On functional strain in some fixed and removable partial dentures

An experimental in vitro study

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An 11-unit fixed maxillary reconstruction with 2 bilateral cantilever pontics in combination with a removable partial denture (RPD) with a palatal bar was fabricated. The RPD was retained to the fixed reconstruction with precision attachments. A laboratory model system was constructed in such a manner that the mechanical properties of the biologic supporting tissues involved were simulated by artificial materials. By means of a strain-gauge technique the deformation was studied in both the fixed and the removable partial denture. In different laboratory loading situations with and without the RPD the deformation in the fixed dental appliance was more extensive and more complex when the RPD was excluded. □ *Dental materials; denture, partial, fixed; denture, partial, removable; denture, precision attachment; in vitro deformation*

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Extensive loss of teeth is a treatment challenge when the patient desires or demands a fixed dental reconstruction.

Long-term studies have shown that extensive bridges can function properly with good prognosis on abutment teeth with reduced periodontal tissue support (1, 2). The functional capacity as chewing and biting forces has also been studied for bridges (3). Reduced periodontal bone support seems to decrease the biting and chewing forces in subjects with cross-arch bridges (4). When constructing a bridge with several units it is of major importance to design the bridgework in such a manner that the forces will be as evenly distributed as possible over the supporting tissues. This principle is valid for all reconstructions, including bridges combined with removable partial dentures.

The prognosis for extended fixed cantilevered reconstructions has been shown to vary in such a manner that the frequency of technical failures in these reconstructions is directly related to the total number of cantilever pontics incorporated and to the time in service (5).

The energy distribution in different types of complete, fixed, and removable partial dentures has been shown to be very complex when studied under controlled and standardized laboratory loading conditions (6–9). The rigidity of the supporting structures of a fixed mandibular reconstruction in an in vitro loading situation has been shown to have a dramatic influence on the deformation of the bridgework studied (8).

In both laboratory and clinical experiments it has been shown that in fixed partial dentures, the stress and strain concentration increased and was more complex in relation to the degree of cantilever extension (8, 10). From this point of view it is reasonable to believe that a removable partial denture with a palatal bar will reduce the tendency of movements in directions deviating from the long axis of the supporting abutments. It was therefore considered worthwhile to study the deformation under standardized laboratory loading conditions of an extended conventionally designed fixed dental appliance with and without a removable partial denture incorporated on a supporting model system with physical variables comparable to the corresponding supporting oral tissues.

Materials and methods

A patient who was in need of maxillary prosthetic treatment and with remaining teeth 13, 12, 11, 21, 22, and 23 was studied. The left canine was orthodontically moved to position 24. In the lower jaw all teeth were present except the first molar at each side. The upper teeth were prepared for veneer crowns in a conventional manner (11). An impression was taken with silicone (President Light and Putty, Colthène AG, Altstätten, Switzerland) in a standard tray, and an 11-unit bridge was made of a high gold alloy and with 2 cantilever pontics at each end. In the distal parts of the pontics precision attachments (McCollum, Cèndre Metaux, Switzerland) were placed, and a chromium cobolt skeletal removable partial denture (RPD) was made (Fig. 1). After the bridge and connected denture were fabricated, the model construction was built up in the following manner. Inside the crowns model teeth were formed of epoxy resin, filled with quartz (78% weight) to obtain a modulus of elasticity (16 GPa) close to that of dentin (18 GPa). A steel wire was placed in the middle of each tooth to facilitate the build-up of the root part. To simulate the periodontal membrane, a 0.2-mm layer of silicone (Xantopren blue, Bayer, Germany) was coated and bonded to the roots of the model teeth with the enclosed adhesive. The model teeth were removed, and the bridge was then placed in the mouth and thereafter taken out in silicone impression (President). The resin teeth were positioned into their respective crowns. A thin layer (0.4 mm) of polysulfide impression material (Permlastic, Sybron/Kerr, Romulus, Mich., USA) was coated over the palatal part of the impression to simulate the palatal tissues. Acrylic resin was poured around the silicone-coated root tips (Fig. 2). After this had hardened, resin was also poured on the polysulfide impression surface to a thickness of about 2 mm. The model was then mounted in

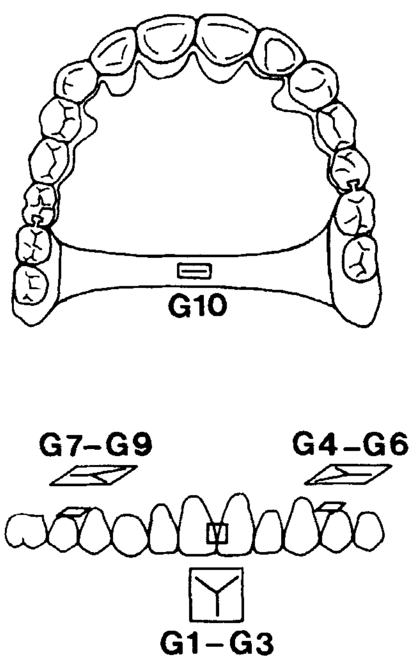

Fig. 1. An 11-unit bridge with a chromium cobalt skeletal removable partial denture. At marked sites strain gauges are glued on the bridge and the bar.

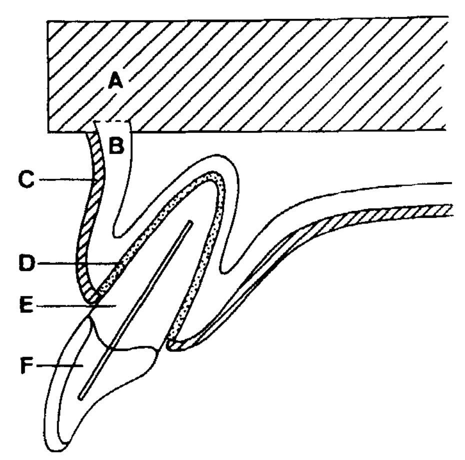

Fig. 2. An anterior cross-section of the model of different materials simulating bone, soft tissues, and teeth. A = socket in gypsum; B = acrylic resin; C = polysulfide impression material; D = silicone impression material; E = expoxy resin; and F = gold bridge.

gypsym. The modulus of elasticity of bone is between 1 and 7 GPa but is strongly dependent on structure and type of bone (12). The modulus of elasticity of cold-curing acrylate is around 2 GPa, and the choice of material represents a simplification of the actual biologic conditions. Thus the model consisted of resin teeth with a 'periodontal membrane' of silicone and 'oral soft' tissues of a polysulfide impression material.

Three stacked rosette strain gauges, type WA-09-030-WR-120 (Micro-Measurements, Romulus, Mich., USA), were used. Each of them consisted of three linear strain-gauge components. The resistance was 120 ± 0.5 Ω, and the gauge factor was 2.08 for all the gauges used. Two of the three rosette strain gauges were positioned close to the distal abutments in the right and left cantilever part of the bridgework on flat surfaces opposite the occlusal surface. The third rosette strain gauge was located on the buccal surface in the midline of the fixed reconstruction. The general position of the gauges is given in Fig. 1. The gauges were attached to the bridgework with a type M-bond 43b Adhesive (Micro-Measurements) and covered with a silicone material type 314 ORTV (Dow Corning Co., Midland, Mich., USA) for later use in the oral cavity. Each component of the strain gauges was connected with three wires to a coupling box, type DC-375 (McMurdo, Portsmouth), and then to a strain gauge conditioner and amplifer, model 2150 (Vishay Instruments, Vishay Intertechnology Inc., Malvern, Pa., USA), and finally with a special connection to an ultraviolet oscillograph, type SE 6150 (MkII (S.E. Labs EMI Ltd, Feltham). In the strain gauge conditioner and amplifier the original R7 resistor with resistance of 70 kgΩ was replaced by one with a resistance of 20 kΩ, to extend the balance of the gauge signals. All the recordings were performed in a laboratory with a controlled temperature of 21 ± 0.5°C, in which the experimental model system had been stored for 24 h.

The models of upper and lower jaw and the experimental dental reconstructions were mounted in a Dentatus ARL Special articulator (Dentatus A.B., Stockholm) in accordance with routine procedures. The articulator was positioned in an Alwetron universal testing machine (A. B. Lorentzen & Wettres Maskinaffär, Stockholm) in such a manner that in the intercuspal position

Table 1. Strain ($\mu\varepsilon$) and direction of principal strain in a combination of fixed and removable maxillary reconstruction at various levels of loading (49–491 N) on a model simulating biologic supporting tissues as recorded by 10 strain gauges (G1–G10). Positive strain values denote elongation, and negative strain values denote contraction (n = 1)

	Strain										Directions of principal strain*		
	Front			Left side			Right side						
Load	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	Left side	Front	Right side
49	0	14	56	42	0	35	−21	0	−7	0	17.8 L	60.5	95.7 L
98	−7	28	83	56	−11	63	−35	0	−21	−7	25.5 L	55.9	101.6 L
147	−21	14	111	69	−23	70	−42	7	−42	−28	22.8 L	60.1	112.5 L
196	−28	14	125	83	−23	85	−56	14	−49	−49	23.0 L	59.8	109.6 L
245	−35	0	139	97	−23	106	−63	14	−63	−63	24.6 L	61.8	112.5 L
294	−42	−14	139	97	−11	106	−69	14	−70	−76	24.9 L	63.1	112.8 L
343	−49	−21	139	97	−11	106	−69	14	−63	−90	24.9 L	63.3	110.4 L
392	−56	−43	146	104	−11	113	−63	7	−56	−76	24.7 L	65.7	109.6 L
441	−63	−56	153	118	−11	113	−63	7	−56	−69	21.4 L	66.6	109.6 L
491	−69	−70	153	125	−11	127	−42	7	−42	−56	22.9 L	68.6	112.5 L

* Directions of principal strain in different positions of the bridge in relation to the long axis of the cantilever bar. L = in lingual direction. In the front the direction of principal strain is given in relation to the long axis of the teeth (tension).

compressive forces of 49–491 N could be applied continuously.

All the strain gauges used were balanced and calibrated to give stable readings before the main test series was performed. This procedure was repeated when these loading experiments were finished.

As the test model was so complexly constructed, it was decided to perform only one series of loading for each experimental situation, to minimize the risks for technical failures. Afterwards minor fractures of the supporting rubber material could be detected, but not enough to have major influence on the collected data.

In some of the experiments cotton rolls (20 mm) were placed between the cantilever pontics or between the removable partial denture and the opposing teeth. Loadings were made with and without the RPD connected to the bridge. The strains were recorded, and the principal strain directions were calculated.

The following laboratory loading experiments were performed with a loading range from 49 to 491 N: I) A combination of a fixed and removable partial denture (RPD); II) A fixed cantilevered reconstruction without the RPD; III) As in I but loading on the right cantilever part of the reconstruction (with the RPD); and IV) As in II but loading on the right cantilever part of the reconstruction (without the RPD).

Results

With the combination of the fixed and the removable partial dentures (experiment I) elongation was found in gauges G3, G4, G6, and G8 and contraction in gauges G1, G5, G7, and G9 in the three stacked strain gauges (Table 1). The directions differed, however. Initially in this situation an elongation was found in strain gauge G2, which shifted to contraction during increased loading. The single linear gauge, G10, attached to the palatal midline of the bar on the free oral surface of the removable denture, showed contractions. Strain gauges G5 and G7 shifted from contraction to elongation when the removable denture was not incorporated. All the other strain gauges (Tables 1 and 2) showed the same general deformation pattern throughout the experiments both with and without the RPD incorporated (Tables 1 and 2, experiments I and II). As can also be seen from these tables, not only

Table 2. Strain ($\mu\varepsilon$) and direction of principal strain in a fixed maxillary bridge with two bilateral cantilever pontics at various levels of intercuspal loadings (49–491 N) on a model simulating biologic supporting tissues as recorded by 9 strain gauges (G1–G9) ($n = 1$)

	Strain											
	Front			Left side			Right side			Directions of principal strain*		
Load	G1	G2	G3	G4	G5	G6	G7	G8	G9	Left side	Front	Right side
49	−21	−7	153	42	0	35	0	0	0	17.8 L	69.8	0
98	−7	0	111	56	0	56	0	0	0	22.5 L	69.2	0
147	−21	−7	153	69	0	63	7	7	0	20.0 L	69.8	13.5 L
196	−42	−28	194	90	0	85	14	14	−7	20.9 L	69.2	22.5 L
245	−56	−49	250	111	11	99	21	28	−14	19.1 L	68.2	28.2 L
294	−69	−56	271	125	23	99	28	28	−14	15.3 L	68.6	22.5 L
343	−69	−49	285	139	34	99	35	42	−21	12.1 L	69.1	26.1 L
392	−69	−42	299	139	57	85	35	42	−21	5.8 L	69.2	26.1 L
441	−69	−28	306	139	91	56	35	42	−21	7.5 B	70.6	26.1 L
491	−69	−14	306	139	91	42	35	42	−21	9.3 B	71.7	26.1 L

* Directions of principal strain in different positions of the bridge in relation ot the long axis of the cantilever bar. L = in lingual direction; B = in buccal direction. In the front the direction of principal strain is given in relation to the long axis of the teeth (tension).

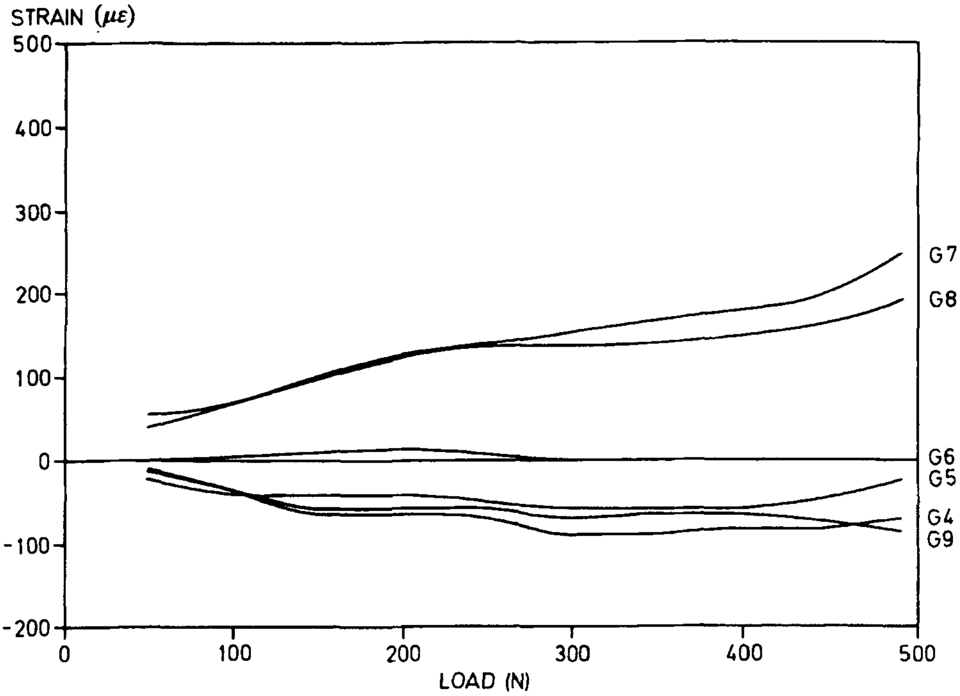

Fig. 3. Strains (με) in posterior strain gauges at various levels of loading (N) with the loading point on the cantilever on the right side and with attached removable partial denture (experiment III).

the general deformation pattern changed in some directions but also the degree of deformation. The direction of principal strain showed major variations only on the right side of the bridgework with and without the removable denture (Tables 1 and 2).

Deformations of the gauges from loadings on the right side of the premolar region are given in Figs. 3 and 4 (experiments III and IV). In the fixed part of the reconstruction strain gauge G4 shifted from contraction to elongation when the removable denture was excluded in experiment IV. All the other gauges showed the same general deformation pattern in these two experimental situations. The magnitude of the deformation varied in such a manner that minor deformations were recorded in the distal parts of the reconstruction and major deformations in the center of the bridgework with the removable denture in position as recorded from the gauges in the front. When only the bridgework was loaded (Fig. 4), major deformations were recorded in all the distal attached gauges on the right side (G7, G8, G9) and a reduced strain concentration was found in the front of the reconstruction. On the left side the magnitude of deformation did not vary to a major extent in these two different experimental situations but changed in a principal manner from contraction to elongation, as recorded in strain gauge G4. The direction of principal strain showed a major change on the left side but minor variation on the right side when the reconstruction was loaded in the right cantilever region with or without the removable partial denture in position (Figs. 3 and 4). In the removable denture (Fig. 3) contraction was noted, and this deformation was of the same type and approximately the same magnitude as that found when the corresponding reconstruction was loaded in intercuspal position (Table 1).

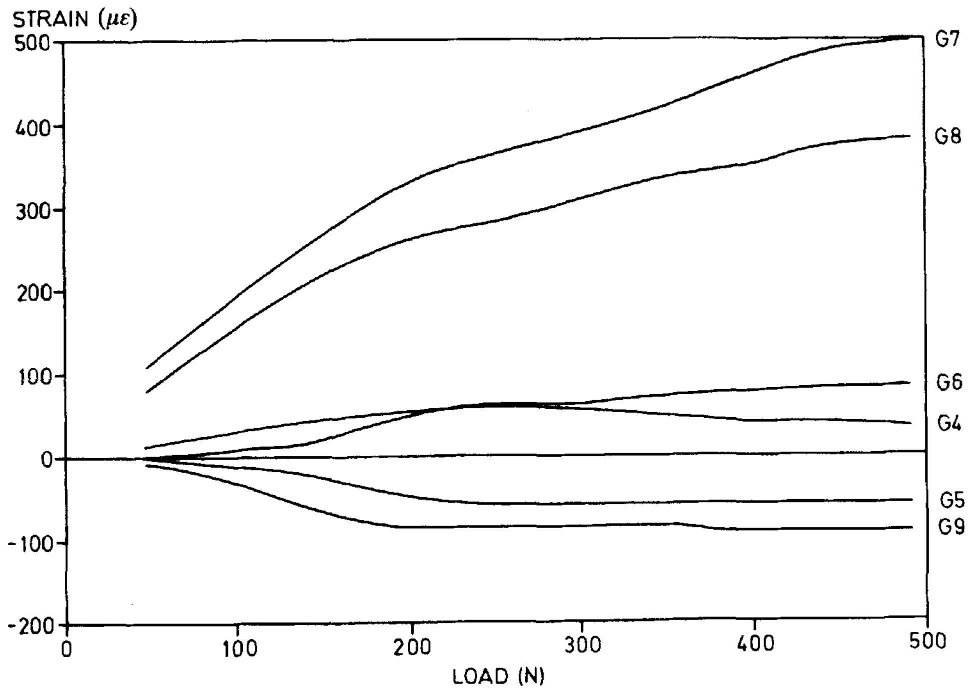

Fig. 4. Strains (με) in posterior strain gauges at various levels of loading (N) with the loading point on the cantilever on the right side (without removable partial denture, experiment IV).

Discussion

It is generally accepted that all fixed and removable dental reconstructions should be designed to be as rigid as possible. In a functional situation this will mean that the possible clinical deformations of the reconstructions will be low and that no critical stresses and strains will appear. One way to examine possible critical stresses is to use model studies, which have been commonly reported. No laboratory loading studies exist in which efforts have been made to simulate all biologic supporting tissues involved by artificial materials with comparable mechanical properties. This complexity in comparing mechanical and biomechanical experimental situations was observed by Smyd already in 1954 (13). A major prerequisite in building up models is that the elastic properties of the materials used are close to those of the reconstruction, teeth, bone, and soft tissues relevant to the clinical situation or properly scaled. In this investigation a true bridge and RPD were used, which had as a consequence that the E-modulus of the rest of the model was chosen in accordance with known values of human tissues. In contrast, all model materials were, however, isotropic. In spite of these obvious problems, studies of deformations of a loaded structure were conducted.

The central loading point in the articulator could simulate central occlusion. The strains in the measuring points in all the experimental loading situations showed a nonlinear behavior. It is reasonable to believe that this was an effect of compression of the rubber and, subsequently, of the supporting resin materials. The highest tensile strains occurred in the front, which was reduced when the RPD was attached to the bridge.

The RPD retained to the bridgework by intracoronal precision attachments will, principally, act as an extended fixed reconstruction with cantilever pontics. However, there are main differences, such as the palatal bar and the saddles in the RPD, which do not exist in the extended fixed partial denture. When the RPD was removed, the general deformation changed in such a manner (Table 2, Figs. 3 and 4) that it is reasonable to believe that the RPD will change the energy distribution throughout the combined reconstruction when loaded.

The cotton rolls were used to simulate the initial rheologic properties of a bolus of food and to simulate unilateral loading. The strain in the reconstruction showed that the RPD reduced the strain in the loaded cantilever part of the reconstruction. In the front a greater bending moment was found when the RPD was incorporated, which is probably due to the function of the RPD and its palatal bar and saddles to make the combined system stiffer.

The deformation of the palatal bar of the RPD was in accordance with the direction of principal strain in the rosette strain gauges in the cantilever portions of the fixed reconstruction, so that when the distal parts of the bridgework showed a tendency to move in lingual directions, the free oral surface of the palatal bar of the RPD was under compression.

The results of this study will be compared with an experimental clinical study performed with the same reconstruction.

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