Measurement of Strains in Fixed Bridges with Electronic Strain Gauges

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The general location and types of stresses, as well as theoretical deformation and strain in dental bridges, have been described. Mahler and Terkla[1] have described qualitatively the types of stresses expected in a dental bridge consisting of two abutments with a soldered pontic.

Brumfield[2] has discussed the fundamental mechanics of dental bridges from an engineering standpoint and has discussed the design of dental bridges based on simplified models constructed from cubes and tetrahedrons for teeth and pontics and from simple beams. He also has presented criteria for determining the load capacities of posterior bridges.[3]

Weinberg[4] has considered the biomechanical aspects of splinting teeth and has presented the analysis in terms of the direction of the occlusal force, the axial inclination, the area of contact, the resultant line of force, and the arch form.

Craig and Peyton[5] have studied the general patterns of surface strain in fixed bridges, using a brittle lacquer coating technic. Maxillary and mandibular bridges were loaded under static conditions, and the location and direction of the cracks appearing in the lacquer at various loads yielded information about the position and magnitude of the surface strain and the direction of the tensile stresses.

The measurements did not concern a relationship between strain and load throughout the range of loading but indicated the surface strain at the point where the strain exceeded the tensile strength of the lacquer. Observations using brittle coatings, however, are useful since they indicate locations where the strain gauges should be attached for a more detailed study of the surface strain.

The purpose of this study was to use information obtained with brittle lacquer coating to determine the placement of gauges on anterior and posterior fixed bridges cemented to models and to measure the surface strain in these areas as a function of static loading.

Materials and Methods

The bridges consisted of (1) a six-unit maxillary anterior bridge with pin-ledge preparations on the canine, (2) a six-unit mandibular anterior bridge with three-quarter crowns on the canine, and (3) a four-unit maxillary posterior bridge with a three-quarter crown on the first premolar and a full crown on the second molar. The anterior bridges were cemented onto abutment teeth that had been cast from brass. The posterior bridge was cemented onto typodont abutment teeth that were positioned in a plastic model. The static load was applied by using a hand-loading tension-compression tester.* The loads were applied to the teeth or pontics by small dental stone tips that conformed to the shape of the portion of the tooth being loaded. The load was applied in 2.5-lb. increments on a spring-operated dial gauge.*

The electronic gauges† were cemented to the appropriate position of the bridge with a cyanoacrylate adhesive. A temperature-compensating bridge circuit was used, and the strain was recorded directly, using strain gauge amplifiers‡ with scale ranges of 100, 500, 1,000, 2,500, and 5,000 microinches

This investigation was supported by USPHS Research Grant DE-01817 from the National Institute of Dental Research, National Institutes of Health, Bethesda, Md.
Presented in part at the 43rd General Meeting of IADR, Toronto, Ont., Canada, July 22-25, 1965.

Received for publication October 21, 1966.

*Baldwin-Southwork Company, Philadelphia, Pa.

†A-18, A-19 or FA-03-12, Baldwin-Lima-Hamilton Corp., Waltham, Mass.

‡Daytronic Type 80, Daytronic Corp., Dayton, Ohio.

per inch μin./in. The amplifiers had an internal standardization source.

The reproducibility of the readings from one run to the next was ± 5 μin./in. on the lowest scale, and was ± 100 μin./in. on the highest scale. The plots of load versus strain were obtained from means of four individual sets of strain values at comparable loads. Simultaneous recordings were made of the load and strain from loads of 0 to 60 lb. Plots of strain (in μin./in.) versus load (in pounds) were constructed for a variety of areas and loading positions.

The fixed bridges were constructed of crown and bridge gold† and were tested in the hardened condition below the yield strength. To convert the strain at the surface of the gold portion of the restoration to stress, it should be multiplied by the elastic modulus of 14×10^6 psi. For example, a strain of 1,000 μin./in. would represent a surface stress of 14,000 psi. An estimate of the stress on the surface of the porcelain pin facings can be calculated by multiplying the strain by the modulus value of approximately 10×10^6 psi. A strain of 20 μin./in. would indicate a surface stress of 280 psi.

Results

The plot of strain versus load is presented (Fig. 1) for the maxillary anterior bridge with the strain gauge attached to the labial surface of the right central incisor pontic. When the load was applied to the pontic containing the strain gauge, the strain increased rapidly and was nearly 2,500 μin./in. when the static load was 50 lb. Application of the load to the left central pontic resulted in much lower strain with a maximum of 400 μin./in. when the load was 50 lb.

The strain-load curves for the maxillary anterior bridge are shown (Fig. 2) with the strain gauge attached to the lingual surface of the right lateral incisor pontic adjacent to the cuspid abutment preparation. When the load was applied to the right lateral pontic, high strain values were obtained, with a maximum of 2,600 μin./in. at 50 lb. of load. Application of loads to the right and left central pontics resulted in decreasing strain on the right lateral pontics, the magnitude at 50 lb. of load being 500 to 600 μin./in.

†Ney G-3, The J. M. Ney Co., Hartford, Conn.

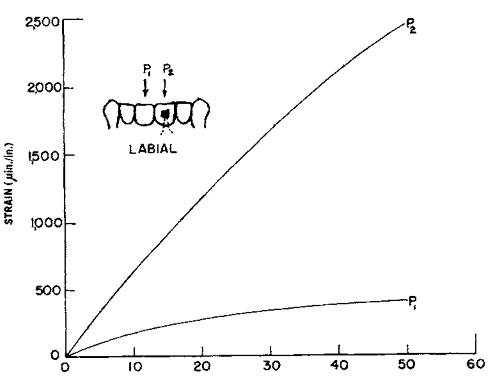


FIG. 1.—Maxillary anterior bridge with strain gauge on the labial surface of the central pontic.

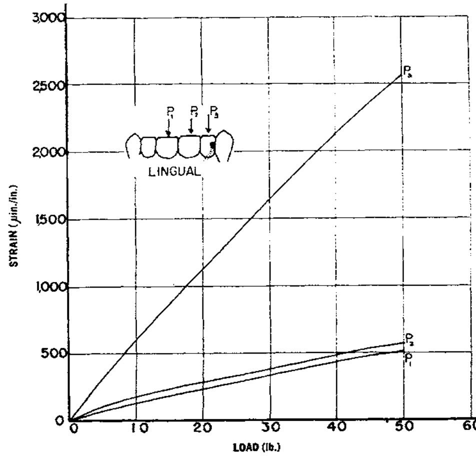


FIG. 2.—Maxillary anterior bridge with strain gauge on the lingual surface of the lateral pontic.

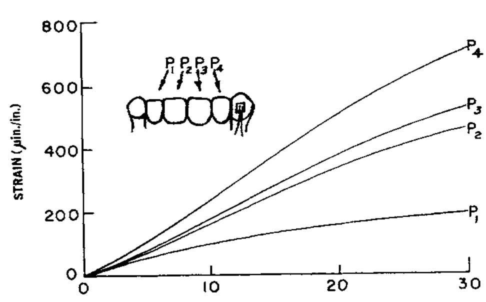


FIG. 3.—Maxillary anterior bridge with strain gauge on the lingual surface of the canine abutment preparation.

The strain on the lingual aspect of the abutment preparation of the right cuspid is shown (Fig. 3) for the maxillary anterior bridge. When the right lateral incisor pontic was loaded up to 30 lb., a strain of about 700 μin./in. was observed on the abutment preparation. Progressively smaller strains were observed as the distance between the load and the strain gauge increased, and the strain was only 200 μin./in. when the 30-lb. load was applied to the left lateral incisor pontic.

Surface strain on the porcelain facing of the left central incisor pontic are shown (Fig. 4). Of particular interest was the low magnitude of the strain on the facing; the maximum was 63 μin./in. when a load of 40 lb. was applied to the incisal edge of the pontic. The order in which strain on the surface of porcelain facing decreased when the load was applied was (1) right central incisor, (2) lateral incisor, and (3) right lateral incisor.

Similar results were observed with the mandibular anterior bridge. The strain versus load curves in Figure 5 were obtained when the strain gauge was attached to the mesial aspect of the right lateral pontic. The highest strain, about 3,200 μin./in. at 56 lb. of load, was observed when the load was placed directly on the incisal edge of the right lateral pontic.

The strain on the lingual aspect of the three-quarter crown abutment under various conditions of loading is shown (Fig. 6). A load of 30 lb. on the right lateral and central and the left central and lateral incisors produced a strain of 300, 270, 210, and 120 μin./in., respectively. The strains observed, therefore, were approximately half the values of those observed in the maxillary anterior bridge. The strain on the porcelain facing again was low as seen in Figure 7, where the values for a load of 40 lb. were from 10 to 25 μin./in.

The strain-load curves for the maxillary posterior bridge are shown (Fig. 8—10). The strain on the buccal surface of the second premolar pontic is shown (Fig. 8). The strain was 260 μin./in. when a load of 60 lb. was applied to the cusp of the abutment and was 200 μin./in. when applied to the central fossa of the first molar pontic. These low strain values were a result of the bulk of the restoration and the lack of any cantilever action, compared with the anterior

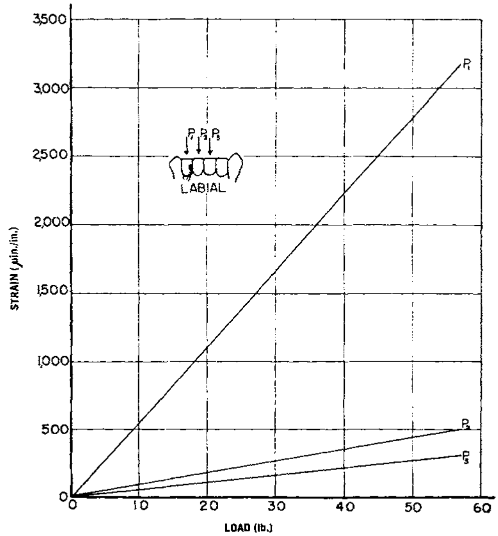


FIG. 5.—Mandibular anterior bridge with strain gauge on the labial surface of the lateral pontic.

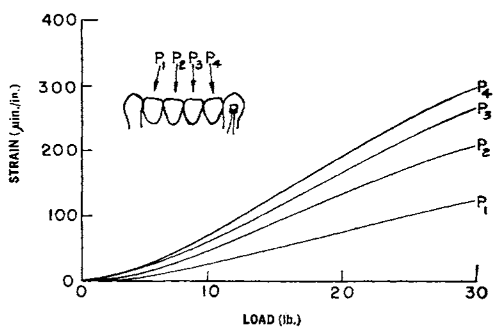


FIG. 6.—Mandibular anterior bridge with strain gauge on the lingual surface of the canine abutment preparation.

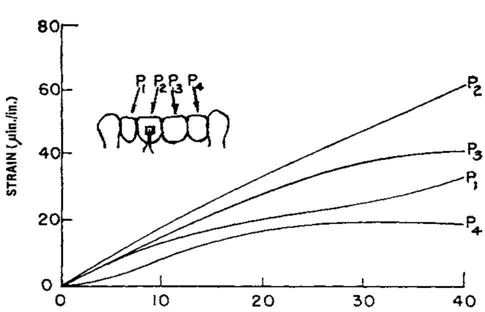


FIG. 4.—Maxillary anterior bridge with strain gauge on the porcelain facing of the central pontic.

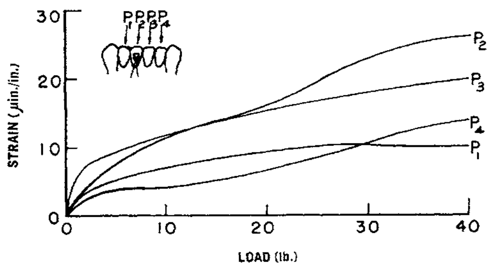
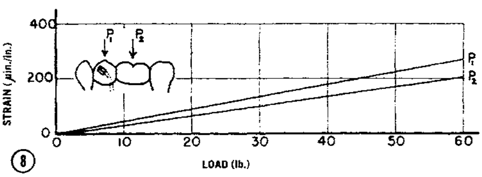


FIG. 7.—Mandibular anterior bridge with strain gauge on the porcelain facing of the central pontic.



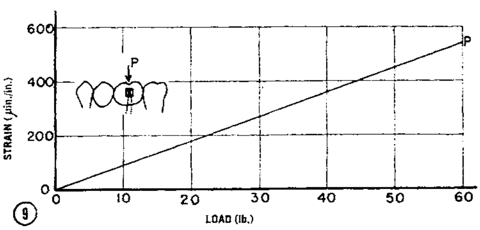


FIG. 8.—Maxillary posterior bridge with strain gauge on the buccal surface of the second premolar.

FIG. 9.—Maxillary posterior bridge with strain gauge on the buccal surface of the first molar.

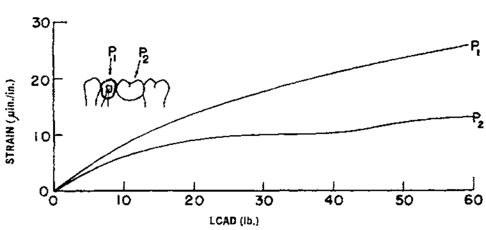


FIG. 10.—Maxillary posterior bridge with strain gauge on the porcelain facing of the second premolar.

restoration. The span of the posterior bridge also was shorter than the maxillary anterior bridge. The strain on the molar pontic when the load was applied to the central fossa is shown (Fig. 9). A maximum of 550 μin./in. was recorded at 60 lb. of load. This higher value was a result of the strain gauge being positioned nearer the center of the span than when it was attached to the premolar. The strain on the porcelain facings again was low (Fig. 10), with maximum values of 13 to 26 μin./in. at 60 lb. of load.

Discussion

The results on the maxillary bridges without porcelain facings show that the surface strain is higher the closer the strain gauge is to the point of loading. The equally high strain observed on the lingual surface of the lateral pontic and the labial surface of the right central pontic of the maxillary anterior bridge, when the load was applied to the pontic to which the strain gauge was attached, can be interpreted that more strain occurs on the lingual than the labial surfaces of pontics of this bridge. This statement is based on the assumption that the cuspid abutment should reduce the strain on the lingual surface of the adjacent lateral pontic more than on the labial surface of the central pontic. This interpretation and the magnitude of the values for the surface strain are in agreement with results using brittle lacquer coatings.[5]

Generally higher strains were observed while loading the mandibular anterior bridge on the pontic containing the strain gauge; these resulted from the smaller bulk (width and depth) of the pontics that overshadowed the stiffening effect of the shorter span with less cantilever action. The effect of the shorter span is evident when Figures 2 and 5 are compared, since loading the central pontics of the mandibular bridge gave strains, at 50 lb. of load, of 250 to 400 μin./in. Loading the central pontics of the maxillary bridge at 50 lb. gave strains of 500 to 600 μin./in. in spite of its greater bulk.

The effect of bulk and length of span was more pronounced when strains were measured on the maxillary posterior bridge. There, loads of 60 lb. produced low strains from 300 to 550 μin./in., even when the load was applied directly to the pontic where the strain gauge was attached. It should be mentioned that essentially no cantilever action was possible during the loading of the posterior bridge. These factors contribute to the success of posterior bridges.

The low strains observed on the surface of the porcelain facing, compared with the corresponding positions on the metal bridge, are related to the distance between the load on the metal and the strain gauge. It is also possible that the film of zinc phosphate cement used for attaching the facing keeps the strain on the surface of the porcelain low, since the cement has a low modulus of about 3×10^6 psi and, therefore, it deforms easily.

Summary

Strains in fixed bridges cemented to models were measured with strain gauges. The position and the magnitude of the static load was varied, and strains were measured on the metal surface and on the porcelain facings.

Larger surface strains were observed when the load was applied directly on the pontic bearing the strain gauge. The strain decreased, depending on the distance from the load and the amount of support given by the abutment.

Under similar conditions, maxillary anterior bridges had more surface strain than mandibular anterior bridges, and the posterior bridge had low surface strains. These observations are explained on the basis of the length of span, balk of the restoration, and the presence of cantilever action.

The surfaces of the porcelain facings were under low strain, even when the bridges were loaded to the maximum of 60 lb.

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