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Strain Induced within Anterior Lithium Disilicate Cantilever Bridges Under Different Loading Directions

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Abstract

Background: Lithium disilicate has proven its clinical success in many clinical situations but no studies supported its use as a cantilever bridge in restoring missing maxillary lateral incisor.

Aim: This study was designed to evaluate the strain induced in lithium disilicate anterior bridges replacing maxillary lateral incisor, as influenced by bridge design; cantilever bridges (CB) versus fixed-fixed bridges (FFB), and direction of loading; vertical and lateral.

Materials and methods: A total of 20 heat-pressed monolithic lithium disilicate bridges were constructed and divided according to bridge design into two main groups (n=10), 1. **CB:** Cantilever bridge design with full coverage retainer on the canine, and 2. **FFB:** Fixed-fixed bridge design with full-coverage retainers on the central incisor and canine. Main groups were subdivided according to the direction of loading into two equal subgroups (n=5). Subgroup (V): Vertical loading, and Subgroup (L): Lateral loading.

Wax patterns were duplicated to achieve identical bridges of each group using a custom-made wax injection mold. Ten duplicate epoxy resin dies were produced for each bridge group to hold the bridges during the strain test.

The samples were subjected to vertical and lateral loading until complete fracture using universal testing machine. The strain induced in the samples was measured by a KYOWA strain meter. One-way Analysis of Variance (ANOVA) was used to compare between the two bridge designs.

Results: The fixed-fixed bridge design Group (FFB) (control group) showed statistically significant higher mean strain value (678.90±34.40) than cantilever bridge group (CB) (411.80±35.13); while upon lateral loading, the CB showed a significantly higher mean strain value (399.40) than the FFB (262.60).

Conclusion: The strain values induced in lithium disilicate anterior bridges have no catastrophic effect regardless of bridge design, indicating that cantilever bridge design could resist both vertical and lateral loading in a favorable and clinically acceptable mode.

Key words: post operative pain, manual dynamic agitations, master cone, irreversible pulpitis.

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Introduction

Maxillary lateral incisors are among the most commonly missing teeth in the dental arch, which could be due to congenital causes; e.g., partial anodontia, acquired causes, e.g., trauma or pathological causes, e.g., carious lesions (1). Several restorative treatment modalities are proposed for their replacement; including single-tooth implant or tooth-supported fixed partial dentures (FPDs). Single-tooth implant is considered the most conservative of which (2,3); its use over the last several years has greatly grown. However, implant placement is not always viable for all cases; it is contraindicated in many cases like diabetes, severe bone loss, bruxism (heavy occlusal loads). Also, in many instances the patient might prefer a non-surgical or a lower cost treatment alternative. In such situations, tooth-supported FPDs would offer many reliable treatment options including conventional fixed-fixed partial denture resin-bonded FPD, and cantilevered FPD. Since tooth conservation is ultimately the main consideration of fixed prosthesis, the cantilevered FPD would provide a viable replacement option that is both conservative and mechanically reliable in such area. It would also provide more superior esthetics than fixed-fixed by leaving one natural tooth intact. In a cantilever FPD, one or more abutments are present at one end while the other, end is unsupported. This arrangement creates a Class I lever system (4,5). Although fixed-fixed bridge design is preferred for achieving maximum retention and resistance, the cantilever bridge design is more conservative, and is a viable replacement option in the anterior region when the conditions are favorable (6,7). Shillingburg et al. (8) stated that a cantilever fixed prosthesis replacing a maxillary incisor has a reasonable chance for long-term success if the canine abutment is favorable, and if no occlusal contacts are present on the pontic in centric or excursive jaw movements. Lithium disilicate glass-ceramic is well-known for its superior esthetics (9–11)(12), which surpass other ceramic materials like zirconia; yet, keeping reasonable mechanical properties (13,14). Literature has supported using lithium disilicate to fabricate anterior cantilever resin-bonded bridges; however, there is still limited experience with its use in anterior bridges in general. When a FPD is subjected to functional loading, the transferred forces give rise to stress and, in turn, to strain within the structure. The distribution of stress influences the treatment success. Several factors can influence the resulting stress distribution, for example, the prosthesis design as well as the magnitude and direction of applied forces (15). Therefore, the likely amount of generated stresses in the oral cavity must be quantified. The measuring of biting forces on teeth is described in several studies in the dental literature. Biting pressures on adult teeth show a gradual decrease from the molar region to the incisors, with value of 150 N, in anterior area (16). The stresses in a cantilevered FPD can be assessed by strain gauge analysis method. Based on this argument, the stress induced upon vertical and lateral loading of lithium disilicate anterior cantilever bridges was assessed in the current study and compared to that of fixed-fixed bridges; in order to evaluate the performance of the material with such bridge design in the anterior area.

The hypothesis of this study was that the strain induced in cantilever lithium disilicate bridges upon average normal loads in the oral cavity, would be acceptable, to be considered as an option for the treatment planning of replacing maxillary lateral incisor, in comparison with conventional fixed-fixed three-unit bridge, and that the direction of loading would have an effect on the induced strain in lithium disilicate cantilever bridges.

Materials and Methods:

A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis. The factorial element was the design. Primary outcome of the study was strain, studying monolithic restorations. By adopting an alpha (α) level of (0.05), a beta (β) of (0.2) (i.e. power=80%), and an effect size (f) of (0.851) calculated based on the results of a previous similar study by El-Etreby and Morsi (2015) (15)1; the minimum required sample size (n) was found to be (20) samples (i.e. 5 samples per group). Sample size calculation was performed using G*Power version 3.1.9.7(17).

Acrylic typodonts (ElBanna, Alexandria, Egypt) with a missing right maxillary lateral incisor were used. Then, the acrylic teeth (maxillary right central incisor and canine) were prepared to receive either the cantilever bridge design (CB) or the fixed-fixed bridge design (FFB). For the cantilever bridge group (CB), only the right maxillary canine was prepared for full-coverage retainer, while for the fixed-fixed bridge group (FFB) both the maxillary central incisor and canines were prepared for full-coverage retainers (Fig. 1). Teeth preparation was done using tapered stone with flat end (Komet, Germany) (1mm tip diameter and 6 degrees taper), following standardized preparation criteria of: a uniform 1mm shoulder finish line, 2 mm incisal and 1.5mm axial reduction with a 6-degree taper, where the stone was held parallel to the long axis of the tooth (18). The needed axial inclination was verified/ checked using a parallellometer (BEGO, Germany).

(Fig. 1) Preparations for bridge designs used in the study. (a) Cantilever bridge design with full-coverage retainer on the canine. (b) Fixed-fixed bridge design with full-coverage retainers on the central incisor and canine.

After finishing the preparations for both groups, addition silicone impression material

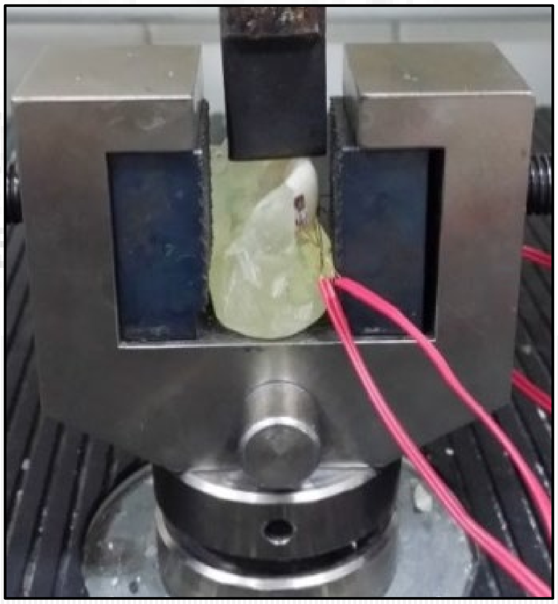
(Elite HD+; Zhermack Dental, Italy) was used for taking impressions of the preparations for the two bridge design groups and master casts were obtained. A total of 20 monolithic lithium disilicate bridges were constructed, with connector dimension of 3mm buccolingually and 4mm occluso-gingivally. The bridges were divided according to bridge design into two main groups (n=10), **Group CB:** Cantilever bridge design with full coverage retainer on the canine, **Group FFB:** Fixed-fixed bridge design with full-coverage retainers on the central incisor and canine. Each group was further equally subdivided according to the direction of loading into two subgroups (n=5). **Subgroup (V):** Vertical loading (parallel to tooth long axis), **Subgroup (L):** Lateral loading (45 degree from tooth long axis).

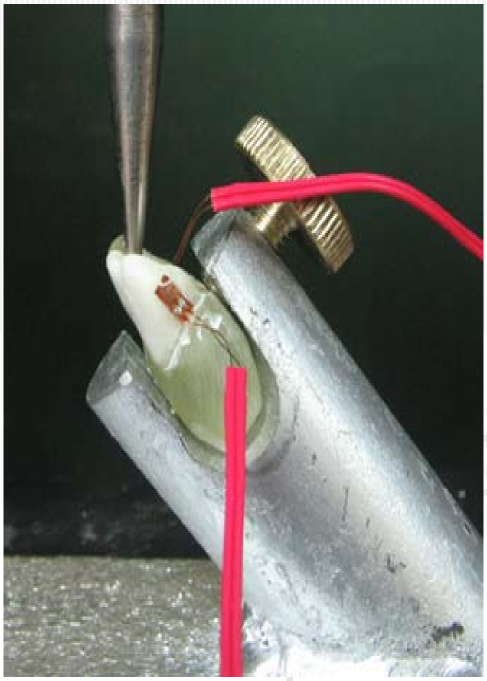
Standardization of the study samples

To standardize the wax patterns for production of bridges for each group, silicone impressions were made, to duplicate the external and internal contours of the master bridges, inside a custom-made wax injection mold. The mold contained a crucible former at its end, to form a crucible in the produced impressions. Molten wax was injected to fill the impressions. Standardized wax patterns were produced for each bridge design, with exact external and internal dimensions as the master bridges. Lithium disilicate press ingots (IPS e.max press; Ivoclar Vivadent, Germany) were used to fabricate 9 bridges from the standardized wax patterns duplicated from the master bridge of each design group. 20 epoxy replica dies were produced identical to master cast and working die; 10 epoxy dies for each bridge design group. Duplicate epoxy resin dies were produced for each bridge group via pouring silicone molds (duplicating master casts), with epoxy resin material (Chemapoxy 150, CMB, Egypt) following the manufacturer instructions. 10 epoxy dies were constructed for each group in order to hold the lithium disilicate bridges during the strain test. The intaglios of the lithium disilicate bridges retainers were etched with 9% hydrofluoric acid for 20s, then silanated (1 min). Self-Adhesive dual-cure resin cement (Breeze; Pentron Clinical Technologies, LLC, USA) was used for bonding of bridges to their epoxy resin dies.

Strain test

Two strain gauges (KFG-1-120-C1-11L1M2R, KYOWA; Tokyo, Japan) of 1 mm length were cemented at the cervical one third of the buccal surface at the mesial and distal line angles of each retainer using strain gauge cement. Load was applied to the samples inside a universal testing machine (UTM) (model LRX-plus; Lloyd instruments Ltd., Fareham, UK) with a load cell of 5 KN. Samples were loaded to a forces exceeding 150 N, until complete fracture of the specimen. The strain gauge lead wire was connected to a KYOWA Strain Meter (BCD 300 A, KYOWA; Tokyo, Japan) to measure the strain induced in the bridges until complete fracture occurred





(Fig. 2) ***Strain Test.*** *(a) Vertical loading. (b) Lateral loading*

1. Vertical loading procedure

Samples were individually mounted in a 90º angulation custom made jig that was placed in the lower compartment of a computer controlled Universal testing machine. Lithium disilicate bridges were compression loaded perpendicular to the incisal edge of the pontic. (Fig. 2a)

2. Lateral loading procedure

Samples were individually mounted in a 45º angulation custom-made jig. Lithium disilicate bridges were loaded via a stainless-steel rod at the middle third of the pontic lingual surface. (Fig. 2b).

Statistical Analysis

Data were explored for normality using Kolmogorov-Smirnov test of normality. A low significance value (less than 0.05) of Kolmogorov- Smirnov test indicates that the distribution of the data differs significantly from a normal distribution. Strain data showed a normal distribution, so parametric tests were used for the comparisons. One-way Analysis of Variance (ANOVA) was used to compare between the two bridge designs. Tukey's post-hoc test was used for pair-wise comparison between the means when ANOVA test is significant.

Results:

Data are presented as mean and standard deviation (SD) values in micro strain and their statistical significance are shown in **Tables 1 & 2** and **Fig. 3**.

The **fixed-fixed bridge design group (FFB) (control group)** showed higher mean strain **value** (678.90 ±34.40) upon vertical loading than **cantilever bridge group (CB)** (411.80 ±35.13); and the difference was statistically **significant** ($p<0.001$).

Table 1: Descriptive statistics for strain of different

Load	Design	Mean	SD	Median	Min.	Max.
Vertical	Group CB	411.80	35.13	400.15	382.00	472.23
	Group FFB (ctrl)	678.90	34.40	692.49	617.50	697.45
Lateral	Group CB	399.40	29.19	397.13	360.05	440.37
	Group FFB (ctrl)	262.60	33.57	266.45	220.18	299.90

However, upon lateral loading the **CB group** demonstrated a **significantly** higher mean strain value (399.40 ±29.19) than the **FFB group** (262.60 ±33.57).

Both groups have shown a lower amount of strain under lateral loading than under vertical loading; however, the difference was only significant for the FFC group.

Table 2: Mean & ± Standard Deviation (SD) of strain for different loads bridge designs and their statistical significance

Load	Design (mean±SD)		p-value
	Group CB	Group FFB	
Vertical	411.80±35.13^{B}	678.90±34.40^{A}	<0.001*
Lateral	399.40±29.19^{A}	262.60±33.57^{B}	<0.001*
p-value	0.532 ns	<0.001*	

Different superscript letters indicate a statistically significant difference within the same horizontal row; significant ($p \le 0.05$) **ns**; non-significant ($p>0.05$)

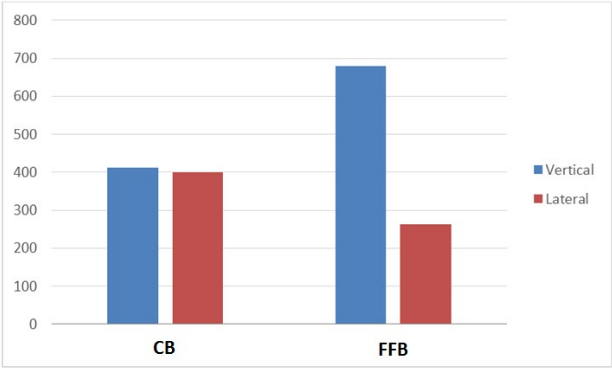


Fig. 3: Bar chart showing average strain for different loads and designs

Discussion:

This study was conducted to evaluate the difference in strain induced in lithium disilicate anterior cantilever bridges compared to fixed-fixed bridges replacing the missing maxillary lateral incisor, upon vertical and lateral loading.

Results have shown that the strain induced in the cantilever bridge design upon vertical loading is significantly lower than that in fixed-fixed bridge design.
This indicates that, upon vertical loading, the cantilever bridge design showed more limited amount of strain before fracture than that showed by fixed-fixed bridge design.
This result might be attributed to the limited surface area of the FPD compared to the fixed-fixed bridge, which would not withstand a greater amount of forces before fracture.
Both bridge designs showed a lower amount of strain upon lateral loading than vertical loading, which indicated that under this more destructive type of force (15), the bridges will fracture sooner before showing a high amount of strain.
Upon lateral loading, the cantilever bridge design showed a significantly higher amount of strain than the fixed-fixed. This might also be justified by the lack of support from a terminal abutment, which would provide a more favorable distribution of stresses (on two abutments on two ends rather than one abutment at one end, while the other end is free causing class I lever system); and hence, a less concentrated strain induced within the bridge material. (15) On the other hand, the more stable design of the fixed-fixed bridge would contribute to a better stress distribution of the uneven destructive forces, leading to less amount of strain.
Many studies have discussed that the choice of the materials and their modulus of elasticity have a great effect on strain (19–21).

The significantly lower modulus of elasticity of lithium disilicate (22) than that of zirconia (23) might justify some contradictions between the current strain results and those of zirconia bridges in a similar study by El-Etreby and Morsi (2015) (15), their overall strain values of cantilever zirconia bridges lower than our values , which is also quite predictable; it could be explained by that the much lower modulus of elasticity for pressed lithium disilicate dictates a higher amount of deformation exhibited by the restoration before complete fracture (20,24). Also conflicting with the current results, the latter authors recorded decreased strain results with the increased overall surface area of the bridge. This might be because the much higher modulus of elasticity of zirconia would allow less strain of the bridges under loading, even when the area of the bridge is increased (11).

Our results were in well accordance with Romeed et al. (25), who found that inclusion of one more abutment in a cantilever FPD may result in up to 60% less displacement under lateral loading. They claimed that increasing the number of abutments increases the support and results in a more favorable distribution of stress within the cantilever FPD structure (26). The strain values for both groups in the current study were higher than those of zirconia cantilever bridges with different retainer designs reported by El-Etreby and Morsi (15), which is quite predictable, due to the difference in modulus of elasticity between bridge materials in both studies. The much lower modulus of elasticity for pressed lithium disilicate (e.max™) (**94-95 GPA**) in the current study, than that of zirconia (VITA In-Ceram YZ) (**210 GPa**), dictates a higher amount of strain exhibited by the bridge before complete fracture (27).

Our results correspond with Yousief, (2019) (19), who indicated that more load energy absorption and more deformation occurred in e.max cantilever bridges compared to the more rigid PFM ones. They explained that the stiff material concentrates the stress more inside it rather than transfer it to the underlying structure.

Limitations of the study:The testing in present study was conducted under static monotonic load. Yet, in the oral environment, the forces applied on dental restorations are more likely to be of a cyclic nature (28). Therefore; testing of the current material with the bridge designs is important to be performed under cycling loading in further investigations, as it would be better simulating of the clinical situation.

The recent CAD/CAM technology for production of the wax patterns for bridges duplication may provide better accuracy, and should be considered in further situations.

In this study also, some clinical conditions were not accounted for, like artificial aging, dynamic loading, and physiologic tooth mobility within the periodontal ligament simulation (29,30); however, the uniform fabrication of all the bridge designs together with standardization of abutment substrate and its dimensions allowed to reveal a realistic performance of the material, with respect to an in vivo study where the bridges and abutments have different shapes and dimensions.

Finite element modelling can analyse the magnitudes and distributions, of internal stress by changing the characteristics of materials, which means that the results of finite element analysis would depend on its modelling methods and the given values of material properties, yet, it can be further studied and linked to the actual strain measurements under loading, obtained in our study to better understand stresses exhibited by the material in such designs.

Conclusions:

Within the limitations of the present study, the following can be concluded:

1. The strain values induced in lithium disilicate anterior bridges have no catastrophic effect regardless of bridge design, indicating that cantilever bridge design could resist both vertical and lateral loading in a favorable mode regarding clinical acceptable forces and may offer a

reliable conservative option for replacing the missing maxillary lateral incisor.

2. Anterior lithium disilicate fixed-fixed bridge design resists vertical forces in a more favorable way than lateral forces.

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