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ORIGINAL RESEARCH

Quantitative Evaluation and Comparison of Stress Transmission Characteristics of Bar-Clip and Short Coping Overdenture Attachments Under Dynamic Loading: A Photoelastic Stress Analysis

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ABSTRACT

Statement of problem: When two canine abutment teeth are used to support an overdenture prosthesis, optimal stress distribution to minimize forces to abutments is desired.

Purpose: This study used photoelastic stress analysis to compare the stress patterns generated around canine abutments using two different overdenture retainer designs.

Materials and methods: Two canine abutments were anchored in the photoelastic mandible and overdentures were fabricated using two different overdenture attachments. The fitting surface of dentures were lined with resilient layer of light bodied silicon rubberbase impression material to simulate oral mucosa. The attachments used were Bar-Clip and Short coping type. Verticalload of 5 to 50 lb was applied by jaw simulator. Resultant stress fringes were photographed and evaluated quantitatively.

Results: Bar-Clip type of attachment transmitted more amount of stress than short coping type transmitted. There was gross difference in magnitude of stresses between two types of retainers.

Conclusion: As the retentivity of the attachment increased there was more stress concentration around the abutments.

Keywords: Photoelasticity, Short coping, Tissue-bar, Overdenture retainer, Fringes.

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INTRODUCTION

In prosthodontics, we regularly encounter patients who are partially edentulous as a result of caries, periodontal disease, etc; our task is to restore the masticatory function and to preserve for as long as possible what remains in dentition and hard and soft supporting structures.

The stresses of mastication are very well dissipated by supporting structures when the individual is dentulous but when the teeth are lost these stresses directly come on the residual alveolar ridge and they become deleterious to the residual ridge and cause resorption of ridge.[1]

Dentists have long recognized this problem and have tried to develop treatment modalities like telescopic dentures, overdentures, resilient lining of dentures, etc. to reduce the stresses coming on the supporting bone.[2]

A variety of methods for using natural teeth to support and stabilize complete dentures have been used such as natural teeth with metal coping,[3] tissue bars[4] and resilient and nonresilient stud attachments.[5]

In all these methods the abutment teeth and residual ridge share the force of mastication in varying degrees and the degree of load sharing depends upon the specific attachment system used. However, the major premise of overdenture treatment is to transfer occlusal forces along the long axis of the supporting tooth, to minimize horizontal torque, and to allow for a more favorable situation for periodontal ligaments.[6-9]

Photoelastic stress analysis[10-14] provides a method for visualizing and analyzing the forces exerted around abutments. It is based upon a unique property of some transparent materials like glass, mica, quartz, certain epoxy resins, etc. when a photoelastic model is stressed and a beam of polarized light enters the model, the light is divided into two components waves, each with its plane of vibration parallel to one of the principal planes of stress. The stress fringes within the models are viewed, photographed and calculated quantitatively.

In this study, the stress patterns generated around the overdenture abutment apex under dynamic loading were evaluated and compared using bar-clip type attachment and short coping systems, by photoelastic stress analysis. Since, the oral cavity is subjected to cyclic dynamic loading during mastication, therefore, this study was carried out simulating the similar conditions of mastication, to evaluate stress generated by two types of abutment retainers.

MATERIALS AND METHODS

Mandibular arch model, with only two canines remaining, were made using photoelastic plastic resin CY 212 (Araldite), Hardener HY-951, release agent QZ-5111 (Ciba Specialty Chemicals Limited, off Arraey Road, Goregaon, Mumbai, Maharashtra, India) and extracted mandibular canines. Light bodied silicon rubber was used to simulate periodontal ligaments.

For bar-clip type of attachment, the canines were prepared with the round end diamond creating a definite chamfer finish line for copings. Wax patterns for copings and bar were prepared, wax bar attached to wax copings and cast together with Ni-Cr alloy. The bar assembly was finished and polished and cemented. For short coping attachments, preparation was done with round end diamond forming a definite chamfer finish line. Wax patterns for copings were prepared and cast. Short coping attachments were also cemented. Complete dentures were fabricated over these attachments and placed on the photoelastic models.

Photoelastic models with dentures were divided into two groups:

Group A: Bar-clip type

Group B: Short coping type

Five models with dentures were prepared for each group (Fig. 1).

Jaw Simulator

The machine devised to generate masticatory strokes was named 'jaw simulator'. It generates 150 masticatory strokes per minute. It constitutes an upper jaw in which upper denture was mounted with the cast. It has a centrally located rod to hold the dead weights. The lower jaw is suspended with pins to hold the photoelastic model. A bigger gear of 10 inch diameter with 200 teeth and a 'pinion' gear of 18 teeth is attached with quarter horsepower 1,400 rpm motor. The bigger gear mounted on a double ball-bearing pedestal, was connected to lower jaw through a series of linkages. When the gear makes revolutions the lower jaw generate opening and closing movements through attached linkages.

The upper denture was fixed on the upper cast and the cast with the denture was fixed on 4 × 4 metal plate which was screwed in the upper jaw of the jaw simulator. The photoelastic model with denture was fixed to the same size of plate and screwed to lower jaw. Similar procedure was followed for all dentures. The jaw simulator mounted with dentures was placed between light source and the analyzer on polariscope anteroposteriorly such that light from the source passes through the photoelastic models uninterruptedly.

Still photographs of dentures were taken in nonstressed conditions. For loading the dentures dead weights of 5, 10, 15, 20, 24, 30, 35, 40, 45 and 50 lb were used. The dentures were first loaded by 5 lb and jaw simulator was made to perform movements and stress fringes were photographed. The load was gradually increased upto 50 lb. Sequential photographs with canon fully automatic camera were taken after every increase of 5 lb weight. The same procedure was repeated for every sample of each type of overdenture (Figs 2 and 3).

The fringe values were calculated quantitatively for applied load in each group and compared with each other.

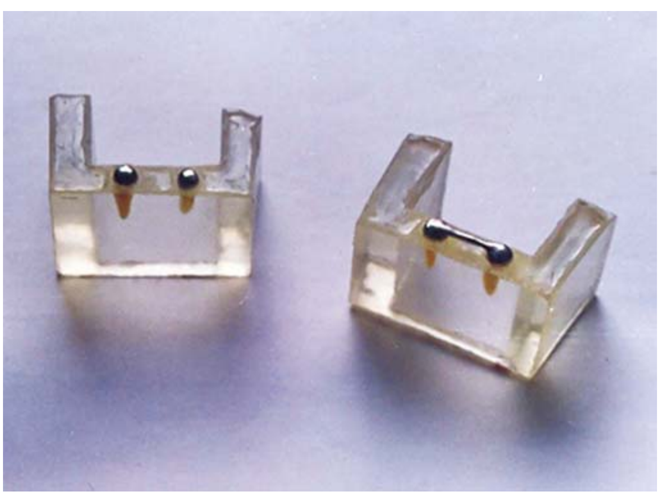


Fig. 1: Bar-clip and short coping attachment

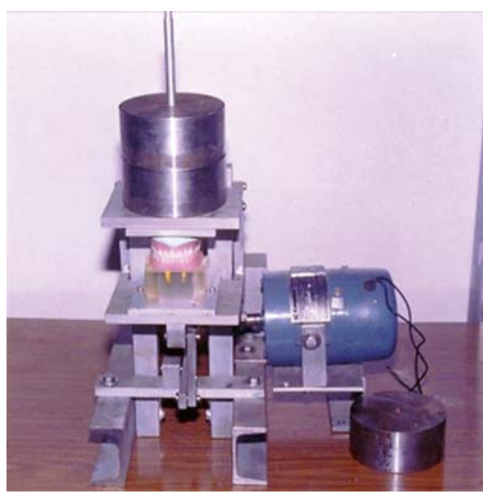


Fig. 2: Jaw simulator with dentures

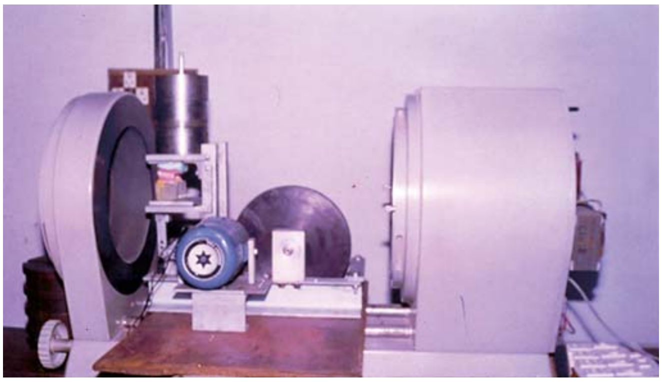


Fig. 3: Jaw simulator with polariscope

The evaluation of the stress through a polariscope means measuring the difference between the principal stress (compressive and tensile) which are named S1 and S2 (sigma 1 and sigma 2).

This stress (kg/mm^2) is derived from the equation:

$$S1\text{-}S2 = \frac{F \times N}{h}$$

Where S1 and S2: The principal stress
F: Stress optical coefficient
N: Number of fringes
h: Thickness of model

The maximum shear stress (t) at a given point can be calculated by equation:

$$t = \frac{S1 - S2}{2} \quad \text{therefore, } t = \frac{F \times N}{2h}$$

Stress optical coefficient (unit kg/mm^2 per fringe) was necessary to calculate the stress values. It is determined by using following equation:

$$F = \frac{P}{N \times W}$$

Where W: Width of specimen
N: No. of fringes
P: Required load

The stress optical coefficient for epoxy resin CY 212 is 20.08 kg/mm^2.

OBSERVATIONS AND RESULTS

The observations were made for quantitative evaluation and comparison of stress distribution patterns in these two types of overdenture attachment designs. The fringe values were calculated quantitatively for applied load in both groups and compared with each other. The calculated fringe values are shown in Tables 1, 2 and 3.

t-test was applied to compare the means of specimens of both groups by using following equations:

$$t = \frac{\bar{X}_1 \times \bar{X}_2}{S} \sqrt{\frac{n_1 \times n_2}{n_1 - n_2}}$$

Table 1: Group A (bar-clip type overdenture) stress values for 5 to 50 lbs

S.no.	*Loads in pounds*	*Stresses in samples in kg/mm^2*					*Mean*
		1	*2*	*3*	*4*	*5*	
1	5	0.669	0.621	0.653	0.636	0.644	0.644
2	10	1.338	1.357	1.412	1.423	1.326	1.371
3	15	2.008	2.001	2.014	2.067	2.027	2.029
4	20	2.677	2.631	2.683	2.601	2.702	2.658
5	25	3.346	3.313	3.377	3.352	3.401	3.357
6	30	4.016	4.070	4.062	4.060	4.031	4.047
7	35	4.685	4.666	4.671	4.633	4.691	4.669
8	40	5.354	5.301	5.373	5.361	5.322	5.342
9	45	6.693	6.681	6.677	6.623	6.701	6.675
10	50	7.362	7.311	7.388	7.370	7.323	7.350

Table 2: Group B (short coping type overdenture) stress values for 5 to 50 lbs

S.no.	*Loads in pounds*	*Stresses in samples in kg/mm^2*					*Mean*
		1	*2*	*3*	*4*	*5*	
1	5	0.317	0.211	0.309	0.333	0.328	0.299
2	10	0.669	0.601	0.644	0.623	0.603	0.628
3	15	1.338	1.311	1.320	1.303	1.392	1.332
4	20	1.401	1.417	1.473	1.469	1.464	1.444
5	25	2.008	2.017	2.035	2.029	2.030	2.023
6	30	2.93	2.037	2.011	2.081	2.077	2.059
7	35	2.677	2.611	2.634	2.693	2.640	3.5143
8	40	3.346	3.311	3.326	3.378	3.401	3.52
9	45	4.016	4.021	4.006	4.021	4.091	4.031
10	50	4.117	4.105	4.201	4.237	4.120	4.156

Table 3: Comparative statistical analysis of stresses at various loads (groups A *vs* B)									
Load	*Group A*			*Group B*			*t-value*	*p-value*	*Inference*
	n	*X*	*SD*	*n*	*X*	*SD*			
5 lb	5	0.644	0.016	5	0.290	0.045	0.511	<0.01	Sign Inc
10 lb	5	1.371	0.639	5	0.628	0.025	11.35	<<0.01	Sign Inc
15 lb	5	2.029	0.023	5	1.332	0.031	12.77	<<0.01	Sign Inc
20 lb	5	2.658	0.037	5	1.444	0.029	18.26	<<0.01	Sign Inc
25 lb	5	3.357	0.029	5	2.023	0.009	31.11	<<0.01	Sign Inc
30 lb	5	4.047	0.020	5	2.059	0.030	39.00	<<0.01	Sign Inc
35 lb	5	4.047	0.020	5	0.059	0.030	39.00	<<0.01	Sign Inc
40 lb	5	5.342	0.026	5	3.52	0.033	33.50	<<0.01	Sign Inc
45 lb	5	6.675	0.027	5	4.031	0.030	46.32	<<0.01	Sign Inc
50 lb	5	7.350	0.029	5	4.156	0.052	37.94	<<0.01	Sign Inc

n: Frequency distribution; X: Mean; SD: Standard deviation

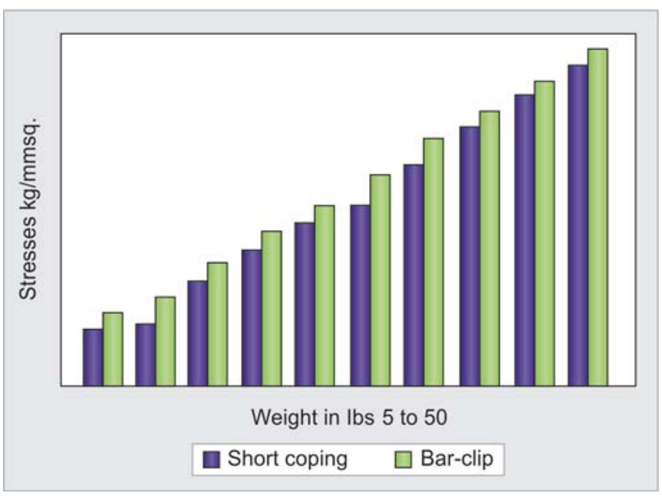
Where X_1: Mean of specimen 1
X_2: Mean of specimen 2
S: Combined standard deviation
n_1: Size of specimen 1
n_2: Size of specimen 2

Standard deviation 'S' is given by the equation:

$$\sqrt{\frac{\Sigma(x_1-\overline{x_1})2+\Sigma(x_2-\overline{x_2})^2}{n_1+n_2-2}}$$

Fringe values were calculated statistically and following results were obtained.

1. The value of stress transmitted to the abutment by using both overdenture attachments ranged from 0.211 kg/mm^2 to 7:388 kg/mm^2 when 5 to 50 pounds load were applied.
2. The value of stress transmitted to the abutment by using bar type overdenture attachment (group B) ranged from 0.601 kg/mm^2 to 7.388 kg/mm^2.
3. The value of stress transmitted to the abutment by using short coping overdenture attachment (group C) ranged from 0.211 kg/mm^2 to 4.237 kg/mm^2.
4. On comparing the mean values of stresses transmitted to the abutment by groups A and B, it was found that there was significant increase in the stresses transmitted by group A ($p << 0.01$) (Graph 1).



Graph 1: Stresses transmitted

DISCUSSION

Overdentures are prosthesis supported by one or more natural teeth with the objective of preserving the remaining supporting tissue and to restore lost tissues in such a way to provide maximum service for maximum amount of time.[15-17] The nature of stresses produced by forces on overdentures, relation between attachment systems of overdenture and stress distributions is vital aspect in different prosthetic placement. Force transmission characteristic of the attachment is the most important factor in overdenture design.[18,19]

Favorable stress transmission through attachments to abutments and other structure ultimately helps in achieving the primary goal of overdenture therapy. The most desirable criterion for the selection of overdenture attachment system is the way these attachments transmit the stresses to the supporting structures.[20,21] The sharing of stresses by the abutments in cross-arch manner as well as between abutments and posterior edentulous ridge is always beneficial for preservation of residual ridge and health of the periodontal ligament.

In the oral cavity teeth are subjected to dynamic loading conditions, hence the present study evaluates the stress patterns around the apex of abutment teeth using photoelastic model representing human mandible under dynamic vertical loading conditions.

The photoelastic models employed in this study revealed that varying degree of stresses are produced by both overdenture attachments designs at variable loads. Stress transmission through overdenture attachment in the photoelastic model is influenced by many factors *viz* amount of force, retention of overdenture on the abutments, area of contact of load with overdenture attachment, direction of the loading, shape and size of root of abutment, inclination of abutment tooth, interarch relationship, etc.[22-24]

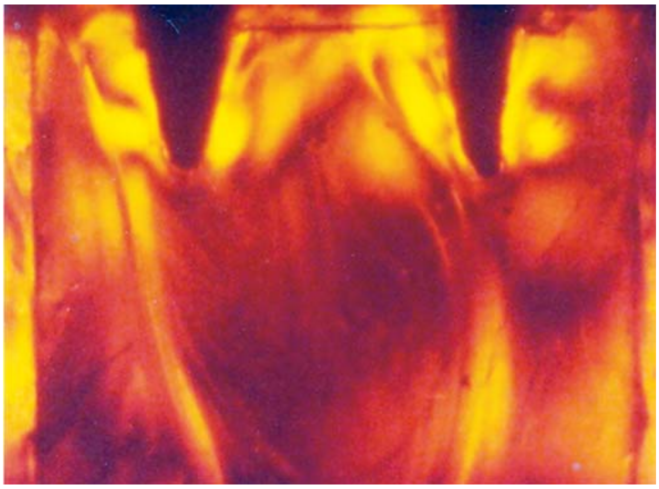


Fig. 4: Stress fringes in bar-clip at 45 lbs

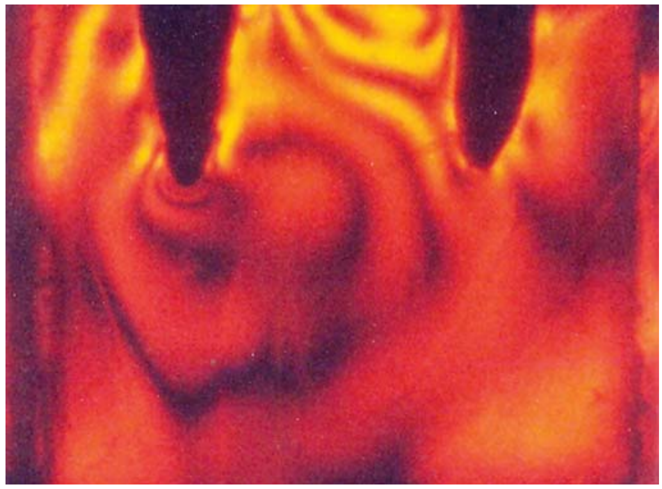


Fig. 6: Stress fringes in short coping at 45 lbs

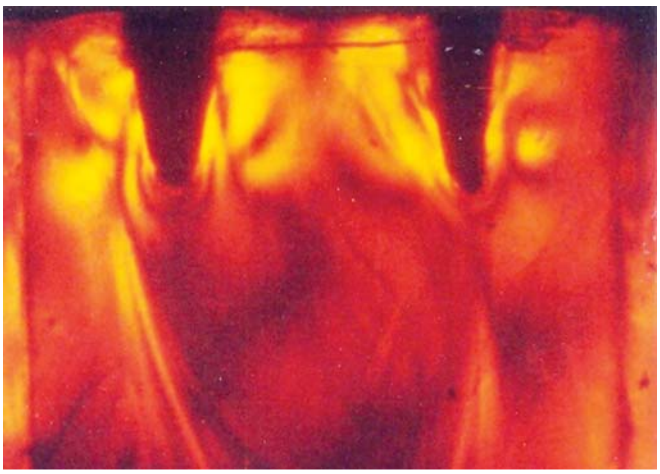


Fig. 5: Stress fringes in bar-clip at 50 lbs

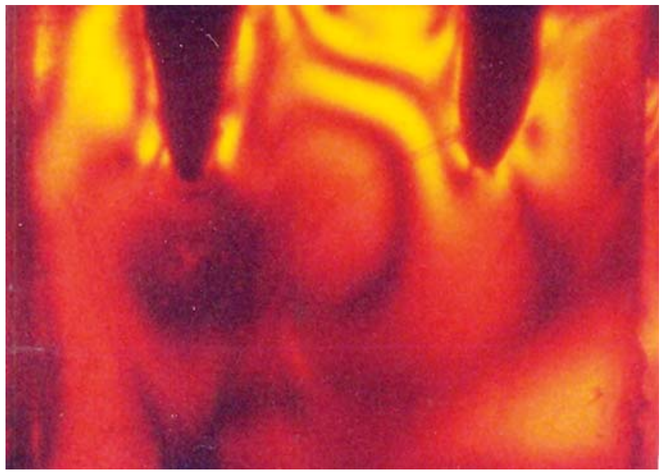


Fig. 7: Stress fringes in short coping at 50 lbs

Between two different overdenture attachments used in the present study, the bar-clip type[25] of attachment transmitted more amount of stress. More retentivity of this attachment accounted for maximum stress transmission (Figs 4 and 5). In study of overdenture attachments Warren and Caputo[26] (1975) found that there was a direct relationship between stability and retention that each design provided and the amount of stress and torque transferred to the supporting structures. The most retentive design tended to produce most severe stress concentration around the supporting alveolar bone. Similar, results were obtained by Thayer and Caputo (1977 and 1980).

The short coping attachment design transmitted lesser concentration of stresses as compared to tissue bar design. The reason being short copings allowed freedom of movement for the denture. Therefore stresses were shared between abutments and residual ridge (Figs 6 and 7). The force transmission characteristics of these attachments must be considered during the selection of the attachment systems along with the other factors like laboratory expertize, time, cost, periodontal health of teeth, interarch distance and length, shape and size of root of teeth.

For maximum stress distribution the best way is to fabricate an overdenture attachment design with maximal distribution of load between attachment and residual ridge. Resiliency between attachment and denture should be present so that there is some freedom for the movement of dentures in relation to residual ridge so that forces coming on the abutment can be favorably distributed between abutments and the residual ridge.[27,28]

All overdenture attachment designs which result in an overall reduction of stress to the supporting structures through sharing of occlusal forces, would provide the best potential for a favorable environment for abutment teeth and residual ridge.

CONCLUSION

The following conclusions are drawn in the present study after the evaluation of stresses transmitted to the abutments by photoelastic stress analysis:

1. There is considerable difference in the character of stress transmission for two different overdenture attachment designs at various loads.

2. The bar-clip attachment transmitted higher amount of stresses to the abutment teeth.
3. As the retentivity of the attachment system increased, there was increase in the stress concentration around apex of the abutment teeth.
4. The bar-clip can be used for short rooted teeth with less supporting bone because it has a splinting effect for teeth.
5. In cases of less interarch distance short coping attachments can be successfully used.

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