International Journal of Dentistry and Oral Health

Volume 7 Issue 4,
April 2021

Citation
Mark Tharwat Fouad et.al (2021), Effect of Retainer Design on the Mode of Failure of All Ceramic Cantilever Adhesive Fixed Dental Prosthesis. Int J Dent & Ora Hea. 7:4.

ISSN 2471-657X

Published by
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www.biocoreopen.org/ijdoh/archive.php

Research Article

Effect of Retainer Design on the Mode of Failure of All Ceramic Cantilever Adhesive Fixed Dental Prosthesis

Mark Tharwat Fouad[1] ,Nadia Zakaria Fahmy[1],Marwa Mohamed Wahsh[2],Maged Mohamed Zohdy[2]

[1] *Fixed Prosthodontics Department, October University for Modern Sciences and Arts (MSA), Egypt.*
[2] *Fixed Prosthodontics Department, Ain Shams University, Egypt.*

Corresponding author: Mark Tharwat Fouad
Fixed Prosthodontics Department, October University for Modern Sciences and Arts (MSA), Egypt.
E-mail: drmarktharwat@gmail.com

Article History: **Received:** April 13, 2021;
Accepted: April 19, 2021;
Published: April 22, 2021.

Abstract
Objectives: The present in vitro study aimed to compare the fracture resistance and the mode of failure of two all ceramic retainer designs on cantilevered maxillary lateral incisor on the adjacent maxillary canine using palatal and labial veneer retained fixed dental prosthesis.

Material and Methods: Twenty cantilever all ceramic resin bonded fixed dental prostheses (RBFDPs) were divided into two groups according to the preparation design: palatal veneer retained fixed dental prosthesis (palatal VRFDP) (n=10) and labial veneer retained fixed dental prosthesis (labial VRFDP) (n=10). Preparations were done on a maxillary canine typodont model to receive veneer retained fixed dental prosthesis (VRFDP) replacing maxillary lateral incisor and duplicated into 20 epoxy resin models. The prostheses were subsequently designed using CAD software and constructed using heat pressing technique, after which the prostheses were bonded to their corresponding epoxy resin model. All specimens were subjected to thermo-mechanical fatigue stresses and then loaded to failure. Data were collected, tabulated and statistically analyzed through paired t-test.

Results: The results showed that the palatal veneer retained fixed dental prosthesis group recorded statistically non-significant ($p= 0.0903>0.05$) higher mean value than the labial veneer retained fixed dental prosthesis group mean value as indicated by paired t-test.

Conclusion: Both palatal and labial veneer retained fixed dental prosthesis can provide a viable treatment option in case of maxillary lateral incisor loss. However, from the failure mode observed it could be assumed that labial retained group would be a preferred treatment modality since the failed restorations may be replaced as opposed to 50% chance of abutment fracture observed within the palatal retained group.

Declaration of Conflicting Interest
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Clinical Recommendations
1. Labial VRFDP could be a feasible alternative treatment option for replacement of missing maxillary lateral incisors.
2. Clinical trials with long-term follow-ups are recommended.

Introduction
One of the most prevalent malformations in humans is the congenital absence of teeth. The most frequently affected teeth in the anterior area are maxillary lateral incisors. Other major reasons for missing incisors are traumatic incidents, whether as a direct consequence of an event or as a late complication.[1]

Common treatment alternatives vary from orthodontic treatment as distalization of the canine tooth to prosthodontics treatment as fabrication of conventional three unit fixed dental prosthesis, single tooth implant-supported crown restoration or a resin-bonded fixed dental prosthesis (RBFDP). Since conservatism is always our goal with greater emphasis being positioned on esthetics in addition to functionality, so minimally invasive dentistry has become an essential component in creating restorations that have increased longevity especially after the significant developments in adhesive dentistry.

RBFDP is considered a valid treatment alternative to single implant or conventional tooth-retained fixed dental prosthesis, particularly in young patients or patients with medical contraindications for implant surgery. RBFDP achieve clinical outcomes in longevity in comparison with those of conventional fixed dental prosthesis.[2]

The use of cantilever RBFDPs as an alternative treatment was reported to be a highly recommended option. **Wei et al (2016)**, [3] concluded that cantilever RBFDPs showed higher survival rates than fixed-fixed RBFDPs in a systematic review and meta-analysis study. **Botelho et al (2016)**, [4] reported that the two-unit cantilevered RBFPDs had a high success rate in replacement of a long-missing permanent incisors as it was documented that no debonding or other complication occurred which is often the case in 2 retainer RBFDP.

A labial veneer retained fixed dental prosthesis has been used in this study for the replacement of missing lateral incisor coinciding with the need for esthetic abutment improvement, simulating the work of **Sun et al (2013)**,[5] who used the labial surface of the maxillary canine as an abutment for RBFDP.

Ceramic resin bonded prosthesis require some glass component for the establishment of adequate bonding especially in cantilever prosthesis which are exposed to tensile forces.[6] Lithium disilicate was chosen for its adequate strength and good aesthetics.

This study was designed to compare the fracture resistance and the mode of failure of two proposed all ceramic retainer designs on cantilevering maxillary lateral incisor on the adjacent maxillary canine using: palatal veneer retained fixed dental prosthesis (Palatal VRFDP) and labial veneer retained fixed dental prosthesis (Labial VRFDP).

A null hypothesis was set stating that the retainer design will not affect fracture resistance mean values as well as mode of failure between the 2 designs.

Materials and Methods

In this study two typodont maxillary canines (Nissin Dental Products INC) were used for the purpose of standardization.

Sample Grouping

Two preparations were done on the typodont , one palatal and one labial for each proposed design. Each preparation on the master model was impressed, poured and duplicated 10 times, bringing the total of duplicated models to 20. Twenty cantilever all ceramic RBFDPs were fabricated to replace a missing maxillary lateral incisor. The prostheses were divided into two groups according to the preparation design (n=10)

i) Palatal VRFDP.

ii) Labial VRFDP.

Teeth preparation

Palatal VRFDP preparation design

Wheel diamond stone instrument (909/018, OkoDENT) was used to place grooves with 0.5 mm depth along the palatal surface. Water-insoluble dye was painted on the palatal surface to calibrate the amount of reduction. A 0.5 chamfer finish line was done using round end tapered diamond stone (856 014 F FG, OkoDENT), where the stone was held parallel to the long axis of the tooth. The reduction mesially was extended beyond the contact area to end before the labio-proximal line angle **(Figure.1)**

Labial VRFDP preparation design

Three wheel depth cutter diamond stone (4142, OkoDENT) was used to place grooves to standardize the preparation in 2 planes. Water-insoluble dye was painted on the labial surface to calibrate the amount of reduction. A 0.5 chamfer finish line was done using round end tapered diamond stone (856 014 F FG, OkoDENT) 1where the stone was held parallel to the long axis of the tooth. The reduction mesially was extended beyond the contact area to end before the palato-proximal line angle.**(Figure.2)**

All sharp lines and angles were smoothened using finishing stone and finally, the preparation was checked using the putty index and periodontal probe.

Impressions were taken for each type of preparation by single viscosity medium body rubber base impression material (Monophase Medium 3M ESPE) and then poured into epoxy resin models (**kemapoxy** 150, CMB), which were further duplicated to form another epoxy resin models using silicon indices (**REPLISIL** 22 N, Dente-Con).

Figure 1 Palatal VRFDP preparations.

Figure 2 Labial VRFDP preparation

One epoxy model from each group was scanned using 3 axes blue scanner (Identica Hybrid, Medit). The designs were performed using Exocad program (version 6136). The STL file was ready to send to the 5 axes dry milling machine (VHF K5, P&S) for milling on PMMA blank to produce standardized patterns for the two groups. Each resin pattern was seated on its corresponding epoxy model and checked for its fit and marginal accuracy (Figure.3). It was then sprued, invested, pressed and finished to form lithium disilicate resin bonded bridge (Ivoclar Vivadent) (Figure.4).

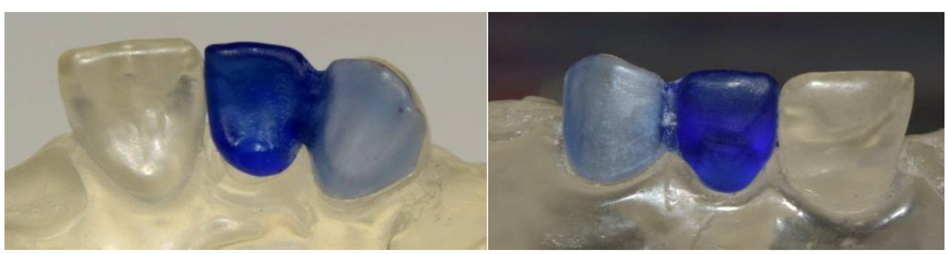

Figure 3 Palatal and Labial VRFDP PMMA Pattern

Figure 4 Palatal and Labial VRFDP

Epoxy dies surface treatment

Air abrasion of epoxy dies was done using aluminum oxide of 50 microns particle size for 5 seconds at 10 cm distance with pressure 2.5 bar. The dies were then cleaned with steam and air dried.

Prosthesis surface treatment

The prosthesis were prepared one at a time: 5% hydrofluoric acid gel (IPS Ceramic etching gel, Ivoclar Vivadent) was applied on the fitting surface of the retainer wing for 20 seconds, washed thoroughly with air/ water spray then dried well with air . Silane coupling agent (Pre-Hydrolized Silane Porcelain Primer, BISCO) was then applied using micro brush on the fitting surface for 1 minute and dried gently with air.

Figure 5 Robota chewing simulator.

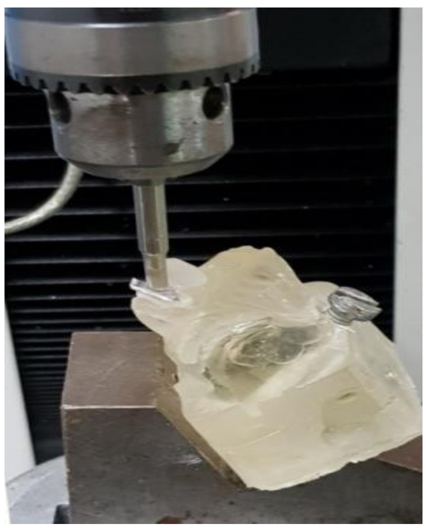

Figure 6 Fracture resistance test

Bonding

Dual Cure adhesive resin cement (Panavia F 2.0, Kuraray) was used to bond the prosthesis on the epoxy dies.

Testing

Fracture resistance test **(Figore.6)** was performed on all specimens after chewing simulator with thermo-mechanical aging (ROBOTA Chewing Simulator) for 150,000 mechanical fatigue cycles of 50 N loads **(Figure.5)**. Data were collected, tabulated and statistically analyzed through paired t-test. The Fractured samples were imaged using Nikon D5200 camera body with macro lens 105 mm then the mode of failure was analyzed.

Results

After homogeneity of variance and normal distribution of errors had been confirmed, data were presented as mean, standard deviation (SD), range (Minimum-Maximum) for values. A paired t-test was used to compare materials after thermo-mechanical aging. A chi-square test was used for failure mode analysis. The significance level was set at $P \leq 0.05$. The sample size (n=10) was large enough to detect large effect sizes for main effects and pair-wise comparisons, with the satisfactory level of power set at 80% and a 95% confidence level. Statistical analysis was performed using InStat Graph Pad statistics (Graph Pad, Inc.) software for windows.

Variable		Mean± SD	SEM	Median	Range	
					Minimum	Maximum
Prep. Design	**Palatal veneer**	**204.89±27.28**	8.63	202.14	163.21	283.52
	Labial veneer	**176.21±40.57**	12.83	173.24	121.84	253.41

Table 1 Comparison of fracture resistance (Mean±SD) between both groups after thermo-mechanical aging

The palatal veneer group recorded statistically *non-significant* (p= 0.0903>0.05) higher mean value than the *labial veneer group* mean value as indicated by paired t-test.**(Table 1)**

Mode of Failure			Preparation design groups (results in percentage)	
Time	**Type**		**Labial**	**Palatal**
During Dynamic load test	Prosthesis Fracture	Connector	0	0
		Retainer	20%	0
		Retainer + abutment	0	0
		Pontic	0	0
	Total Debonding		0	0
	Die fracture		0	0
During Fracture resistance test	Prosthesis Fracture	Connector	0	10%
		Retainer	80%	0
		Retainer + abutment	0	40%
		Pontic	0	0
	Total Debonding		0	0
	Die fracture		0	50%

Table 2 Comparison of the frequent distribution of failure mode and site after thermo-mechanical aging.

Failure mode analysis

For *the palatal veneer group*, failure analysis predominantly revealed die fracture (50%), the *retainer + abutment* fracture was recorded in (40%) mean while minority of samples recorded *Connector* fracture (10%) **(Table 2).**

For *the labial veneer group*, two samples (20%) failed during fatigue testing while in all the remaining samples (80%) retainer fracture was observed (Table 2).

Discussion

The standards of dentistry are being elevated, with greater emphasis being positioned on esthetics in addition to functionality. Minimally invasive dentistry has become an essential component in creating restorations that are functional and have increased longevity especially after the significant developments in adhesive dentistry.

Resin bonded fixed dental prostheses is used to restore single tooth anteriorly with strict guidelines to achieve moderate to long term serviceability. Moreover, it adds further advantages as it may be applied to young patients, allowing preservation of tooth structure.

The use of palatal VRFDP became well documented in the literature with mid-term and long-term survival rates. [7], [8] However, with the need of esthetic enhancement and corrections, labial VRFDP has emerged through clinical reports as a possible treatment option. [5]

This study was designed to compare the fracture resistance and the mode of failure of two proposed all ceramic retainer designs on cantilevering maxillary lateral incisor on the adjacent maxillary canine using: palatal VRFDP and labial VRFDP.

A null hypothesis was set stating that the retainer design will not affect fracture resistance mean values as well as mode of failure between the 2 designs.

One of the main concerns of this study was to standardize in vitro specimens in order to analyze the results and simulate clinical conditions as close as possible to in vivo situations. The use of extracted natural teeth as samples simulates clinical circumstances more closely. However, standardization of natural teeth is difficult regarding selecting the same teeth dimensions, age, storage time after extractions, enamel and dentin conditions and extraction procedures leading to large variations in their mechanical properties. [9]

Epoxy resin models duplicated from the typodont model were selected to replace the natural abutments due to their modulus of elasticity (11.8 GPa) which is close to that of the dentin (18.6 GPa). [3] In addition, the epoxy surface could be treated to promote good adhesion with the RBFDPs. Those surface treatments include etching with 40% phosphoric acid [9] or sandblasting. [10] In the current study, sand blasting with 50 microns aluminum oxide particles was used. Moreover, epoxy abutments have successfully served to standardize the specimen's dimensions and the condition of the substrate where the prostheses were bonded.

Two types of tests were used, dynamic load test and fracture resistance test. The dynamic load test was used to simulate the clinical conditions by subjecting repeated subcritical loads that eventually leads to fatigue, then the non-failed specimens were subjected to fracture resistance test to evaluate the load required to produce failure of the prosthesis.[11]

Dynamic loading to the specimens was performed for 150,000 cycles to simulate the clinical functioning of the prostheses for an average of one year in service. [12][13][14] The loads were applied in the middle third of the pontics to reproduce the average vertical overlap in normal occlusion. Dynamic load synchronized with thermal cycling since aqueous environment can reduce the number of cycles required to produce fatigue failure in glass-ceramics.[13][14][15] This corresponded to Koutayas et al (2000), [15] who used thermo-dynamic loading in testing cyclic fatigue on RBFDP.

The samples which survived dynamic fatigue were exposed to a fracture resistance test. This was similar to the work of Kheradmandan et al (2001), [16] who declared that 75% of Empress II anterior FDP survived after dynamic loading test where the non-failed prostheses were subjected to fracture resistance test. The mean fracture resistance they reported was 292.92N.

Forces subjected to the 2 groups were directed palato-labially, but the resolution of the force differed between palatal VRFDP design and labial VRFDP design. 20% of the labial VRFDP failed at the retainer during dynamic loading while no failure occurred to the retainers in the palatal VRFDP. This could be due to transmission of the directed forces (palato-labial) to the retainer-abutment interface as they acted as tensile forces causing partial debonding of the retainers that lead to their eventual fracture. Whereas, the directed forces in case of the palatal VRFDP were resolved as compressive forces, which were transmitted to the abutment. [17]

During fracture resistance testing, the majority of failures of the labial VRFDP (80%) occurred at the retainer while for the palatal VRFDP the majority (50%) occurred at the abutment neck (die fracture). This finding could be explained in how the forces were resolved with the 2 different designs. It may be suggested that forces in the palatal VRFDP were transmitted to the neck of the abutment where the prosthesis did not fail while the die failed due to the rigidity of the lithium disilicate ceramic compared to the low modulus of elasticity of the epoxy models close to that of dentin. This scenario is opposite to the labial VRFDP in which it failed at the retainer due to the tensile stresses that allowed debonding at the first place followed by retainer fracture due to the brittleness of the ceramic which was unsupported by the substrate as a result of debonding. Fracture of the abutment was also observed by Rosentritt et al (2008). [2] This finding is also comparable with the findings of Keulemans et al (2015), [18] who reported in a finite element study the concentration of the stresses at the cingulum and cervical area of the abutment of a cantilevered glass ceramic RBFDP.

The lowest predominance of fracture was at the connector; cohesive fracture of the palatal VRFDP (10%).This could be due to the connector thickness (14mm2) and the connector radius of curvature (0.45mm) which leads to better stress distribution. This is supported by Oh et al (2002) [19] who explained the importance of the radius of curvature on the fracture strength of a 3 unit fixed dental prosthesis.

The null hypothesis was partially accepted as the labial retainer design of the VRFDP did not affect the fracture resistance mean values compared to the palatal retainer design of VRFDP. However, regarding the mode of failure between the 2 designs the hypothesis was rejected.

Conclusion

Within the limitation of this study, the following conclusions were drawn:

1. Both palatal and labial VRFDP can provide a viable treatment option in case of maxillary lateral incisor loss.
2. From the failure mode observed it could be assumed that labial VRFDP would be a preferred treatment modality since the failed restorations may be replaced as opposed to 50% chance of abutment fracture observed within the palatal retained group.

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