis*

Introduction

Cantilevered Fixed Partial Dentures (CFPDs) are among the alternative options available for patients with distal extension edentulous ridges. The evaluations vary, and some researchers have expressed concerns about the risks associated with CFPDs (1). Implant restorations may experience mechanical failure due to the potential interference of cantilevers with biomechanics (2). Patients with critical anatomical features, such as high ridge bone resorption structures near the maxillary sinus floor and inferior alveolar nerves, are recommended to opt for an implant-retained prosthesis. However, the demand for CFPDs has surged due to factors such as cost-effectiveness, patient comfort, and acceptance (3).

Loads on distal extensions can cause bending because of the hinging action of the restorations (4). Despite the absence of a consensus on the maximum permissible cantilever span, suggestions include considering anterior-posterior extension and the use of various prosthodontic materials (5). The Shorter Dental-Arch concept (SDA) may provide an alternative treatment option to reduce restoration bending and stress on implant/bone contacts caused by cantilever loads. Therefore, it is advisable to keep the distal extensions as short as possible (6).

ORCID IDs of the authors: T.S. 0009-0003-3576-6591; S.A.M. 0000-0003-0272-7409

[1]Department of Dental Techniques, College of Health and Medical Techniques, Middle Technical University, Ministry of Higher Education and Scientific Research, Baghdad, Iraq

[2]Department of Dental Techniques, College of Health and Medical Techniques, Middle Technical University, Ministry of Higher Education and Scientific Research, Baghdad, Iraq

Corresponding Author: Saja Ali Muhsin

E-mail: assist.prof.dr.sajaalimuhsin@gmail.com

Received: 6 August 2023
Revised: 9 September 2023
Accepted: 12 October 2023

DOI: 10.26650/eor.20241338647

How to cite: *Shihab T, Muhsin SA. In vitro fracture resistance of implant-supported terminal zirconia cantilevered frameworks. Eur Oral Res 2025; 59(1): 27-32.* DOI: 10.26650/eor.20241338647

Recently, the utilization of zirconia (Zr) dental restorations has witnessed a substantial increase. This surge can be attributed to their enhanced biocompatibility and mechanical attributes, including fracture strength and toughness, as well as physical properties such as dimensional stability and tooth color matching (7,3). Several authors have suggested that occlusal forces may have the potential to damage the cantilever structure by acting as a lever. However, there exists a lack of empirical consensus in the literature concerning classic titanium and Zr substructures due to their limited study, primarily in vitro and retrospective research studies (8). Zr ceramics find application in single crowns, implant abutments, frameworks, and fixed partial dentures (FPD) (9). The formation of inherent flaws and microcracks is an outcome of the intrinsic brittleness of ceramics, which continues to pose a fundamental challenge in the use of metal-free ceramic restorations (10). Over time, microcracks may propagate, ultimately leading to restorative fracture and failure (11). Zr dental restorations have demonstrated an increased resistance to crack propagation and microcrack formation. This heightened resistance may be attributed to the conversion of the tetragonal phase to the monoclinic phase through transformation toughening (12).

Computer-aided design and computer-aided manufacturing (CAD/CAM) represents an additional production method that plays a pivotal role in dentistry (13,14). The production of an ideal metal-ceramic restoration involves a myriad of intricate techniques that are method-sensitive, time-consuming and costly. With the advent of state-of-the-art CAD/CAM technology, it is now feasible to precisely fabricate Zr abutments for implant-supported fixed dental prostheses (FDPs) (15,16). Nonetheless, despite their remarkable mechanical capabilities, Zr FPDs are not exempt from challenges (17). FPDs located in posterior regions should ideally be able to withstand masticatory pressures without mechanical failure (18). This is of paramount importance for posterior restorations in terms of biofunctionality, as they are designed for functional mastication rather than purely aesthetic considerations (19). Molars are particularly susceptible to complex occlusal stresses, which can range from 300 to 800N. In certain patients exhibiting parafunctional behaviors, occlusal loads can escalate to 1000N (20). In terms of the implications and survival rates of Zr FPDs, the data is contingent on study designs and specific circumstances (21).

The use of implant-supported CAD/CAM fabricated cantilevered Zr frameworks (ISCZFs) in distal extension-free end saddle zones has arisen out of necessity (22,23). Currently, there is limited and insufficient evidence regarding the strength of ISCZFs concerning the size and dimensions of the cantilever (24,25). The indirect fabrication of restorations through CAD/CAM empowers dentists and practitioners to design a wide range of restorations, from simple inlays/onlays to single crowns, fixed partial dentures (FPDs), and even maxillofacial prostheses. CAD/CAM technology comes with no constraints, resulting in restorations that are long-lasting, aesthetically pleasing, biocompatible, possess greater marginal and internal adaptability, and are efficiently manufactured (26). However, the milling method involving diamond burs for the cutting blocks under torque may initially cause tiny, non-visible fractures that could propagate and eventually lead to restoration failure (27).

Many in-vitro studies related to implant-supported restorations excluded the use of cementation during testing procedures to ensure uniform stress distribution along the occlusal surface. Cement retention is often associated with occlusal integrity (28). Removing any excess cement material entirely from the subgingival area can be challenging (29). During the fabrication process, the flowable cement material may have lined the inner surface of the implant-supported crown, resulting in a tight fit between the restoration and the abutment. Cementless fixation (CLF) involves a recessed device on the occlusal surface of the abutment that uniformly distributes stresses along the occlusal surface (30). Consequently, CLF has been proposed as a novel retentive method for implant prostheses that do not rely on cement or screws. However, there have been few studies investigating the biomechanical aspects of the CLF implant crown, leaving the optimal design for reducing stress distribution on the CLF implant restoration uncertain.

In the present in-vitro study, the fracture load of the cross-sectional dimension of the cantilever on ISCZF was considered as the standard. The ultimate fracture strength of the specimens was assessed using a universal mechanical tester and incremental loading until failure. This method, known for its simplicity and accuracy, has been employed in previous studies to evaluate cantilever prostheses (31,32). The objective of this in-vitro study is to examine the fracture load of three different forms of terminal Zr cantilevers. According to the null hypothesis, the different forms of the terminal cantilevers would not have an impact on the fracture load of ISCZFs.

Materials and Methods

Sample preparation

In this in-vitro study, CAD/CAM ISCZF specimens (n=33) were fabricated using Aconia Zirconia blank (HT+, Sichuan, China). The specimens were then divided into three main groups (n=11) based on the forms of the terminal cantilever: Group A (Oval-shaped cantilever), Group B (Square-shaped cantilever), and Group C (Oval-square shaped cantilever).

The study utilized a Dentium arch (Dentium, Cypress CA, USA) to secure two mono-screw implants measuring 5mm in diameter and 10mm in height (De-Tech mono-screw implant, Ankara, Turkey). Digital implant-supported cantilever zirconia frameworks (ISCZFs) were designed for the study groups using Exocad dental (3.0 Galway 2018, Germany), and fabricated using the In lab imes-icore CORITEC 350i PRO milling device (GmbH & Co, Germany). The frameworks were milled from Aconia Zirconia blank HT+. Two identical cemented-retained mono-titanium abutments were used in the preparation of Zr implant-supported frameworks.

For the Co-Cr base model, a 3D-printed version was created using Bego Co-Cr (BEGO GmbH & Co, Germany) and the Riton Dual-150 DMLS Dental Laboratory Fit Laser Metal 3D Printer (Guangzhou, China) (33,34). All frameworks were designed with dimensions corresponding to the forms of the cantilever, as shown in Figure 1, and were sintered at 1520^{0}C for 8h using ZITIN-TECH (Zhengzhou, China), to achieve full strength. The dimensions of all terminal cantilevers were confirmed using a digital caliper (Shanghai, China).

Fracture strength test

As per the ISO standardization for dental ceramics (6872:1995), each framework with a terminal cantilever underwent testing for ultimate fracture load using a Universal Testing Machine (Instron 1195, England). Failure was identified through naked-eye observation, discerning an audible crack or a sudden drop in the applied force at the terminal end of each specimen. The static load testing involved a traditional load-to-failure approach until fracture occurred (35).

A vertically oriented tapered-shaped plate, with a crosshead speed of 2mm/min, was directed to contact the framework 2mm away from the terminal end of the cantilever (see Figure 2). The maximum load values leading to fracture were recorded in newtons (N), and failure was determined by a sharp decrease in the applied force at the terminal cantilever.

Statistical analysis

The fracture load data for the three-shaped terminal cantilever was recorded and subjected to statistical analysis using IBM SPSS 22.0 (IBM SPSS Inc., Armonk, NY, USA). Analysis of variance (ANOVA) and post-hoc Tukey HSD test were employed to assess the differences between the fracture loads of the ISCZFs. The established statistical significance threshold was set at $p<0.05$.

Results

The study results are presented in Table 1 and Figure 3. Oval-shaped terminal cantilever specimens failed at a mean load of 587.8±112.2N, square-shaped terminal cantilevers at 893.8±145N, and oval-square terminal cantilevers fractured at 591.3±81.3N.

The one-way ANOVA test indicated a statistically significant strength effect for the square-shaped terminal cantilever (p<001). However, a non-significant interaction was observed between the oval and oval-square terminal cantilevers.

Specimens failed due to a fracture of the terminal cantilever without abutment copy damage or plastic deformation. In all oval and oval-squared terminal cantilevers, the distal abutment wall broke, leading to catastrophic crack propaga-

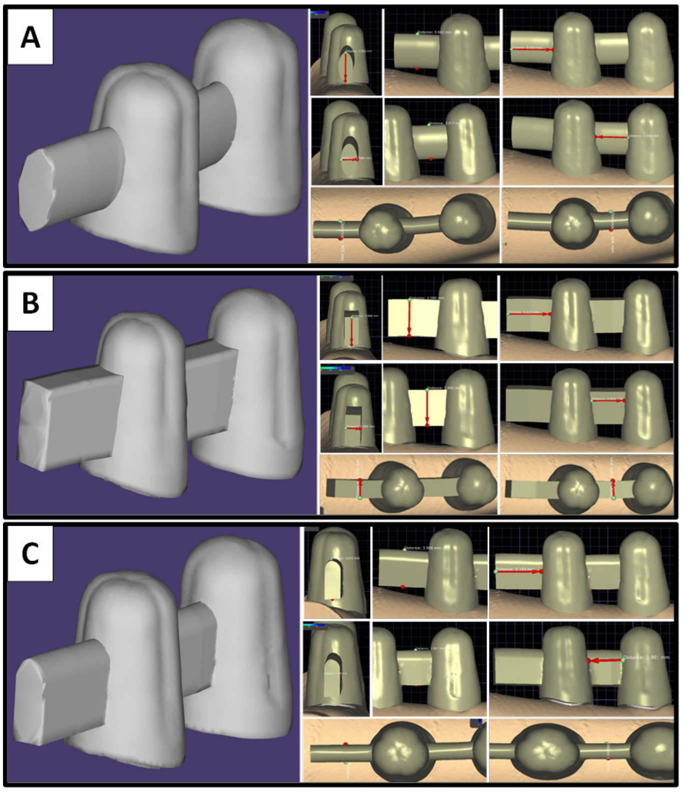

Figure 1. *The CAD design and dimensions of the Zr framework terminal cantilevers, A, oval-shaped; A, Square-shaped; and C, Oval-square shaped cantilever*

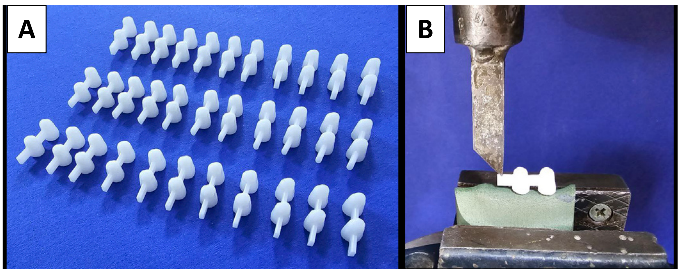

Figure 2. *RPD Zr frameworks, A, Three different terminal cantilever designs; B, Terminal cantilever under load fracture testing chisel*

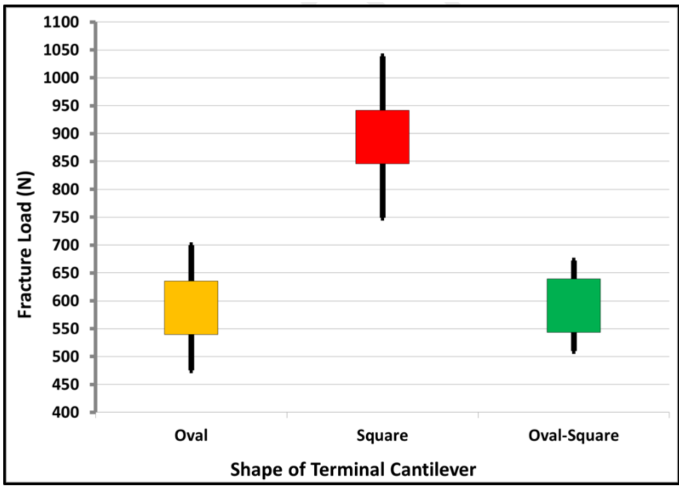

Figure 3. *Box plot represent an ultimate fracture load for three shaped terminal cantilevers.*

Table 1. *Analysis of variance and post-hoc Tukey HSD test showing the mean fracture load differences for three groups.*

Groups		Mean Difference	Std. Error	P-Value	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Oval	**Square**	-306.0000*	49.36945	.000	S	-427.7091	-184.2909
	Oval-Square	-3.4545	49.36945	.997	NS	-125.1636	118.2545
Square	**Oval-Square**	302.5455*	49.36945	.000	S	180.8364	424.2545

tion at the cantilever connector section. Fissures extended around the length of the distal abutment copy wall, reaching the connecting region. In contrast, the squared Zr specimens shattered at the very end of the terminal cantilever (see Figure 4 and Figure 5).

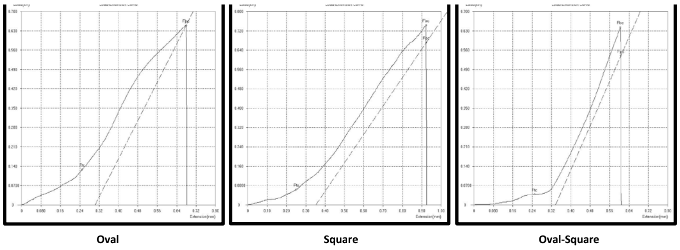

Figure 4. *The mode of failure for shaped terminal cantilevers, A, Oval; B, Square; and C, Oval-square*

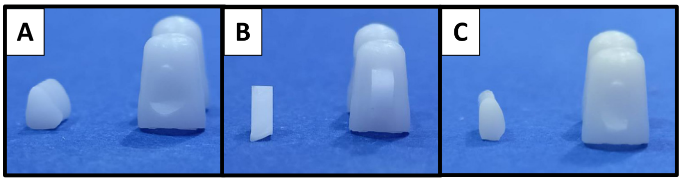

Figure 5. *Fractographical chart for the studied cantilevers.*

Discussion

The testing method, although based on static applied forces, can provide an early assessment of the mechanical properties of cantilevered restorations. Zr materials are prone to crack propagation and fracture due to their brittleness nature. Therefore, it is essential to identify some material's mechanical characteristics in advance, including fracture strength and fractographic analysis (32). Moreover, the use of implant mimics for testing the fracture resistance and stress distribution for implant-supported cemented crowns is well acknowledged (33).

A typical load-to-failure technique was employed to test Zr implant-supported frameworks with variable dimensions of a terminal cantilever. The null hypothesis has been partially rejected. In the case of the square-shaped terminal cantilever, different cantilever forms having the same fracture load were rejected. However, it is accepted in terms of oval and oval-square cross-sectional area cantilevers since non-significant interaction was found between both oval and oval-square terminal cantilevers.

The failure of terminal cantilevered implant-supported frameworks made of Zr occurred at the thinnest region of the abutment wall. Figures 4 and 5 show the failures that occurred within the abutment walls, likely at internal stress concentrators as a result of abutment copy design. Tensile forces cause cracks to propagate and fracture within the thinnest ceramic part of 1mm thickness. Future research should investigate the impact of thickening the abutment copy wall. The distal abutment wall shattered all oval and oval-squared terminal cantilevers, resulting in catastrophic crack propagation to the cantilever connector region.

Despite the lack of long-term successful clinical evidence and complication rates of Zr FPDs, one systematic review advocated for the use of posterior Zr FPDPs (35). The interocclusal space available for restorative material is likely to influence the cantilever dimension. As a result, the cantilever shape must fit inside the given area. It seems that certain connector specifications enable the terminal cantilever to overcome higher loads and have superior fracture resistance (2). This study applied a static load with gradual displacement increases till failure, following the experimental methods over a 3D-printed Cobalt-Chromium (Co-Cr) mandibular testing model. Although this study's static load up to failure testing does not reflect the clinical conditions, it can be considered a preliminary determination for ultimate fracture force. It might denote the sort of fracture force that is applicable to terminal cantilevered Zr restorations, and further studies are needed to highlight the effect of terminal cantilever cross-section on the performance of FPDs.

The current study's cantilever form was a basic Zr beam. To overcome the problem of stresses at the site of failure, future research will properly include the importing of a 3D study component of framework design into modeling and finite element analysis (FEM/FEA) by reinforcing the areas of weakness within the framework. Zr thermocycling loading in a wet environment should also be established to determine how this material is expected to perform in an oral environment, as well as include cementation and the use of the original components of the implant system.

This study was conducted without veneering porcelain, as the overlaying veneering porcelain may weaken the specimens. Recent treatment procedures have incorporated unique Zr with partial designs to reduce or eliminate veneering porcelain fractures. Furthermore, in the current design, Zr FPDFs were mounted on third-party 3D non-titanium implant-printed counterparts with no cementation. The critical fracture force of the frameworks might be lower due to the use of non-original components that cause misfits at the implant-abutment contact (28,29).

Conclusion

This in-vitro data suggests that the use of a 5mm square-shaped short terminal cantilever with Zr frameworks should be limited to the two distal implant-supported occluding units. It appears that employing a cantilevered implant-supported restoration could be a viable alternative in partial edentulous rehabilitations. The success of implant-retainer Zr cantilevers replacing posterior teeth relies on a computerized prosthetic approach that considers the design of the cantilever area. Consequently, for prosthetic construction dependent on the position and shape of the terminal cantilever, a comprehensive examination of the implant-supported case is necessary.

Türkçe özet: *İmplant destekli terminal zirkonya kantilever alt yapıların in vitro kırılma direnci. Amaç: Bu çalışma, implant destekli zirkonya alt yapuların üç farklı şekilli kantilever formunun in vitro kırılma yüklerini araştırmayı amaçlamaktadır. Gereç ve Yöntem: Toplam 30 adet implant destekli zirkonya alt yapı (Aconia, Çin) CAD/CAM ile üretildi ve her biri 5 mm'lik distale uzanan farklı kantilever kesit tasarımına sahip üç gruba ayrıldı: Grup A'da kare, Grup B'de ise oval ve Grup C'de oval-kare şekilli numuneler hazırlandı. Numunelere dikey yükler uygulamak için evrensel test cihaı kullanıldı ve kırılma yükleri kaydedildi. İstatistiksel değerlendirmede varyans analizi ve Tukey post-hoc testleri uygulandı. Bulgular: Grup B (587,8±112,2 N) ve Grup C'nin (591,3 ±81,3 N)* *ortalama kırılma yükleri arasında anlamlı bir fark yoktu, ancak her iki grup da Grup A'ya (893,8±145 N) kıyasla anlamlı derecede daha düşük kırık yükleri sergiledi (her biri için p<0,001). Sonuç: Bu deneysel çalışma kapsamında, her biri distal dayanaktan 5 mm uzanan kare şekilli zirkonya implant destekli terminal kantileverlerin, oval ve köşeli alt yapılara kıyasla dikey yüklere karşı daha fazla direnç gösterme ihtimalinin daha yüksek olduğu sonucuna varılabilir. Anahtar kelimeler: sabit bölümlü protez, zirkonya, implant, kırık yükü, diş protezi*

Ethics Committee Approval: Not required.

Informed Consent: Not required.

Peer-review: Externally peer-reviewed.

Author contributions: TS, SAM participated in designing the study. TS participated in generating the data for the study. SAM participated in gathering the data for the study. SAM participated in the analysis of the data. TS wrote the majority of the original draft of the paper. TS, SAM participated in writing the paper. TS, SAM has had access to all of the raw data of the study. TS, SAM has reviewed the pertinent raw data on which the results and conclusions of this study are based. TS, SAM have approved the final version of this paper. TS, SAM guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of Interest: The authors declared that they have no conflict of interest.

Financial Disclosure: The authors declared that they have received no financial support.

References

1. Norström Saarva, V.; Bjerkstig, G.; Örtorp, A.; Svanborg, P., A three-year retrospective study on survival of ceramic-veneered zirconia (Y-TZP) fixed dental prostheses performed in private practices. Int J Dent 2017; 2017. https://doi.org/10.1155/2017/9618306 [CrossRef]
2. De Andrade, G. S.; Kalman, L.; Giudice, R. L.; Adolfi, D.; Feilzer, A. J.; Tribst, J. P. M., Biomechanics of implant-supported restorations. Braz Dent Sci. 2023; 26. https://doi.org/10.4322/bds.2023.e3637 [CrossRef]
3. Tang, Y.; Yu, H.; Wang, J.; Qiu, L., Implant Survival and Complication Prevalence in Complete-Arch Implant-Supported Fixed Dental Prostheses: A Retrospective Study with a Mean Follow-up of 5 Years. Int J Oral Maxillofac Implants. 2023; 38. https://doi.org/10.11607/jomi.9808 [CrossRef]
4. D'Amico, C.; Bocchieri, S.; Sambataro, S.; Surace, G.; Stumpo, C.; Fiorillo, L., Occlusal load considerations in implant-supported fixed restorations. Prosthesis. 2020; 2:252-65. https://doi.org/10.3390/prosthesis2040023 [CrossRef]
5. Walter, L.; Greenstein, G., Utility of measuring anterior-posterior spread to determine distal cantilever length off a fixed implant-supported full-arch prosthesis: a review of the literature. J Am Dent Assoc. 2020;151:790-95. https://doi.org/10.1016/j.adaj.2020.06.016 [CrossRef]
6. Haroyan-Darbinyan, E.; Romeo-Rubio, M.; Del Río-Highsmith, J.; Lynch, C. D.; Castillo-Oyagüe, R., Thermo-mechanical behavior of alternative material combinations for full-arch implant-supported hybrid prostheses with short cantilevers. J Dent. 2023; 132: 104470. https://doi.org/10.1016/j.jdent.2023.104470 [CrossRef]
7. Alshamrani, A.; Alhotan, A.; Kelly, E.; Ellakwa, A., Mechanical and Biocompatibility Properties of 3D-Printed Dental Resin Reinforced with Glass Silica and Zirconia Nanoparticles: In Vitro Study. Polym. 2023; 15:2523. https://doi.org/10.3390/polym15112523 [CrossRef]
8. Branco, A. C.; Colaço, R.; Figueiredo-Pina, C. G.; Serro, A. P., Recent Advances on 3D-Printed Zirconia-Based Dental Materials: A Review. Mater. 2023; 16:1860. https://doi.org/10.3390/ma16051860 [CrossRef]
9. Solá-Ruiz, M. F.; Leon-Martine, R.; Labaig-Rueda, C.; Selva-Otalaorrouchi, E.; Agustín-Panadero, R., Clinical outcomes of veneered zirconia anterior partial fixed dental prostheses: A 12-year prospective clinical trial. J Prosthet Dent. 2022; 127: 846-51. https://doi.org/10.1016/j.prosdent.2020.09.046 [CrossRef]
10. Liu, C.; Liao, Y.; Jiao, W.; Zhang, X.; Wang, N.; Yu, J.; Liu, Y. T.; Ding, B., High Toughness Combined with High Strength in Oxide Ceramic Nanofibers. Adv Mater. 2023. 2304401. https://doi.org/10.1002/adma.202304401 [CrossRef]
11. Zhang, Y.; Kelly, J. R., Dental ceramics for restoration and metal veneering. Dent Clin. 2017; 61:797-819. https://doi.org/10.1016/j.cden.2017.06.005 [CrossRef]
12. Abbas, M.; Ramesh, S.; Tasfy, S.; Lee, K. S.; Gul, M.; Aljaoni, B., Effect of sintering additives on the properties of alumina toughened zirconia (ATZ). MRS Commun. 2023; 1-9. https://doi.org/10.1557/s43579-023-00400-y [CrossRef]
13. Lancellotta, V.; Pagano, S.; Tagliaferri, L.; Piergentini, M.; Ricci, A.; Montecchiani, S.; Saldi, S.; Chierchini, S.; Cianetti, S.; Valentini, V., Individual 3-dimensional printed mold for treating hard palate carcinoma with brachytherapy: A clinical report. J Prosthet Dent. 2019; 121(4):690-93. https://doi.org/10.1016/j.prosdent.2018.06.016 [CrossRef]
14. Meirowitz, A.; Bitterman, Y.; Levy, S.; Mijiritsky, E.; Dolev, E., An in vitro evaluation of marginal fit zirconia crowns fabricated by a CAD-CAM dental laboratory and a milling center. BMC Oral Health. 2019; 19:1-6. https://doi.org/10.1186/s12903-019-0810-9 [CrossRef]
15. Reuss, J. M.; Reuss, D.; Rutten, L.; Mateo, B.; Vilaboa, B. R.; Vilaboa, D. R., Facially Driven Rehabilitation of a Cleft Lip and Palate Patient with an Implant-Supported Complete Fixed Dental Prosthesis: Outcome of a Multidisciplinary Approach. Int J Prosthodont. 2023; 36. https://doi.org/10.11607/ijp.7622 [CrossRef]
16. Shokry, T. E., Evaluation of Fracture Resistance of Long Span Implant Supported Fixed Dental Prostheses Fabricated from Different CAD/CAM Materials. Al-Azhar J Dent Sci. 2023; 26:15-25. https://doi.org/10.21608/ajdsm.2022.115225.1286 [CrossRef]
17. Hu, M.-L.; Lin, H.; Zhang, Y.-D.; Han, J.-M., Comparison of technical, biological, and esthetic parameters of ceramic and metal-ceramic implant-supported fixed dental prostheses: A systematic review and meta-analysis. J Prosthet Dent. 2020; 124:26-35. e2. https://doi.org/10.1016/j.prosdent.2019.07.008 [CrossRef]
18. Yin, S.; Cizek, J.; Chen, C.; Jenkins, R.; O'Donnell, G.; Lupoi, R., Metallurgical bonding between metal matrix and core-shelled reinforcements in cold sprayed composite coating. Scr Mater. 2020; 177:49-53. https://doi.org/10.3390/ma12142252 [CrossRef]
19. Budală, D. G.; Lupu, C. I.; Vasluianu, R. I.; Ioanid, N.; Butnaru, O. M.; Baciu, E.-R., A Contemporary Review of Clinical Factors Involved in Speech-Perspectives from a Prosthodontist Point of View. Medicina. 2023; 59:1322. https://doi.org/10.3390/medicina59071322 [CrossRef]
20. Dorado, S.; Arias, A.; Jimenez-Octavio, J. R., Biomechanical Modelling for Tooth Survival Studies: Mechanical Properties, Loads and Boundary Conditions—A Narrative Review. Mater. 2022; 15:7852. https://doi.org/10.3390/ma15217852 [CrossRef]
21. Matta, R. E.; Eitner, S.; Stelzer, S. P.; Reich, S.; Wichmann, M.; Berger, L., Ten-year clinical performance of zirconia posterior fixed partial dentures. J Oral Rehabil. 2022; 49:71-80. https://doi.org/10.1111/joor.13276/v1/review1 [CrossRef]
22. Horsch, L.; Kronsteiner, D.; Rammelsberg, P., Survival and complications of implant-supported cantilever fixed dental prostheses with zirconia and metal frameworks: A retrospective cohort study. Clin Implant Dent Relat Res. 2022. https://doi.org/10.1111/cid.13125 [CrossRef]

23. Karasan, D.; Canay, S.; Sailer, I.; Att, W., Zirconia Cantilever Fixed Dental Prostheses Supported by One or Two Implants: An In Vitro Study on Mechanical Stability and Technical Outcomes. Int J Oral Maxillofac Implants. 2022; 37. https://doi.org/10.11607/jomi.8953 [CrossRef]
24. Takaba, M.; Tanaka, S.; Ishiura, Y.; Baba, K., Implant-supported fixed dental prostheses with CAD/CAM-fabricated porcelain crown and zirconia-based framework. J Prosthodont on Complex Restorations. 2016; 225-31. https://doi.org/10.1111/jopr.12001 [CrossRef]
25. D'Albis, G.; D'Albis, V.; Susca, B.; Palma, M.; Al Krenawi, N., Implant-supported zirconia fixed partial dentures cantilevered in the lateral-posterior area: A 4-year clinical results. J Dent Res Dent Clin Dent Prospects. 2022; 16: 258-63. https://doi.org/10.34172/joddd.2022.041 [CrossRef]
26. Lee, B.; Oh, K. C.; Haam, D.; Lee, J.-H.; Moon, H.-S., Evaluation of the fit of zirconia copings fabricated by direct and indirect digital scanning procedures. J Prosthet Dent. 2018; 120: 225-31. https://doi.org/10.1016/j.prosdent.2017.08.003 [CrossRef]
27. Alao, A.-R.; Stoll, R.; Zhang, Y.; Yin, L., Influence of CAD/CAM milling, sintering and surface treatments on the fatigue behavior of lithium disilicate glass ceramic. J Mech Behav Biomed Mater. 2021; 113: 104133. https://doi.org/10.1016/j.jmbbm.2020.104133 [CrossRef]
28. Sancho-Puchades, M.; Crameri, D.; Özcan, M.; Sailer, I.; Jung, R.; Hämmerle, C.; Thoma, D., The influence of the emergence profile on the amount of undetected cement excess after delivery of cement-retained implant reconstructions. Clin Oral Implants Res. 2017; 28: 1515-22. https://doi.org/10.1111/clr.13020 [CrossRef]
29. Gehrke, P.; Bleuel, K.; Fischer, C.; Sader, R., Influence of margin location and luting material on the amount of undetected cement excess on CAD/CAM implant abutments and cement-retained zirconia crowns: an in-vitro study. BMC Oral Health. 2019; 19: 1-12. https://doi.org/10.1186/s12903-019-0809-2 [CrossRef]
30. Al-Sanea, A.; Mutlu, I.; Kişioğlu, Y.; Mohamed, E., The Effect of V-Thread and Square Thread Dental Implants on Bone Stresses. J Biomim Biomater Biomed Eng. 2023; 60: 83-96. https://doi.org/10.4028/p-3qasy2 [CrossRef]
31. Novais, M.; Silva, A. S.; Mendes, J.; Barreiros, P.; Aroso, C.; Mendes, J. M., Fracture Resistance of CAD/CAM Implant-Supported 3Y-TZP-Zirconia Cantilevers: An In Vitro Study. Mater. 2022; 15: 6638. https://doi.org/10.3390/ma15196638 [CrossRef]
32. Ghavami-Lahiji, M.; Firouzmanesh, M.; Bagheri, H.; Kashi, T. S. J.; Razazpour, F.; Behroozibakhsh, M., The effect of thermocycling on the degree of conversion and mechanical properties of a microhybrid dental resin composite. Restor Dent Endod. 2018; 43. https://doi.org/10.5395/rde.2018.43.e26 [CrossRef]
33. Gomes, R. S.; Bergamo, E. T. P.; Bordin, D.; Cury, A. A. D. B., The substitution of the implant and abutment for their analogs in mechanical studies: In vitro and in silico analysis. Mater Sci Eng: C. 2017; 75: 50-54. https://doi.org/10.1016/j.msec.2017.02.034 [CrossRef]
34. Stamenković, D.; Popović, M.; Rudolf, R.; Zrilić, M.; Raić, K.; Đuričić, K. O.; Stamenković, D., Comparative Study of the Microstructure and Properties of Cast-Fabricated and 3D-Printed Laser-Sintered Co–Cr Alloys for Removable Partial Denture Frameworks. Mater. 2023; 16: 3267. https://doi.org/10.3390/ma16083267 [CrossRef]
35. Sadid-Zadeh, R.; Lin, K.; Li, R.; Nagy, K., Fracture strength of screw-retained zirconia crowns assembled on zirconia and titanium implants. J Prosthodont. 2023. https://doi.org/10.1111/jopr.13683 [CrossRef]