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Stabilization of an abutment under a rigidly fixed bridge by holographical-speckle interferometry*

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Abstract: Objective: There are no detailed reports of three-dimensional measurement of abutment teeth in mastication, because it is knotty to observe the rotation in chewing directly, and inexact to estimate indirectly. This work studies the three-dimensional stability of rigidly fixed bridge under the stresses of distributed loads and concentrated loads by optical method that gives the tip angle and rotation angle calculated directly based on measurement data. Methods: The specimen, taken from a 25-year-old male, was a left mandible without the second premolars and the first molars. As abutments, first premolar and second molar have complete periodontium. The specimen was soaked in formaldehyde solution. The bridge was fixed between two abutment teeth (first premolars and second molars), and the mandible was cemented in a steel box. The load was increased from 0 kg to 23 kg. Laser holographic technique was used to measure the three-dimensional bit shift of the dens, both buccolingual bit shift and mesiodistal bit shift, and determine tip angle and rotation angle. Results: The effects of stress distribution on the rigidly fixed bridge were evaluated, and stabilization of the bridge under the stresses of distributed loads and concentrated loads, respectively, were analyzed. The results showed that the tips of two abutments were very similar, and no distinct difference was observed between the distributed load and the concentrated load. However, the maximum rotation angle for the distributed load was two to four times as large as that for the concentrated load. In the experiment, the tip angle of the abutment teeth was no more than 0.65 degree, and the rotation angle was no more than 0.60 degree. All maximum angles occurred in the second molar. Conclusion: The fixed bridge is considered to be safe. In addition, a method for measuring the rotation angle was provided effectively.

Key words: Rigidly fixed bridge, Tip angle, Maximum rotation angle, Laser holographical-speckle interferometry
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INTRODUCTION

The rigidly fixed bridge is frequently used in the restoration of dental loss, providing more comfortable and good-looking teeth with greater support with respect to the occlusal force. Generally, the bridge works well for single dental loss. Theoretically, the rigidly fixed bridge cannot be used for two dental losses if there are only two abutment teeth. However, clinical applications of this type have been performed for more than twenty years with no report of abutment damage. This paper tries to explore why these bridges were safe, and give potential reasons by experiment and mechanical analysis.

Because the dens are curtained off during occlusion, the direct method of occlusal force measurement, especially for rotation of the dens, is rarely used. At the same time, although the metamorphosis and bit shift of the denture bridge framework are very slight, they are complicated for two reasons. First, the shape of the denture is irregular,

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which makes stress analysis of the surface contact even more important. Second, since the dens and dental pad are biologic tissues which are asymmetric in the inner part, the bend is nonlinear under external force. Many published reports described different methods, such as the electrometric method (Craig and Peyton, 1967), the photoelastimetric method (Glikeman *et al*., 1970), laser holographic interferometry (Zhu *et al*., 1985; Young and Altschuler, 1977), and finite element analysis (Liu *et al*., 2004; Farah and Craig, 1988). However, the problem of surface contact in chewing and lack of analysis of rotation during chewing continue to limit investigation of the bridge stabilization.

In this paper, laser holographic technique is used to measure the stress on the dens. This technique is a reappearance and record technique based on laser interference. However, holography alone cannot provide sufficient information for building the three-dimensional bit shift of the dens. Holography alone results in two-dimensional bit shift, limited by the principle of interference (Zhu *et al*., 1985). In that paper, laser holography measured buccolingual bit shift, but did not yield the mesiodistal bit shift. Thus, although holography provides partial bit shift information, a method by which to obtain the buccolingual bit shift should be developed.

In this paper, we measured the small three-dimensional bit shift under two different conditions (distributed load and concentrated load) by holographical-speckle interferometry and analyzed the characteristics of tip and rotation. Because speckle methods were used in the experiment, the buccolingual bit shift was measured, and its 3D displacement could be given (Hayashi *et al*., 2002).

The differences in each specimen, i.e. the tip angle and the rotation angle, rather than the bit shift, strain, or stress, were considered in analyzing the stabilization of the bridge because the dens are more sensitive to rotation than to movement. This method reduces the effects of individual differences, such as the shape of the teeth or the alveolar bone, in experimentation.

The design of the rigidly fixed bridge must be in accordance with the principles of physiology, i.e., the load on the abutments must be kept within the physiological limits. Ante (1926) determined the theoretical number of abutments. Periodontal ligament, or the ratio between the occlusal forces of the first premolar and the second molar, was less than that between the occlusal forces of the second premolar and the first molar. The first premolar and the second molar should not be used as abutments without the second premolar and the first molar. According to the principle of Ante and Nelson, this is not an acceptable application for use in restorative dentistry.

We reviewed 450 rigidly fixed bridge cases (ranging from 17 to 68 years of age) in the Second Affiliated Hospital, School of Medicine, Zhejiang University, which were down from July 1991 to July 1996. There has been no report of abutment damage in the past 15 years for choosing this rigidly fixed bridge for restoration. The patients were instructed to avoid hard foods such as nuts.

SUBJECTS AND METHODS

Subjects

1. Mandible, taken from 25-year-old male cadaver, with complete periodontal tissue (without the second premolar and first permanent teeth), soaked in formaldehyde solution. Mandible fixed on bracket by six screws (3 mm). Using the usual rigidly fixed bridge method, the first premolar and the second permanent teeth were waxed, pounded, burnished, and sandblasted to obtain a favorable surface for holography;

2. The bridge and opposing dentition were made of Ni-Cr alloy, Young's modulus: 202 GPa;

3. Experimental equipment: He-Ne laser set (wavelength: 632.8 nm, power: 60 mW), TianjinI holofilm, pneumatic cushion shock absorber, beam splitter mirror and reflecting mirror.

4. Loading machine: made of steel, structure shown in Fig.1.

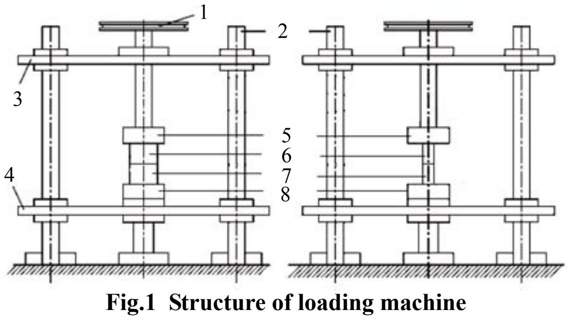

Fig.1 Structure of loading machine
1. Tray; 2. Pillar; 3. Plank; 4. Plank; 5. Fixator; 6. Opposing dentition; 7. Specimen; 8. Bracket

Principle of measurement

Laser speckle interferometry is also based on the principle of laser interference and involves a laser speckle field, double-hole interference and the multiple-record characteristics of holofilm. The laser speckle near the surface of the measured object had the optical structure of a small hole, the speckle structure being defined by the geometry of the field near a point on the surface. The shape of the speckles is related before and after deformation of the object. The distance over which the hole moves is equal to the distance between the hole positions before and after deformation. When one beam passes through both holes, interference fringes are observed. The bit shift of the holes was calculated from the space between two fringes. The laser speckle method also involves double-exposure before and after deformation. Double-exposed speckle film was used to record bit shift information. After development, the bit shifts were obtained in a point-by-point manner, and the beam path was easy to identify. Actually, the stripe in the figure was Young's interference fringes (Young's interference is wavefront-splitting interferometer. It is a classical phenomenon of light and evidence that light is a wave) (Fig.2). Bit shift d was calculated by the following equation:

$$d=\lambda D/b,$$

where D is the distance from the film to the interference fringes, b is the distance between two fringes, and λ is wavelength of laser. The speckle method was used to measure the mesiodistal bit shift.

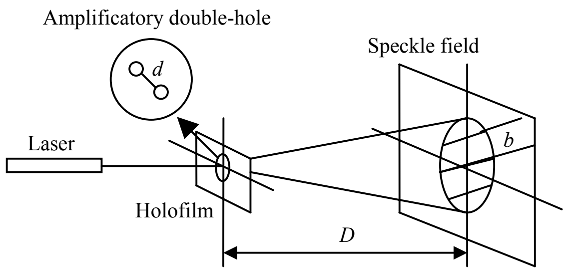

Fig.2 Speckle interferometry

Compared to holography, the speckle method allows measurement of a larger range, but with lower accuracy. In the experiment, the scheme of the load and data processing must be well designed so that these two methods, which have different measurement ranges, can be used in concert.

Holographic interferometry also yielded mesiodistal bit shift by double-exposure before and after deformation. In contrast to holographic interferometry, there is no reference light in the speckle method. In the beam path map of the experiment (Fig.3), the reflecting mirror (part 10 in Fig.3) is shielded.

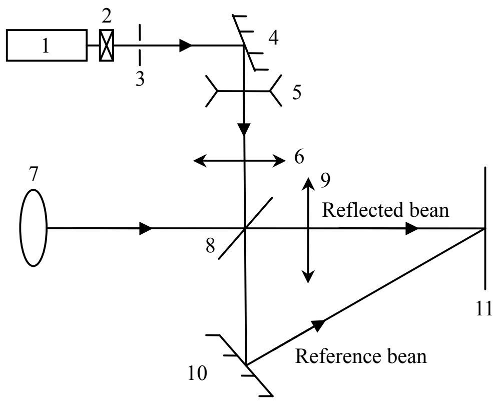

Fig.3 Holographical interferometry

1. Laser; 2. Shutter; 3. Diaphragm; 4. Reflecting mirror; 5. Mini-filter; 6. Collimating mirror; 7. Bridge; 8. Semi-reflecting mirror; 9. Object lens; 10. Reflecting mirror; 11. Holofilm

Three-dimensional bit shift of the abutments was measured using holographic interferometry and the speckle method simultaneously. Laser holography was used to measure the buccolingual bit shift, and the speckle method was used to measure the mesiodistal bit shift. Three-dimensional bit shift phasors of abutments were then composed (Fig.4), based on which the movement, tip and rotation of the abutments were analyzed.

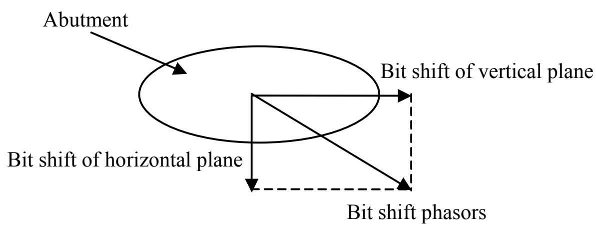

Fig.4 How to calculate rotation angle

Load scheme

Two different conditions should be considered separately: normal chewing (distributed load, bridge contacted to opposing dentition directly) and chewing of hard stuff (concentrated load, press delivered by a pin which posit at central part of bridge). The load was increased from 1 kg to 23 kg in 1-kg increments.

The shift experiment was repeated five times with average shift being considered as result.

The setup of the load is shown in Fig.5. Since the measurement range differed between holography and the speckle method, pictures were taken at each 1-kg increment for the holograph method and at every 5-kg increment for the speckle method.

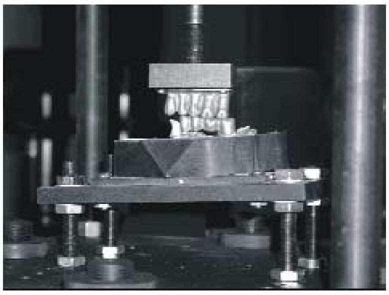

Fig.5 Fixed bridge in experiment

Measurement of the abutment teeth tip angle

The tip angle was calculated using the geometric properties of a right triangle formed by the abutments and the phasor of the abutments.

Measurement of the abutment teeth rotation angle

The rotation angle could not be measured directly. In this paper, measurement of rotation angle is based on two hypotheses. First, the change in the phasor direction occurred due to shear stress and the force couple due to the rotation caused by uneven surface contact during occlusion. Second, there was no slippage between abutments and retainers. Thus, the difference between two phasors was considered to be the bit shift of the rotation on the surface of abutments. The length of the difference is close to the arc length of the rotation angle if the angle is less than 5 degrees, and in the present experiment the rotation angle reaches to only 0.4 degree. Movement of the abutments was described by a series of successive angles. However, this was not sufficient for analysis of the bridge stabilization, because the seriate angle differed for the two load increases, and was not the maximum potential rotation angle. By exhausting all combinations of any two phasors, the maximum angle, i.e., the maximum rotation angle was determined.

Data processing

The phasor of the movement consisted of one buccolingual bit shift and one mesiodistal bit shift; however, the quantity of holographic data obtained from the experiment was five times greater than the quantity of speckle data. Thus, increasing the data from the speckle method was required in order to fit the data from the holograph method. In this paper, the bit shift measured by the speckle method was divided into five equal sets.

The reason for dividing the data is as follows. First, the material of the dens and the alveolar bone was isotropic. Second, the alloy bridge framework limited the movement of the connector on the vertical plane more than on the horizontal plane. This restriction occurred due to the structure of the bridge framework and because the Young's modulus of the alloy was ten times that of the dens. Moreover, the buccolingual bit shift was close to linear. Finally, the data showed that the changes were only slight. Therefore, we assumed the evidence of nonlinear bit shift to be insufficient, and so the negative effect of this data processing method is limited.

RESULTS

Measurement of abutment tipping

Fig.6 shows the holographic interference pattern. The result of the experiment showed that the tips of the two abutments were approximately equivalent (Fig.7), and no distinct difference between distributed and concentrated loading was observed (Fig.8). The second molar showed more nonlinearity changes than the first premolar (Table 1).

Table 1 Tip comparison

Maximum tip angle (degree)	Distributed load	Concentrated load
First premolar	0.459	0.523
Second molar	0.564	0.528

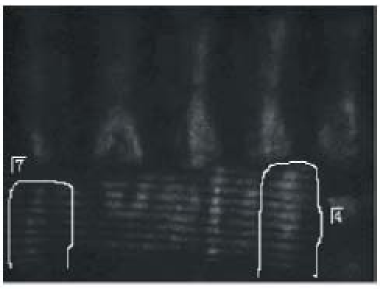

Fig.6 Hologram of fixed bridge

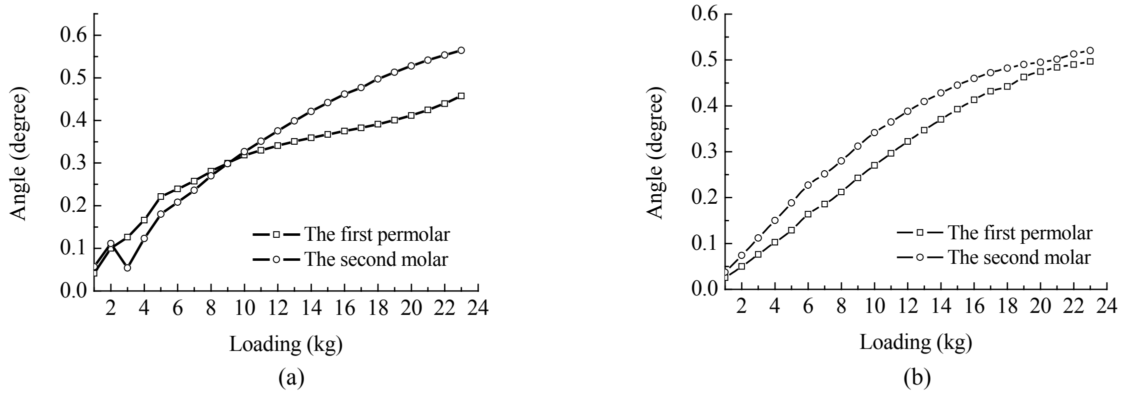

Fig.7 Curve under (a) distributed and (b) concentrated loading

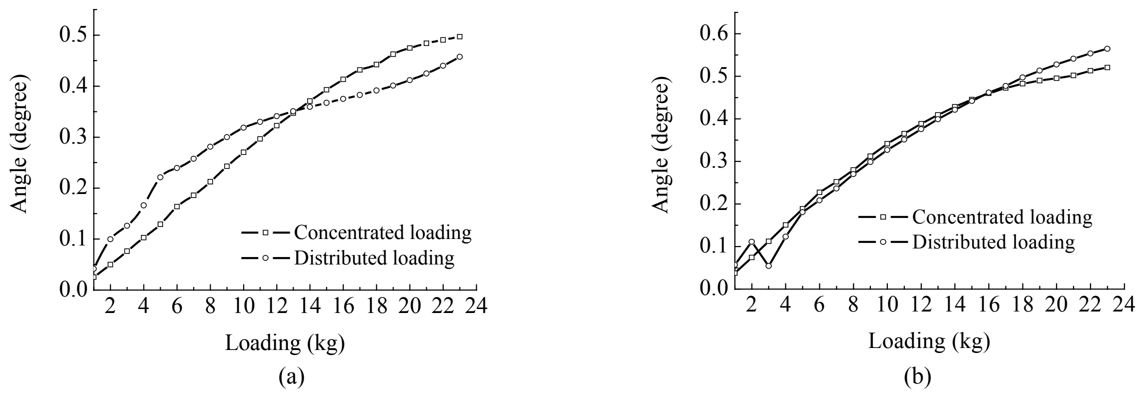

Fig.8 Tip angle of (a) the first premolar and (b) the second molar under different loading

Abutment rotation measurements

The maximum rotation angle for distributed load was two to four times that for the concentrated load. This is apparent in the second molar. The changes in rotation angle were completely nonlinear because the direction of rotation changes unpredictably at any time (Table 2).

Table 2 Rotation comparison

Maximum rotation angle (degree)	Distributed load	Concentrated load
First premolar	0.210	0.107
Second molar	0.597	0.122

DISCUSSION

In Figs.7a and 8b, the curve of the second molar indicated that there was slippage at interface (The wave of the curve would not be notable, if the position of the occlusion was changed. We included the graph as an example of representative nonlinearity). Taking the maximum rotation angle into consideration, larger surfaces contacting the crown may lead to a more complex reaction to loading for the second molar. In concentrated loading, fewer surfaces are contacted, resulting in a greater degree of linearity, as shown in Fig.8b. However, the difference in the tip angle between the distributed load and the concentrated load was small. These findings indicate that the second molar is not sensitive to the rigidity of food; rather, the coarseness of the bridge surface and the chewing habits affect the molar.

In Fig.8a, the difference between the distributed load and the concentrated load was notable, and the linearity of concentrated load was greater than that of the distributed load. As abutment teeth, the first premolar was affected to a greater extent by the rigidity of food. The relatively smaller rotation angle showed that rotation is not the major movement for the first premolar.

In Fig.7b, the load carried by the second molar is greater than that carried by the first premolar, and the difference grew larger as the load increased. This showed that the second molar is a major abutment tooth in chewing, especially of hard food. In addition, the second molar has larger rotation angle than the first premolar. Therefore, the second molar is the primary support for the occlusal force of the bridge.

CONCLUSION

In the experiment, the tip angle and the rotation angle were much smaller than the angle caused by the dens orthopedic [Please see (de Pauw *et al*., 2003) for comparison of angles]. For normal biting and chewing, the load of the abutments is within the physiological limits. The results of experiment and mechanical analysis showed that the bridge's compressive stress is greater than anti-turn stress, which corresponded with tooth physiological character. So the method can be applied to measure tooth 3D displacement.

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