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Stress analysis of partial dentures*

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ABSTRACT

Three-dimensional photoelastic stress analysis has been used to examine the stresses on disjunct partial dentures. Three types of denture were studied: tooth-borne, mucosa-borne and tooth- and mucosa-borne. The method of calculating the stresses is outlined and the significance of the findings is discussed.

INTRODUCTION

There are several ways of carrying out a stress analysis in connection with partial dentures but the method which is suitable for detecting and measuring the distribution of load to simulated dental tissues is three-dimensional photoelastic stress analysis, which is a well-accepted technique for studying the direction and distribution characteristics of forces on various systems.

Clenched and masticatory loads on partial dentures are supported by mucosa, bone and periodontium but the distribution of these loads depends on many variables and is often unknown. It is important to know how stresses are distributed from partial dentures, not only for the success or failure of the appliance but also for the preservation of the health of the remaining tissues of the mouth.

Three-dimensional photoelastic stress analysis consists of modelling a system in plastic, loading the system, then recording and analysing the stress patterns which develop when viewed through polarizing lenses. The technique is especially useful for structures which have a complicated shape, or complex loading conditions, as in partial dentures or similar appliances, because in three-dimensional photoelastic stress analysis the magnitude and direction of stresses can be determined at any position within the object being analysed. This is a distinct advantage over some other methods of stress analysis. It is also possible to determine the shear stress distribution quantitatively by determining the fringe constant for the plastic used in the test model.

Photoelastic stress analysis was first introduced into dentistry by Noonan (1949). He used two-dimensional photoelastic stress analysis to evaluate amalgam restorations and cavity design. Since that time photoelastic stress analysis has received much attention in the field of restorative dentistry (Haskins et al., 1954; Mahler and Peyton, 1955; Walton and Leven, 1955; Lehman and Hampson, 1962; Colin et al., 1963; Klötzer, 1964; Granath, 1965; Craig et al., 1967a, b, 1971; Johnson et al., 1968; El-Ebrashi et al., 1969; Nally et al., 1971; Farah, 1972; Koran and Craig, 1974; Fisher et al., 1975; Warren and Caputo, 1975), but the technique has been used only in a limited way in the field of partial dentures.

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In any particular clinical case or test situation the number of partial denture designs is almost infinite, the range of possible designs being due, among other things, to the following: saddle outline and fit; size and number of the pontic teeth; relative position of saddles; position, direction, magnitude and duration of the load; position, dimension and material of the connectors used; position, size, number and dimension of rests; position, number and dimension of retainers; design and material of the test model; the use and design of stress-breakers; the type of occlusion and jaw movement.

Once a design is decided, if that design is used in a clinical case or on a test model and five dentures of the design are made for the same mouth or test model, then wide variations will occur because of small individual differences between the dentures. The variations will be due to differences between one impression or duplication technique and the next, the dimensions of wax for the pattern, differences in finishing the alloy base, size and fit of occlusal, cingulum and incisal rests, and so on. Clearly, it is impossible to make identical dentures for the same mouth or test model and therefore testing of such dentures leads to variations in results, although the design is apparently identical.

Making test dentures under laboratory conditions has obvious advantages over clinical conditions because differences between impressions can be eliminated, and tooth movement which takes place between impressions, even though successive impressions might be made at the same sitting, can be disregarded. The nature of mucosa and its behaviour is another variable not found in laboratory test models, although it has to be admitted that the behaviour of silicone rubber, which is often used to simulate oral mucosa in saddle areas, is not always known under all conditions of testing.

The objective of the present study was to make a number of disjunct partial dentures on epoxy resin test models, to subject the dentures to known loads under controlled laboratory conditions and to evaluate the stresses in the test models by means of three-dimensional photoelastic analysis.

The disjunct principle of partial dentures design is a reasonably well-established method of joining differently supported parts of a denture (MacGregor and Miller, 1974). Thus, in the bilateral free-end situation the mucosa-borne part is separate from the tooth-borne part (*Fig. 1*). In a lower denture of this type the anterior tooth-borne part is made in cast alloy and a buccal bar extends distally from the last abutment tooth on each side. The mucosa-borne part is attached to the buccal bars by means of pins and sleeves which allow vertical movement when a load is applied to the denture. The movement of the sleeves on the pins can be adjusted so that when the mucosa is compressed (and therefore accepting a load) any further load is directed forwards, via the buccal bars, to the tooth-borne part of the denture. Thus, the disjunct design has the following advantages:

1. It prevents harmful loads to the remaining teeth.
2. It reduces excessive loads on the mucosa and alveolar bone of the free-end saddle areas in which there is always a deficit of supporting tissue (Watt et al., 1958).
3. By varying the pin/sleeve movement, the overall load can be shared proportionately between mucosa and abutment teeth, the proportion on each depending on the clinical findings in any particular case.

However, these advantages, particularly that of load distribution, are pure conjecture, and because of this a photoelastic experiment was set up to analyse the distribution of loads applied to disjunct dentures.

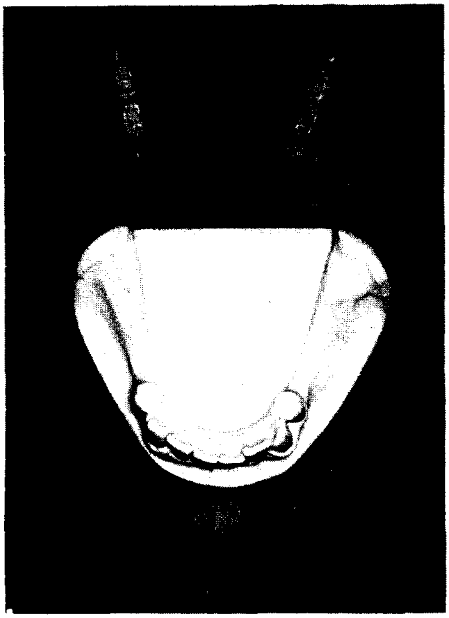

Fig. 1. Exploded view of a disjunct partial lower denture. The tooth-borne component is at the bottom of the photograph; the mucosa-borne component is at the top. The two parts are joined by buccal bars.

MATERIALS AND METHODS

A lower cast made of dental stone was selected. The standing teeth were the incisors, canines and first premolars. The teeth and the region of the roots were removed to allow the positioning of typodont teeth (urea-formaldehyde polymer). The inside of the cast was removed to form a horseshoe shape more suited for loading; the base was thickened by adding wax. An acrylic tray was made for each free-end saddle area. The tray was located mesially on the abutment tooth and distally on the end of the cast. An impression was made of the saddle area.

The surface of the saddle area of the cast was reduced by about 1 mm overall by scraping away the dental stone. A silicone* mould was made of the cast. The roots of another set of typodont teeth of identical size were reshaped, coated with gauge 24 casting wax and fitted into the mould. An epoxy resin model (made from Epon 828† and an amine hardener Jeffamine D400‡ in the ratio of 2:1) was poured under vacuum from this mould. The model was annealed in an electric oven at 60 °C for 30 minutes.

A layer of silicone§ rubber 'mucosa' was added to the model by means of the acrylic trays. The silicone 'mucosa' was attached to the epoxy resin surface with Citricon adhesive.

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*Silastic RTV No. G, Dow Corning, Midland, Mich.

†Shell Chemical Co., Plastics and Resins Div., New York.

‡Jefferson Chemical Co., Austin, Texas.

§Citricon, Kerr Mfg Co., Romulus, Mich.

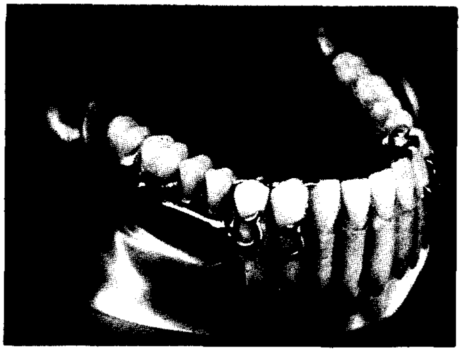

Fig. 2. Disjunct denture fitted to an epoxy resin model ready for testing. Note the close fit of the alloy base in the prepared lug (rest) seats in the anterior teeth.

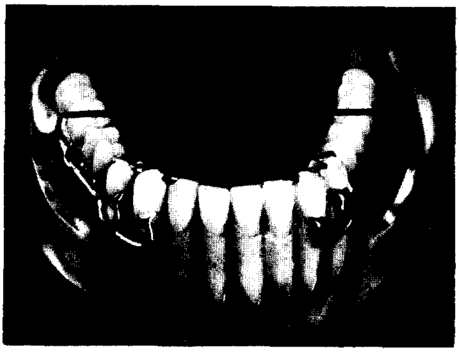

Fig. 3. Representation of the position of application of a 5-kg bilateral load on a test denture.

Rest seats were cut in all the teeth except the central incisors in much the same way as in a clinical case, and normal laboratory procedures were used to make a disjunct partial lower denture. The alloy used was Wisil M* and the lingual bar made of wrought stainless steel (*Fig. 2*).

The model was laid in a bed of polysulphide rubber (Permlastic) about 10 mm thick. This in turn was mounted in the loading jig by means of plaster-of-Paris. The whole structure was placed in a stress-freezing oven for 1 hour at 50 °C without load. A load of 5 kg was applied to the denture (*Fig. 3*) for an additional hour at 50 °C and then the oven was allowed to cool to room temperature over 20 hours with the load in place. The oven cooled approximately 1–2 °C per hour during this time. The model was removed from the oven and examined in a polariscope (*Fig. 4*).

In this study three disjunct dentures, each on its own epoxy model, were made. In the first denture the pins moved freely within the sleeves and therefore the saddles were assumed to be mucosa-borne. In the second denture the pins were located at the top of the sleeves and there was no movement in the pin/sleeve junction. Thus a load applied to the posterior teeth would be accepted almost entirely by the tooth-borne element as the load would be transferred via the buccal bars to the alloy base and little, if any, would be accepted by the mucosa on the saddle areas. This denture was therefore considered to be tooth-borne. In the third denture the pin/sleeve movement was adjusted so that when a load was applied to the posterior teeth and the mucosa was compressed, the pin contacted the top of the sleeve. This meant that when further load was applied, the extra load might be transferred via the buccal bars to the tooth-borne component, i.e. the alloy base. Thus the load would be shared between the mucosa of the saddle areas and the anterior teeth. The third denture was termed tooth- and mucosa-borne.

In each of the three dentures, which in all other respects were identical, the anterior alloy base (the tooth-borne component) was well retained by clasps but was not otherwise fixed.

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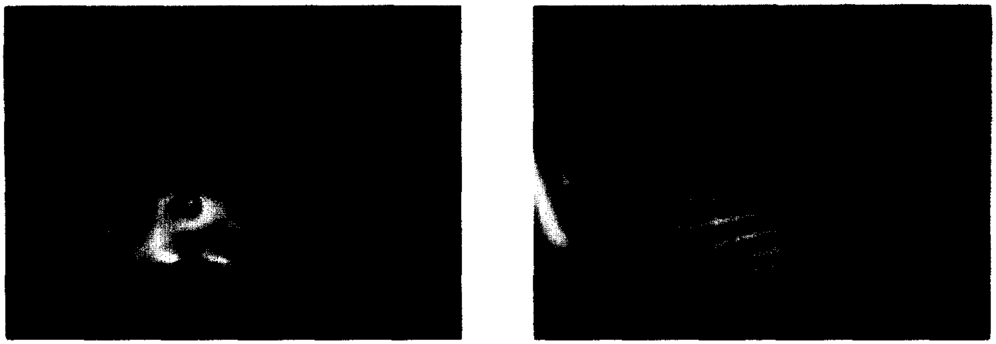
*Krupp, Essen, West Germany.



a *b*

Fig. 4. Typical fringe patterns in a test model as viewed in a polariscope. *a*, Fringes around the apices of the anterior teeth. *b*, Fringes in the posterior (saddle) region of the model.

RESULTS

For all three models the fringe orders were calculated in the saddle areas, the apical regions of all standing teeth and the distal root surfaces of the first premolars (*Table I*). The values in *Table I* represent the means of five separate loadings, as after each model had been examined it was stress-relieved and then reloaded with the same denture in place.

The numbers given in *Table I* are for the fringe orders (N). N (lbf/in^2 fringe^{-1} in^{-1}) is related to the stress by the following formula:

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{Nf}{2t},$$

where $\tau_{\max}$ is the maximum shear stress, σ_1, σ_2 are the principal stresses, i.e. maximum stress in compression or tension, t is the thickness of the model (in the anterior area $t \cong 0{\cdot}4$ in, in the posterior ridge area $t \cong 0{\cdot}8$ in) and f is a material constant and is approximately 6.

For an approximate estimate of the shear stress in the anterior area the following calculation can be used:

$$\text{Stress at apex} = \frac{N \times 6}{2 \times 0{\cdot}4},$$

e.g. at the apex of $\overline{1/}$ in the mucosa-borne denture the shear stress is:

$$\frac{1{\cdot}62 \times 6}{2 \times 0{\cdot}4} = \frac{24{\cdot}3}{2} = 12{\cdot}2 \text{ lbf/in}^2,$$

and in the right saddle area the shear stress is:

$$\frac{3{\cdot}41 \times 6{\cdot}0}{2 \times 0{\cdot}8} = \frac{25{\cdot}57}{2} = 12{\cdot}8 \text{ lbf/in}^2.$$

Table I. Fringe orders for each disjunct denture

Type of denture	*Right saddle area*	*Distal root surface of* $\overline{4\rvert}$	*Apical region of:* $\overline{4\rvert}$	$\overline{3\rvert}$	$\overline{2\rvert}$	$\overline{1\rvert}$	$\overline{\lvert 1}$	$\overline{\lvert 2}$	$\overline{\lvert 3}$	$\overline{\lvert 4}$	*Distal root surface of* $\overline{\lvert 4}$	*Left saddle area*
Tooth-borne	3·31	3·09	3·12	2·45	2·37	1·70	2·29	1·82	2·87	2·86	2·42	2·82
Mucosa-borne	3·41	3·07	2·42	1·92	1·69	1·62	1·52	1·69	1·77	2·14	2·55	3·14
Tooth- and mucosa-borne	3·90	3·00	3·10	2·35	1·40	1·10	1·10	1·35	1·80	2·10	2·80	3·40

Total load 5 kg (bilateral), i.e. each side loaded 2.5 kg. Results are the mean values in lbf/in^2 fringe^{-1} in^{-1} of five separate loadings.

Table II. Shear stresses for each disjunct denture

Type of denture	*Right saddle area*	*Distal root surface of* $\overline{4\rvert}$	*Apical region of:* $\overline{4\rvert}$	$\overline{3\rvert}$	$\overline{2\rvert}$	$\overline{1\rvert}$	$\overline{\lvert 1}$	$\overline{\lvert 2}$	$\overline{\lvert 3}$	$\overline{\lvert 4}$	*Distal root surface of* $\overline{\lvert 4}$	*Left saddle area*
Tooth-borne	12·4	23·2	23·4	18·4	17·8	12·8	17·2	13·7	21·5	21·5	18·2	10·6
Mucosa-borne	12·8	23·0	18·2	14·4	12·7	12·2	11·4	12·7	13·3	16·1	19·1	11·8
Tooth- and mucosa-borne	14·6	22·5	23·3	17·6	10·5	8·3	8·3	10·1	13·5	15·8	21·0	12·8

Results in lbf/in^2.

The stresses in all the areas studied were calculated and are shown in Table II. The results in *Table II* can be further simplified by averaging the stress (lbf/in^2) in the anterior (tooth) areas and the posterior (saddle) areas:

	Anterior area	Posterior area
Mucosa-borne	13·9	12·3
Tooth-borne	18·3	11·5
Tooth- and mucosa-borne	13·4	13·7

From these values it can be seen that when a denture is mucosa-borne the stress at the apex of the teeth is lower, and when a denture is more tooth-borne it is higher. In a tooth- and mucosa-borne denture the results can be interpreted as showing that the anterior teeth support less of a load and the mucosa more load.

In the tooth-borne denture, i.e. with fixation of the buccal bar, there is less stress on the saddle areas and more on the abutment teeth, while in the mucosa-borne case, in which the buccal bars and pins move freely, there is slightly more stress on the saddle area (though more would have been expected) and less on the teeth. In the tooth- and mucosa-borne denture the stress on the saddle areas and on the teeth appears to be more equally divided, which is to be expected if the pin/sleeve movement is correctly adjusted.

There is a high level of stress on the first premolars, which are the most terminal abutment teeth, in all three designs. The stress in the region of the distal root surface means that there is distal flexion of these teeth when load is applied to the denture saddles, presumably because the load is acting from the buccal bars. This level and direction of stress occurring in a clinical situation would probably be damaging to these teeth.

The results are sufficiently encouraging to propose repeating the series. The main variables which will have to be carefully controlled in future work are the fit of the saddles on the 'mucosa', the fit of the alloy bases on the different models, the movement of the pins in the sleeves and the differences in thickness and compressibility of the mucosa in all the models. Designs other than the disjunct will be examined in the future, although this is a long term aim because three-dimensional photoelastic stress analysis is an extremely time-consuming technique.

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