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PHOTOELASTIC ANALYSIS COMPARING STRESS DISTRIBUTION AMONGST DIFFERENT CROWN MATERIAL ON TITANIUM IMPLANT

Dental Science

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ABSTRACT

Introduction: Tooth loss leads to poor and insufficient masticatory performance and implants serve as effective mode of replacement. Investigating bone turnover rate via stress analyss holds utmost importance. A restorative material fulfilling basic requirements of functional and esthetic restoration is also deficient. **Aim:** To evaluate and compare the amount of stress transmitted to the supporting structures on loading implant with different restorative superstructures on vertical and oblique direction of loading. **Materials and methodology:** Photoelastic model of single tooth implant and natural tooth were made with three different restorative superstructures and the stress distribution pattern was analysed using photoelastic stress analysis. The stress concentration was evaluated by calculating the fringe order and fringe values using the equations of stress optic law and the data obtained was statistically analysed. **Results:** One way ANOVA post hoc analysis revealed PFM showed significantly (p value < .05) greater stress concentration compared to Ni-Cr and zirconia for both vertical and oblique direction of loading. Oblique loading resulted in greater stress concentration compared to vertical loading for all restorative materials. **Conclusion:** Zirconia use is beneficial when compared to PFM and all metal Ni-Cr restoration as restorative superstructure for fixed prostheses.

KEYWORDS

Dental Implant, Metal Ceramic, Stress Analysis, Zirconia

INTRODUCTION

Masticatory function plays an important factor in maintaining the general health and affects the nutritional status, quality of life and overall health of an individual.[1] Tooth loss especially of the posterior tooth, leads to poor and insufficient masticatory performance [2] and replacement of missing natural tooth by implant has good survival rate for both single crown and implant supported fixed prosthesis.[3] The health of supporting structure also plays a key role in longevity of this restoration which in turn depends on various factors like the magnitude and direction of load and the relative stresses.Vertical forces applied along the long axis of tooth are less injurious compared to obliquely directed forces, excessive occlusal forces results in bone resorption.[4,5] Stress analysis thus holds utmost importance in investigating the bone turnover since incorrect or overloading may lead to implant loss.[6] The amount of stresses developed, depends on various factors such as magnitude and direction of load,[7] quantity and quality of supporting tissue,[8] the type of restorative material[9] and the resiliency or stiffness of the restorative materials.[10] Photoelastic stress analysis is considered to be one of the recognized engineering method to evaluate the stress distribution pattern and has been used in the past for analysis of experimental stresses.[11,12,13] The determination of stress distribution around the implant with different restorative materials used for fabrication of implant structure in the present study was thus evaluated by photoelastic stress analysis_ Analysis of existing literature revealed that the materials exhibiting high degree of resiliency causes less damage to the supporting structures; [10, 14, 15] however, such materials wear off quite rapidly and need replacement. This in turn warrants the detection of a restorative material which fulfills all the basic requirements of functional and esthetic restoration along with adequate physical properties without compromising the health of supporting structures. The present in–vitro comparative study was thus aimed to evaluate and compare the amount of stress transmitted to the supporting structures by loading the natural tooth and titanium implant as an abutment with various different restorative superstructures. The objectives were to evaluate the stress distribution pattern with varying direction of load transfer (vertical loading and oblique loading) and to evaluate the resiliency of the various restorative materials.

MATERIALS AND METHOD

The present in vitro comparative study on ten samples was conducted to evaluate the stress distribution pattern on the supporting tissues with titanium implant as an abutment when subjected to masticatory forces, natural tooth in the present study served as control group whereas implant as the study group. Non- precious base metal alloy, PFM and Zirconia were the restorative materials used as superstructure which were then subjected to various magnitude and direction of loading. Two dimensional photoelastic stress analysis polariser (Fig. 1) was used to evaluate the stress transmitted. The testing of samples and their interpretation was carried out at Madras Institute of Technology (MIT) Chromepet, Chennai. Permission to conduct the study was obtained from the authorities and the ethical clearance was obtained from Institutional Review Board of Government Dental College, Chennai. The sample size estimation for the present study was done using G power software and the estimated sample size for the present study was found to be 10. The present study thus incorporated a sample size of 10 samples with five in the control and five in the study group. The restorative materials were divided into three groups depending upon the various restorative materials. The restorative material in Group A consisted of Non- Precious Nickel Chromium alloy, Group B consisted of Porcelain Fused to Metal and Group C consisted of Zirconia. Master die Type III dental stone was measured and mixed with measured quantity of water in a flexible rubber bowl with plaster spatula in accordance to the manufactures instruction and kept on the vibrator to allow the escape of entrapped air. The stone mix was subsequently shaped to form a rectangular block and allowed to set for 30 minutes. The rectangular block was then trimmed to obtain a rectangular die of size measuring (3 2 inches). Mold preparation included mixing base and catalyst of poly-vinyl siloxane putty elastomeric impression material in equal proportion of 1:1 ratio, adapting all over the surfaces and borders of the master die except one and then subsequently allowing to set. Medium fusing impression compound was then softened in warm water bath and kneaded to obtain a workable mass which was then adapted all over the area covered by poly-vinyl siloxane putty elastomeric impression material, and was allowed to set. Finally the master die was retrieved to obtain the mold space for fabrication of photoelastic model. (Fig. 2) The positioning of natural tooth in the mold space was done by keeping one end of sprue wax fused to the proximal surface of the natural tooth (mandibular first molar) above its cement-enamel junction and the other end of this was fused with the vertically positioned block of modeling wax placed over the side of mold. Precautions were taken while positioning the natural tooth within the mold space such that it is placed at the center of the mold space and should not make any contact with the side walls of the mold. In order to obtain the photoelastic model Epoxy resin and hardener in the ratio of 10:1 were measured and mixed in a plastic cylinder with a plastic spatula for about 30 minutes. The resulting mixture was then poured along the side walls of the mold and set for 48 hours to ensure that no air bubble gets entrapped while pouring. Once set, it was then retrieved from the mold and was then trimmed, finished, and polished to obtain a mirror like surface finish. (Fig. 3)

Tooth preparation on the photoelastic model to receive full veneer crown was done according to the biomechanical principles of tooth preparation. For recording the impression of the prepared natural tooth, self-cure auto-polymerizing acrylic resin custom tray was made and impression were recorded using poly-vinyl siloxane putty and light body elastomeric impression material (Fig. 4). The impression was then poured with Type IV dental stone to obtain the working die. Restorative superstructure of non-precious base metal alloys, PFM, and zirconia were made in the conventional manner on the working die. The fit of these full coverage extra-coronal restorations were checked and then luted on the prepared natural tooth of the photoelastic model. Titanium implant (diameter 4.2mm; Length 13.00 mm) with abutment (Cuff height 1.00 mm) was used for the study group, the fabrication of photoelastic model was done in the similar manner to the control group. Restorative superstructure of non-precious base metal alloys, PFM, and zirconia were also made in the conventional manner and were luted onto the implant abutment to have a cement-retained restoration. The loading of the model was then contemplated to study the load transferred to the supporting structures especially on the bone. The models were loaded with a load of 50 lbs. to simulate the masticatory load during function and the resulting stresses were then calculated from the photographed fringes. Vertical and oblique loads of 50 lbs. were applied onto the occlusal surface of the restorative superstructure through the loading frame that was attached with the straining frame. The stresses transmitted to the model resulted in formation of colored fringes when viewed through the polariscope which were then photographed. (Fig. 5) All the photographs were evaluated visually for the stress induced fringes by calculating the corresponding fringe order and fringe value and the same procedure was then repeated for all five samples of both the control group and the study group with different restorative materials as superstructure.

The data collected was entered in Microsoft Excel and subjected to statistical analysis using Statistical Package for Social Sciences software version 20.0.Analysis of Variance and post hoc tukey test was employed to determine the statistical significance. Probability value (p value) of ≤ 0.05 was considered as significant level**.**

RESULTS

An in vitro comparative study was performed on titanium implant and natural tooth to evaluate the stress distribution pattern with different restorative superstructure. Photoelastic model for single tooth implant and natural tooth were made. Full coverage extra-coronal restorative superstructure made from non-precious Ni-Cr alloy, PFM, and zirconia were fabricated and subjected for testing by two dimensional photoelastic stress analysis for evaluation of stress distribution pattern. Vertical and oblique loads were applied by the loading frame that results in formation of colored fringes when viewed through the polariscope which were then photographed. These photographs were then evaluated visually to evaluate the stress concentration by calculating the corresponding fringe order and fringe value using the equations of stress optical law. Table 1 shows the evaluation of stress distribution by loading titanium implant with different restorative superstructures. A comparative evaluation revealed significant differences among the restorative superstructures for vertical and oblique loading with highest mean value for PFM restorations for both oblique and vertical loading. Post hoc analysis revealed no significant difference between all metal and zirconia for vertical loading and vertical loading. A significant difference between PFM with all metal and zirconia was seen for both oblique and vertical loading (p value $\leq$ .05) (Table 2). Loading natural teeth as an abutment also revealed significant difference for vertical and oblique loading stress distribution with greater mean stress for PFM restorations (Table 3). Significant difference via post hoc analysis was also seen between PFM with all metal and zirconia was seen when natural teeth was used as an abutment (Table 4). Stresses created by the materials were found to be significantly higher under oblique loading when compared to vertical loading (Table 5).

DISCUSSION

Dental implant treatments for replacement of missing teeth serve as predictable and safe method; however, an implant supported FPD has a direct implant-bone interface in contrast to natural tooth surrounded by periodontal ligament, and so it does not benefits from the proprioception.[16] The stress analysis is thus required to investigate the bone turnover as incorrect or overloading may leads to distributed bone turnover and consequent implant failure.[6, 17] The two dimension photoelastic stress analysis is a recognized engineering method used to evaluate the stress distribution pattern of the photoelastic model fabricated from the photoelastic material that exhibits the photoelastic property. The temporary double refraction pattern under stress of the photo elastic model is utilized for the photoelastic analysis. The principal behind this involves the ray of light which gets split into two different rays that travel at different magnitude of velocity along the principal plane of the material and then emerge retarded with respect to each other. The resulting amount of retardation is thus directly proportional to the difference between the principal stresses which results in formation of colored fringes when viewed through the polariscope. These fringes have corresponding fringe order and fringe value. The colored patterns of the fringes in the photoelastic model indicate the relative magnitude and distribution of stresses that results from the applied force. The total numbers of isochromatic fringes observed were directly proportional to the magnitude of the force and the areas of high stress concentration are represented by how close the fringes are to each other. Fringe order is based on the fringe color position in the color sequence namely as the colors become brighter (black, gray, white, yellow, orange, red, blue, green) fringe order increases.The present study thus utilized two dimensional photoelastic stress analysis method to evaluate the stress distribution pattern which is in accordance to the studies conducted by Inan O et al.,[7] BernardesSr et al.,[12] Titanium is considered to be the first choice of dental implant for treating partially or completely edentulous patients due to its excellent corrosion resistance, biocompatibility, high strength to weight ratio, and ability for osseointegration.[18(69)] Initially gold alloy was used for the restorative framework fabrication and recently, Zirconia frameworks were proposed as an esthetic alternative for the metallic frameworks due to their chemical durability, aesthetics, biocompatibility, and superior mechanical properties.[19] The present study thus incorporated titanium implant with their restorative superstructure made from non-preciousNi-Cralloy,PFM, and zirconia. In the present study it was observed that among various restorative materials PFM, exhibits more stress concentration both on vertical and oblique loading with implant and natural tooth compared to all metal and zirconia. The results are in accordance to the studies conducted by *Pross KA et al.*[20] and *K.Vinayagavelet al.*[21] who also reported similar results on natural tooth. Studies conducted by *Suzuki H et al*.[8] and *AnusaviceKjet al*.[22] showed that the restorative materials with high young's modulus, or with higher rigidity seems to induce large stresses compared to material that are less rigid with low elastic modulus. Similar findings were obtained by studies conducted by *S.M. Burgoa-la-Forcada et al*[23] & *Kathleen Manuela D'souza et al.*[24] .The present study revealed more stress concentration for all restorative materials during oblique loading when compared to vertical loading. The results are in line with the studies conducted by *Watanabe F et al.*[5] *and Ciftci Y et al.*[18] and hence the oblique loading is therefore believed to be the most destructive loading condition[25] and should be avoided whenever possible.[26] Compared to natural tooth, implant was found to have a greater stress concentration for all restorative material both on vertical and oblique loading. The reason probably accounts for the direct implant-bone interface in implant supported prostheses rather than fibrous tissue interface (periodontal membrane) in case of natural tooth supported prostheses which acts as viscoelastic shock absorber stated by *Carranza and Newman*.[27] Besides this other factors such as biomechanical design, sensory nerve complex, occlusal material, and the surrounding bone also contributes to this distinct behavior. The present study for determination of stress distribution pattern is simple, cost effective and can be used for other researches in the field of dentistry. However, a smaller sample size hinders the generalization of the present study and hence further research with a larger sample size is needed to interpret the variations in implant fixture design.

CONCLUSION:

Based on the findings of the present study it can be stated that within the limitations stated the use of zirconia as a restorative superstructure for fixed prostheses is beneficial compared to PFM and all metal Ni-Cr restoration**.** Apart from low stress concentration, its excellent esthetics, biocompatibility, superior mechanical properties coupled with life like appearance makes it a restoration of choice.

Table 1: Evaluation of stress distribution by loading natural tooth with different restorative superstructures

PARAMETER FOR IMPLANTS	GROUPS	MEAN ± SD	P VALUE
FRINGE VALUE VERTICAL	All Metal	2.86 ± 0.04	***0.0001***
	PFM	3.78 ± 0.083	
	ZIRCONIA	2.78 ± 0.084	
FRINGE VALUE OBLIQUE	All Metal	3.82 ± 0.08	***0.0001***
	PFM	4.4 ± 0.25	
	ZIRCONIA	3.5 ± 0.24	

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Table 2: Post Hoc Analysis

Dependent Variable	(I) Groups1	(J) Groups1	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Fringe Value Vertical	All metal	PFM	-.92000*	.04583	.000	-1.0423	-.7977
		Zirconia	.08000	.04583	.229	-.0423	.2023
	PFM	All metal	.92000*	.04583	.000	.7977	1.0423
		Zirconia	1.00000*	.04583	.000	.8777	1.1223
	Zirconia	All metal	-.08000	.04583	.229	-.2023	.0423
		PFM	-1.00000*	.04583	.000	-1.1223	-.8777
Fringe Value Oblique	All metal	PFM	-.62000*	.13166	.001	-.9712	-.2688
		Zirconia	.32000	.13166	.076	-.0312	.6712
	PFM	All metal	.62000*	.13166	.001	.2688	.9712
		Zirconia	.94000*	.13166	.000	.5888	1.2912
	Zirconia	All metal	-.32000	.13166	.076	-.6712	.0312
		PFM	-.94000*	.13166	.000	-1.2912	-.5888

Table 3: Evaluation of stress distribution by loading natural teeth as an abutment with different restorative superstructures

PARAMETER FOR NATURAL TOOTH	GROUPS	MEAN ± SD	P VALUE
FRINGE VALUE VERTICAL	All Metal	2.38 ±0.21	***0.0001***
	PFM	3 ± 0.12	
	ZIRCONIA	2.19 ± 0.08	
FRINGE VALUE OBLIQUE	All Metal	3.02 ± 0.08	***0.001***
	PFM	3.36 ± 0.11	
	ZIRCONIA	3 ± 0.16	

Table 4: Post Hoc analysis

Dependent Variable	(I) Groups1	(J) Groups 1	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Fringe Value VERTICAL	All metal	PFM	-.80800*	.09304	.000	-1.0562	-.5598
		Zirconia	-.18800	.09304	.150	-.4362	.0602
	PFM	All metal	.80800*	.09304	.000	.5598	1.0562
		Zirconia	.62000*	.09304	.000	.3718	.8682
	Zirconia	All metal	.18800	.09304	.150	-.0602	.4362
		PFM	-.62000*	.09304	.000	-.8682	-.3718
FringeValue OBLIQUE	All metal	PFM	-.34000*	.07746	.002	-.5467	-.1333
		Zirconia	.02000	.07746	.964	-.1867	.2267
	PFM	All metal	.34000*	.07746	.002	.1333	.5467
		Zirconia	.36000*	.07746	.002	.1533	.5667
	Zirconia	All metal	-.02000	.07746	.964	-.2267	.1867
		PFM	-.36000*	.07746	.002	-.5667	-.1533

Table 5: Evaluation of the stress distribution pattern with varying direction of load transfer (vertical loading and oblique loading)

Material	Fringe Value	Groups (Mean ± SD)		P VALUE
		Implant	Natural tooth	
ALL METAL	VERTICAL	2.86 ± 0.04	2.38 ± 0.12	***0.0001***
	OBLIQUE	3.82 ± 0.08	3.02 ± 0.19	***0.0001***
PFM	VERTICAL	3.78 ± 0.083	3 ± 0.12	***0.0001***
	OBLIQUE	4.4 ± 0.25	3.36 ± 0.09	***0.0001***
ZIRCONIA	VERTICAL	2.78 ± 0.084	2.19 ± 0.84	***0.0001***
	OBLIQUE	3.5 ± 0.24	3.0 ± 0.16	***0.005***

FIGURE 1: PHOTOELASTIC POLARISCOPE

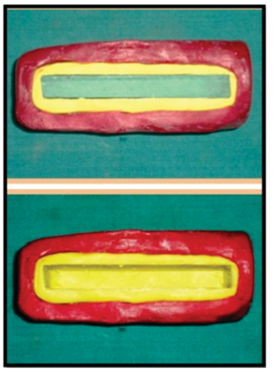

FIGURE 2 : PREPARATION OF MOLD

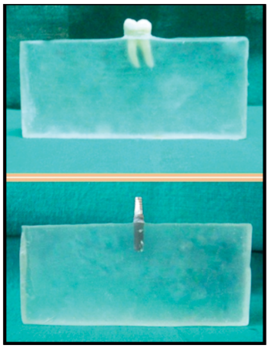

FIGURE 3 : PHOTOELASTIC MODEL OF TOOTH AND IMPLANT

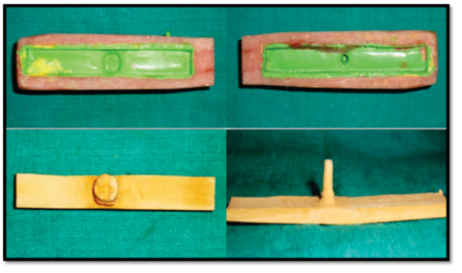

FIGURE 4 : PREPARATION OF DIE FOR RECEIVING DIFFERENT CROWNS

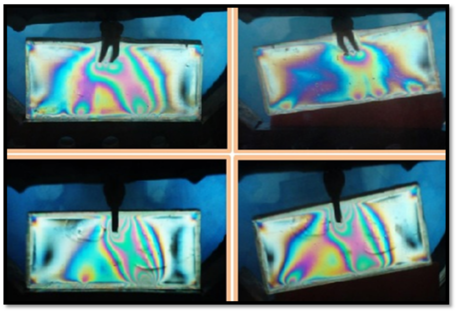

FIGURE 5 : FRINGE PATTERN UPON VERTICAL AND OBLIQUE LOADING

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