Experimental Investigation of Deformation of Teeth by Means of Real Time Holographic Interferometry

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Abstract

When concentrated force apply to tooth on dry jaw of man, small displacement of the tooth and its approximal teeth is quantitatively measured by real time holographic interferometry. Silicone impression material (injection type) is used in place of periodontal menbrane of specimen. The immersing chamber was used to reconstruct accurately the original object wave. Photographic plate was processed not to take off in the chamber. A loading apparatus consists of a alminium rod to put known weights and magnet stand with cylindrical bearing surface. The results obtained in the study will be valuable to considerations of small deformation and mobility in the occlusal and masticatory systems of man.

I. Introduction

Investigation of small deformation of tooth subjected to occlusal or masticatory forces and the effect to its approximal teeth has been a very important problem in oral physiology and prosthetic dentistry. Tooth mobility has been studied until now by means of mechanical methods[1),2)] as well as dial and strain gauges. But the study described on the basis of optics about displacement of tooth subjected to force and its approximal teeth for dry specimen of the lower jaw of man has been not found so far as we can know. Now, methods of holographic interferometry have been studied about mechanical and medical applications.[3)-5)] Double-exposure and real time holographic interferometry are used in these methods. This work describes that displacements of tooth subjected to force and its approximal teeth are measured by real time holographic interferometry.

II. Experiment

Dry specimen of the lower jaw of man was used. Each of teeth had normal contact point

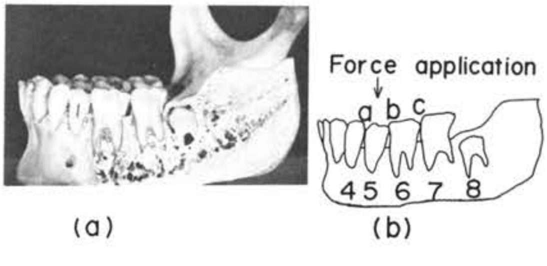

Fig. 1 Diagram of a sagittal section to illustrate specimen used in the experiment. (a) Dry specimen of the lower jaw. (b) Schematic diagram of tooth subjected to force and teeth to be examined holographically. 4; lower first premolar, 5; lower second premolar (tooth subjected to force), 6; lower first molar, 7; lower second molar, 8; lower third molar (impacted tooth). Symbols a, b, and c show contact points.

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with approximal tooth. Alveolar resorption was not found. Silicone impression material (injection type) was injected in place of periodontal membrane into dental socket after each of teeth was extracted. The teeth were relocated into the original dental socket. A part of buccal surface of mandible was eliminated with dental trimmer so that deformation of dental root is able to observe. Mandibular base was fixed with alpha cyanoacrylate adhesive (Aron Alpha) to super hard plaster so that masticating surface becomes to parallel with surface plane of the plaster as shown in **Fig. 1** (a). **Fig. 1** (b) shows teeth to be examined holographically and direction of concentrated force acting on tooth No. 5. Symbols a and b show mesial and distal contact points for No. 5 in **Fig. 1** (b), respectively.

Fig. 2 shows optical system. He-Ne laser was used as light source. Half mirror H divides incident wave into tranparent and reflected waves. Each of waves is called object and reference waves. After object wave was collimated by lenses L_1 and L_2, the wave illuminates specimen O. The wave reflected by specimen is led to the focal plane of Fraunhofer lens L_5. Reference wave is refracted parallel to the axis by lenses L_3, and L_4 and illuminates the photographic plate P as shown in the figure. Density filter D is used to control the intensity ratio of object and reference waves.
To realize real time holographic interferogram, the photographic plate is hold into immersing chamber[6] to reconstruct precisely wave front before deformation.

A hologram of the object in its initial state is recorded by using optical system as shown in **Fig. 2**. Photographic plate is processed in immersing chamber. Density filter D is controlled in optical path of reconstruction wave so that intensity of reconstruction image is equal to intensity of object viewed through the hologram. If the load is increased, a pattern of real time interference fringes corresponded to deformation of the object can be seen over its surface by viewing through the hologram.

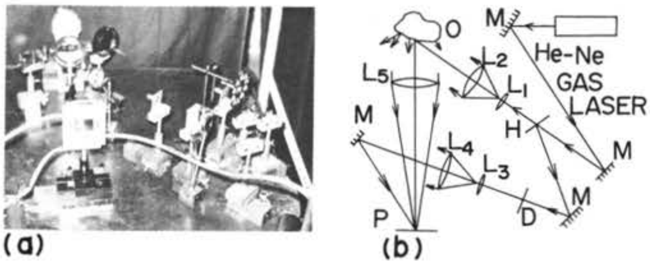

Fig. 2. Optical system. (a) Experimental appratus, (b) Schematic drawing of optical system. M; surface mirror, L_1, L_3; objective lens, L_2, L_4; collimating lens, D; density filter, P; photographic plate, O; object, H; half mirror, L_5; Fraunhofer lens.

A loading apparatus consists of a alminium rod and magnet stand having cylindrical bearing surface. The rod is with about 80-mm height and about 10.0-mm diameter. One of the ends is flat stage to put known weights and the other end is scraped to cone so that a force is concentrated on one point of tooth. For convenience, the rod is inserted into bearing. The apparatus is adjusted so that a force is to be applied axially to the central groove of second premolar. Weights from 46 gf to 226 gf in 5 gf or 10 gf intervals are acted on second premolar (No. 5). Twenty-three real time holographic interferograms are observed by viewing through the hologram and are recorded on photographic films.

III. Results

Fig. 3 shows interference patterns observed for forces of 61 gf, 176 gf, 196 gf, and

216 gf. In **Fig. 3** (a), as the numbers of interference fringes on second premolar (No. 5), *i. e.*, the tooth subjected to force, and the approximal teeth, *i. e.*, first premolar (No. 4) and first molar (No. 6), are the same, three teeth show the same displacement. Displacements of second premolar and first molar incresed more than the case of **Fig. 3** (a) as known from the number of interference fringes in **Fig. 3** (b). It was evaluated that the mesial side of first molar displaced to the direction of incident wave. In **Fig. 3** (c) and **3** (d), displacements of first and second premolar incresed further. Displacements of first and second molar incresed, too and direction of displacement was the same result with **Fig. 3** (b). Although it is possible to make displacement measurements over the whole surface, in practice measurement of second premolar subjected to force was chosen to make only in the directions of interest. Accordingly, plots of displacement against axial distance were made along the line from root apex to cutting edge, assigning an arbitrary zero fringe value to the fringe of root apex. Results obtained in this way are shown in **Fig. 4**.

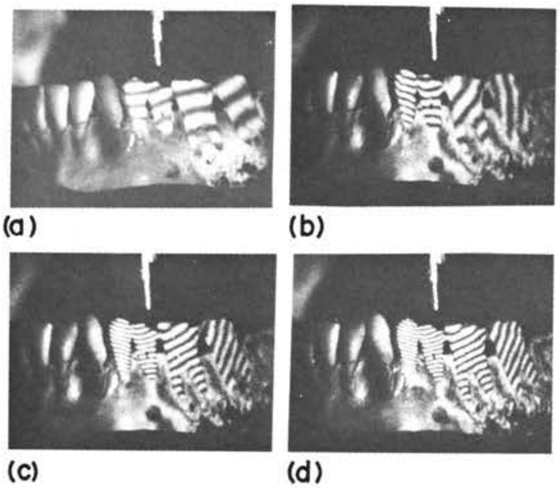

Fig. 3 Reconstruction patterns obtained from real time holographic interferograms for four different loads, 61 gf, 196 gf, and 216 gf, respectively. (a) 61 gf, (b) 176 gf, (c) 196 gf, and (d) 216 gf.

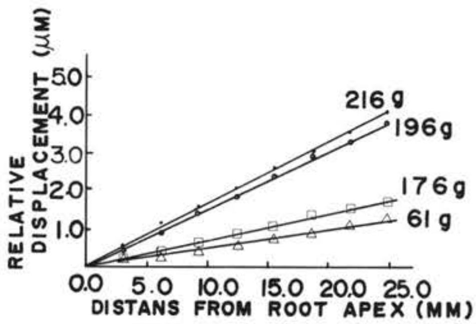

Fig. 4 Relative displacement of second premolar that is, tooth subjected to force for four forces.

Each point on the tooth represents linear displacement in the figure. Gradient of the displacement is almost the same in case of 61 gf and 176 gf and the largest value for force of 216 gf.
As impression material is role of buffer, it is interpreted that tooth did not deform but tilted to out of plane and mandibular bone was not almost deformed under applied force.

These show relative displacement obtained from following equation,

$$d\cos\chi=\frac{N\lambda}{2\cos\{(\theta_o+\theta_i)/2\}}.$$

In the equation, N is the order number of interference fringe and λ is the wave length, 632.8 nm, θ_O is the angle between displacement d and observing directions at a point on the surface, θ_I is the angle between displacement and illuminating directions. An angle $(\theta_O+\theta_I)/2$ is 21.8° under the optical system used here. $d\cos\chi$ is the resolved part of displacement d in the direction bisecting the illuminating and observing directions. χ is the angle between the bisector and displacement d. The fringe width correspond to displacement of 0.34 μm resolved in a direction approximately towards to the observer.

IV. Conclusion

Displacement of tooth subjected to force (No. 5) increased to out of plane with increment of force. As contact point exists between first molar and second premolar (No. 5), mesial side of first molar deformed to out of plane more than its distal side. As third molar of specimen used in the study was an impacted tooth, distal side of second molar has not contact point with mesial side of third molar. Accordingly, it is understood that the second molar rotated about its axis.

It is hoped that investigation *in vivo* of small deformation will be done after the consideration about the light source, fixation of specimen and method to apply the force.[7] One dimensional displacement component was only measured in the study. Three dimensional displacement components of small deformation of used specimen will be precisely measured by using the optical system.[8],[9]

Acknowledgments

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