Dental holographic interferometry *in vivo* utilizing a ruby laser system

II. Clinical applications

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A new method for precision measurement concerning the dynamics of human teeth in function was applied to different clinical situations in a series of experiments. Intraalveolar tooth mobility was recorded utilizing a ruby laser system for double pulsed holographic interferometry.
The masticatory force of the patients caused various interference fringe patterns in the holograms. Their evaluation revealed different types of tooth mobility corresponding to the nature of force application.

Key-words: Lasers; holography; tooth mobility; prosthodontics

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A new method for recording tooth dynamics *in vivo* involving holographic interferometry was described in a previous paper (*Wedendal & Bjelkhagen*, 1974a). The purpose of the present investigation was to demonstrate some clinical applications in patients having different dental conditions.

MATERIALS AND METHODS

Four subjects with different dental conditions were examined.

Case I. The subject was described in a previous paper (*Wedendal & Bjelkhagen*, 1974a).

Female, 60 years of age
Teeth in the upper jaw 17—25
Teeth in the lower jaw 47—37

All teeth were firmly attached to their sockets. The crowns showed a fairly high degree of abrasion. There was a slight tendency to bruxism.

Roentgenographic findings (Table I)

Front tooth relationship:
Horizontal 1 mm
Vertical 1 mm
Molar tooth relationship: Normal

Experiment I: 1. A survey of the experimental conditions is given in Table II. The point of force application was in the distal fossa of 24. This experiment was made before prosthodontic treatment.

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Experiment I: 2. A saddle extension bridge (*Izikowitz & Wedendal,* 1968) was then constructed with 24 and 25 as full-crown abutments. The missing 26 and 27 were replaced by means of saddleborn acrylic teeth. The saddle rested tightly on the alveolar crest.

The muco-periost of the crest was surgically conditioned before the insertion of the prosthodontic appliance. A thin layer of epithelialized soft tissue remained between the saddle and the bone. Teeth 24 to 27 were rigid connected by means of soldered joints. The construction was temporarily cemented and in function during the 8 months between experiments I:1 and I:2. The patient was thus well adapted to the bridge by the time experiment I:2 was performed.

The point of force application was in the distal fossa of 27.

Experiment I: 3. The point of force application was in the distal fossa of 24.

Experiment I: 4. The bridge was removed and separate gold caps were temporarily cemented on the abutments. The point of force application was in a small occlusal groove which corresponded to the distal fossa of the crown of tooth 24.

Case II. Male, 22 years of age

Teeth in the upper jaw 18—28

Teeth in the lower jaw 48—37

All teeth were intact and firmly attached to their sockets. The crowns showed no signs of abrasion.

Roentgenographic findings (Table I)

Front tooth relationship:
Horizontal 4 mm
Vertical 5 mm
Molar tooth relationship: Postnormal

Experiment II:1 (Table II). The point of force application was central to the inclined portion of the palatal cusp.

Experiment II:2. The point of force application was in the mesial fossa of 24.

Case III. Female, 68 years of age

Eleven years ago a total upper saddle-extension bridge was constructed using the extremely elongated full-crown abutments 13, 12, 11, 21 and 23. Teeth 14 to 24 were directly cemented as an extension bridge on the abutment teeth with saddle-born teeth 16, 15, 25 and 26 screwed onto the bridge in order to give a further extension for bilateral molar support. The saddles were in contact with the subjacent mucosa. A slight deflection within the construction was recorded when hard finger-pressure was applied on 26. Rigidity was ensured by means of a palatal bar connecting 16 and 26. A total lower bridge also existed using abutments 46, 45, 44, 43, 33, 34, 35 and 36. Interocclusal contact was recorded distal to 13 and 23. The patient experienced good function with the above construction.

Roentgenographic findings (Table I).

Front tooth relationship:
Horizontal 10 mm
Vertical 3 mm
Molar relationship: Postnormal

Experiment III:1 (Table II). The point of force application was in the distal fossa of 26 (saddle-born).

Case IV. Male, 50 years of age

The patient had suffered from periodontal disease since he was 25 years old. Seven years ago the teeth showed a high degree of mobility. General surgery was performed and a full upper bridge was constructed on the abutments 17, 15, 13, 11, 21, 23 and 25. Tooth 26 was substituted by an extension pontic. The lower jaw 47—37 exhibited normal dentition.

The bridge was reported to be satisfactory in function for the 7 years preceding the experiments. The clinical crowns of all teeth were elongated and a very slight degree of mobility could be clinically recorded in the lower jaw. No signs of severe marginal inflammation were seen. The patient's home care was conscientious.

Roentgenographic findings (Table I)
Front tooth relationship:

Horizontal	4 mm
Vertical	2 mm

Molar tooth relationship: Normal

Experiment IV:1 (Table II). The point of force application was in the distal fossa of the extending pontic 26.

*Roentgenographic study**

The subjects were examined roentgenographically according to *Henrikson & Lavstedt* (1974). The aim of this study was to make a reasonable comparison of the proximal marginal bone heights in the cases I—IV (Table I).

The holographic interferometry technique

The experiments were performed according to a method previously described (*Wedendal & Bjelkhagen*, 1974a). Some technical improvements were, however, made in the previous technique. Prior to holography the jaw section was prepared with a coating of gold dust paint in order to achieve total reflection of the laser light. A new type of paint which was easy to adapt on the tissue was used.

In the present experiments the subminiature force sensor was fixed with a small piece of sticky Orahesive* on the occlusal surface of the tooth to be actuated. The rod of the sensor was embedded in the centre of this material without causing disturbance of the sensor function. The point of force application as well as the direction was controlled. Approximately 60 double-exposed interferograms were registered.

Evaluation and documentation

The static and dynamic evaluations were made by means of the original holograms, with the observed deformation being directly related to the force increase recorded on the oscilloscope screen. As the main purpose of this investigation was to develop the method and to study the interference patterns created in double-exposed holograms as a function of various experimental circumstances, the most readily evaluated hologram of each experiment series was subject to particular attention. Separate interference fringe pattern fields were observed on various segments of the virtual image indicating different degrees of mobility in separate parts of the object. These fields are called *reference fields* in the following. In the comments on each reconstructed and photographed hologram the fields have been individually defined according to their relationship to parts of the holographed jaw section.

RESULTS

The photographed reconstructions of the holograms are shown in Figs. 1—8 combined with the corresponding oscillo-

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* The roentgenological examinations and the evaluations were performed att he Dept. of Oral Roentgenology, School of Dentistry, Karolinska Institutet, Stockholm.

* E. R. Squibb & Sons Ltd, Liverpool London

Table I. _Roentgenographic survey of proximal alveolar bone heigth_*

Patient No.	Tooth No.	Mesial	Distal	Morphology
I	25	16.5	14.7	The marginal bone contour was level and cortically bounded. No retraction proximal to 25 and 24. Small retraction at 23. The opposing teeth had a level, slightly retracted marginal bone contour.
	24	14.3	13.5	
	23	18.1	17.2	
II	26			The marginal bone contour was level and cortically bounded. No retraction.
	25	16.0	15.5	
	24	13.5	12.8	
III	23	10.4	5.0	The marginal bone contour was retracted. The boundary was characterized by a dense zone of bone all along the maxilla. Only in region 23 the bone had an irregular structure, a palatal bone pocket being registered 3.5 mm from the tooth apex.
	21	9.3	8.4	
	11	8.4	8.6	
	12	7.7	5.0	
	13	10.9	7.0	
IV	25	10.1	4.7	The marginal bone contour was level except distally of 25 and 23. A bone pocket was registered distally of 25. The bone contour was cortically bounded, except distally of 25.
	23	10.6	7.4	
	21	11.0	9.8	
	11	11.9	10.4	

* Measurements in mm

Table II. _Experimental conditions and actuating forces_

Experiment No.	Type of tooth loaded (1)	Point of application		Direction (3)	Amplitude (N) Force increase Triggering level 2 N	Duration (μs) of pulse separation
		Tooth no.	Location (2)			
I: 1	S	24	F d	i	0.5	450
I: 2	SE	27	F d	i	3.4	450
I: 3	A	24	F d	i	3.4	450
I: 4	S	24	F d	i	1.1	450
II: 1	S	26	C l	i	0.6	450
II: 2	S	24	F m	i	3.8	450
III: 1	S E	26	F d	i	1.4	450
IV: 1	P E	26	F d	i	2.0	450

Code: 1.) S: separate tooth
A: abutment tooth
PI: pontic, intermediary
PE: pontic, extending
SE: saddle-born, extending

2.) F: fossa
C: cusp
m: mesial
d: distal
b: buccal
l: lingual

3.) m: mesial
d: distal
v: vestibular (labial)
o: oral (lingual, palatal)
i: intrusive (axial)

Table III. *Orientation and amplitude of displacements*

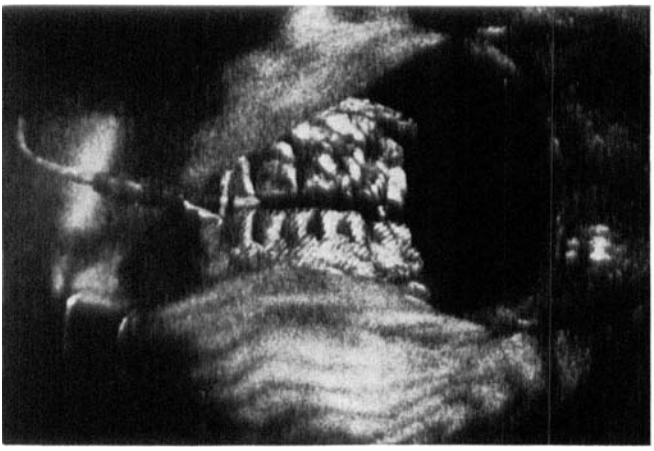
		Reference fields of the holographed jaw section									
		A		B		C		D		E	
Experiment No.	Direction	Amplitude (μm) Abs.	Rel.	Amplitude (μm) Abs.	Rel.	Amplitude (μm) Abs.	Rel.	Amplitude (μm) Abs.	Rel.	Amplitude (μm) Abs.	Rel.
I: 1	Axial	5		6	1 i	5		5		18 45° me	
	Horizontal				2 v		0.5 v				
I: 2	Axial	6 e	2 i	8 e		10 10° d					
	Horizontal										
I: 3	Axial		4 45° mi	4 45° de		11 10° d		7 10° d	2 10° mi	7 10° d	
	Horizontal	4 45° dv	4 45° dv								
I: 4	Axial	5 20° do		6 45° de	0.5 20° mi	8 20° de		18 20° me			
	Horizontal										
II: 1	Axial	5 30° di		5 30° di		5 30° di		24 e			
	Horizontal				<0.5 o						
II: 2	Axial	6 45° di		8 45° me							
	Horizontal										
III: 1	Axial		3 45° di	3 45° di		4 45° me					
	Horizontal	2 45° dv	2 45° dv								
IV: 1	Axial	9 5° me		3 45° me							
	Horizontal										

Letter and digit code concerning directions of displacement.

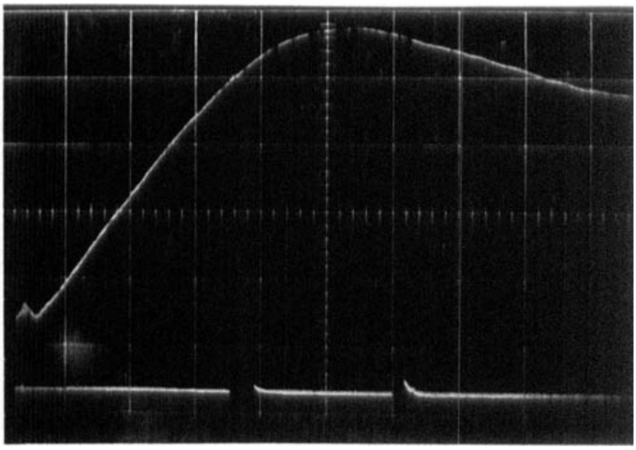
m: mesial
d: distal
v: vestibular (labial)
o: oral (lingual, palatal)
i: intrusive (axial)
e: extrusive (axial)

Values in degrees indicate deviation from the tooth axis. (eg. 30° mi: mesial-intrusive direction of displacement deviating 30° from the tooth axis).

The reference fields A—E are defined in captions to Fig. 1a—Fig. 8a.



1a



1b

Fig. 1a. Experiment I:1. Photographed reconstruction of a hologram. Reference fields: A: 25, B: 24, C: 23, D: 21, 22, E: 31, 41—46
The interference fringe pattern revealed absolute as well as relative mobility within the holographed jaw section.

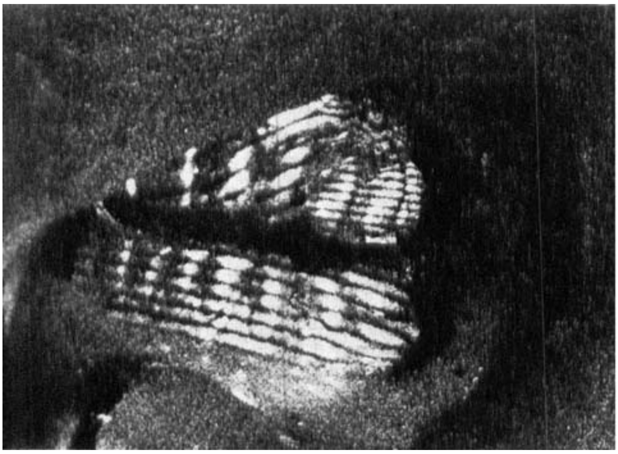
Fig. 1b. Experiment I:1. Oscilloscope curves. Horizontal calibration 200 μsec/div. Vertical calibration 0.8 N/div.
The force increase curve (upper) intersected by the ruby laser pulses (lower) indicated a force increase of 0.5 N between the pulses.

scope curve traces. The orientation and amplitude of the displacements in all clinical experiments are summarized in Table III. Plaster models of the patient's jaws were used as a supplementary simulation equipment to estimate the direction of force application (Table II) via the metal rod of the sensor as well as the direction of the resulting displacements (Table III). The estimated directions were then compared with the true amplitudes and directions as evaluated from the ruby laser holograms. The inherent error of the method was considered by rounding off the values in Table III within the known limits of error (*Wedendal & Bjelkhagen*, 1974a).

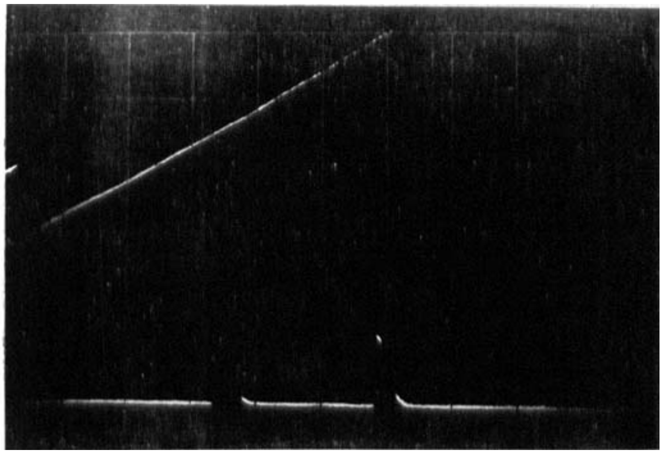
The data in Table I—III, the hologram pictures and the oscilloscope curves together contain abundant and detailed informations about the dynamic process during the 450 μsec, between the two laser pulses. The sweep rate of the oscilloscope as well as the triggering force level of the sensor are adjustable and can therefore be considered as sources for supplementary measurements. In particular, the following conclusions could be drawn from the reactions of the patient in Case I to the various experimental conditions.

In experiment I:2 and I:3 the rigid connection between 24 and 25 after prosthodontic treatment gives rise to certain findings. Inhibition of the closing movement could be experimentally recorded at a force increase from 2.0 N to 2.5 N in experiment I:1 (Fig. 1a & b). Utilizing varying sweep rates of the oscilloscope it was possible to reveal a deflection of the force curve at a level of approximately 2.5 N. This was followed by a new force increase, which was probably caused voluntarily by the patient.

In experiment I:2 (Fig. 2 a & b) and I:3 (Fig. 3a & b) the force increase before inhibition of the closing movement was recorded as 2.0 N to 5.4 N — the deflection point of the force curve not



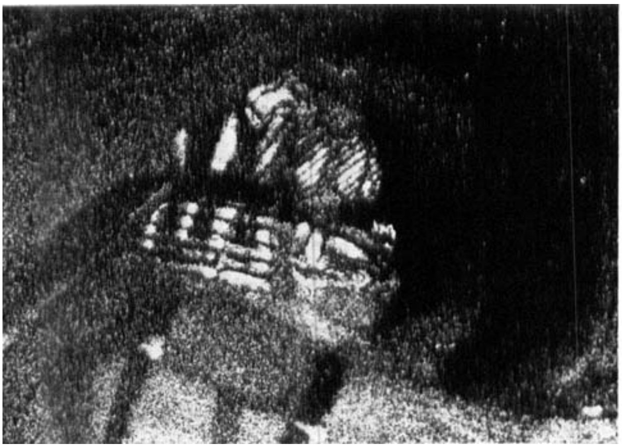
2a



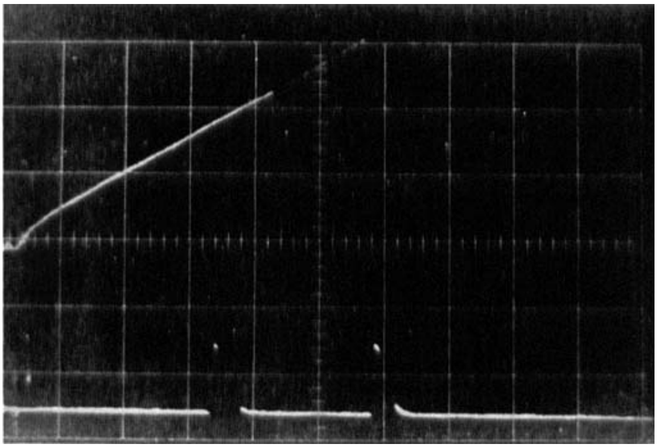
2b

Fig. 2a. Experiment I:2. Photographed reconstruction of a hologram. Reference fields: A 24 25 26, B: 21 22 23, C: 41 31—35
The bridge was slightly moved in cranial direction.
Fig. 2b. Experiment I:2. Oscilloscope curves. Horizontal calibration 200 μsec/div. Vertical calibration 2.5 N/div.
The force increase was 3.4 N.

being reached. This may have depended upon the rigid connection between 24 and 25. As described earlier, a saddle extension bridge was constructed with 24 and 25 as full crown abutments. Teeth 26 and 27 were used as a saddle-born extension. The result as regards force increase was the same as above when the subminiature force sensor was applied on 27 (I:2) and 24 (I:3) respectively. This indicates that

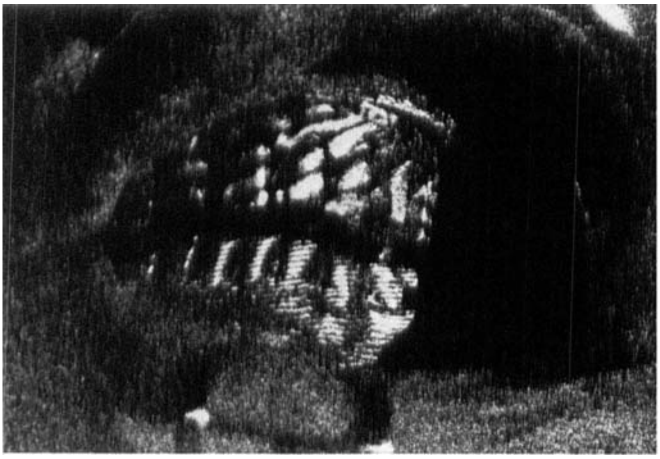


3a

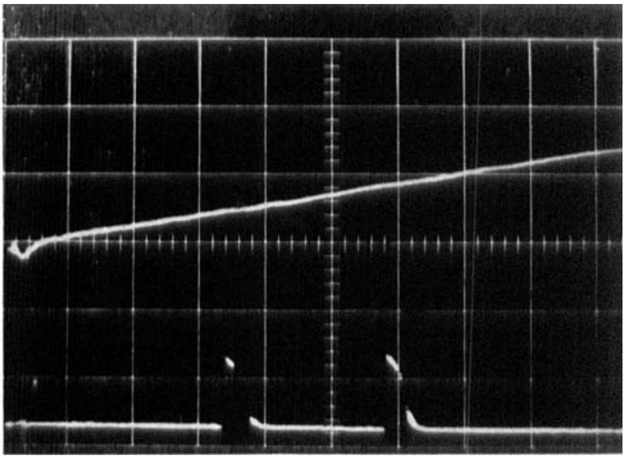


3b

Fig. 3a. Experiment I:3. Photographed reconstruction of a hologram. Reference fields: A: 24, 25, 26, B: 21, 22, 23, C: 41, 31—33, D: 34, E: 35, 36
The fringe pattern revealed labial as well as axial displacement of the bridge. The tooth 34 in hard occlusion on the sensor was intruded 4 μm. A lingual displacement <0.5 μm was recorded.
Fig. 3b. Experiment I:3. Oscilloscope curves. Horizontal calibration 200 μsec/div. Vertical calibration 2.5 N/div.
The force increase was 3.4 N.



4a



4b

Fig. 4a. Experiment I:4. Photographed reconstruction of a hologram. Reference fields: A: 25, B: 24, C: 21—23, D: 41, 31—35.
The tooth 24 was slightly intruded.

Fig. 4b. Experiment I:4. Oscilloscope curves. Horizontal calibration 200 μsec/div. Vertical calibration 2.5 N/div.
The force increase was 1.1 N.

the patient experienced the bridge as a functional unit under these experimental conditions. More refined techniques are required to prove whether this reaction depends purely on periodontal proprioception or whether receptors in the subjacent tissue of the saddle region are involved. The short moment of reaction, 450 μsec, should be considered.

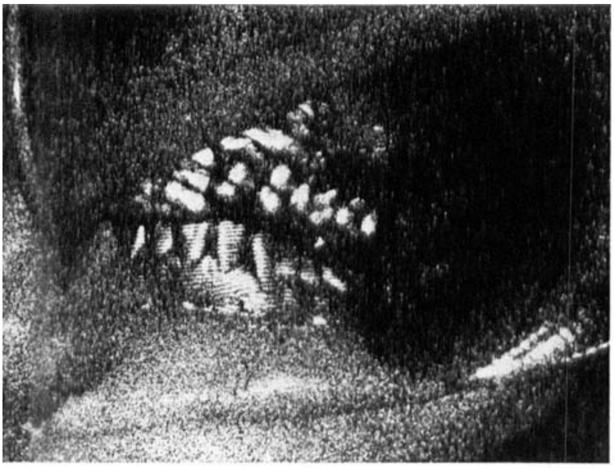
The displacement of the abutment tooth in this patient was quite different than in the earlier experiments (I:1). Force application on 27 resulted in axial motion only. Force application on 24 resulted in both axial and horizontal (labial) displacement.

In the experiment I:4 the relative displacement of the tooth 24 with a separate gold cap was evaluated as 0.5 μm. The actuating force was 1.1 N. This was compared with the actuating force in experiment I:1 which was 0.5 N, causing an intrusion of 1.0 μm. The orientation of the resulting displacements of the tooth 24 in I:1 and I:4 were slightly different. The difference in force and displacement amplitudes in the above experiments is remarkable.

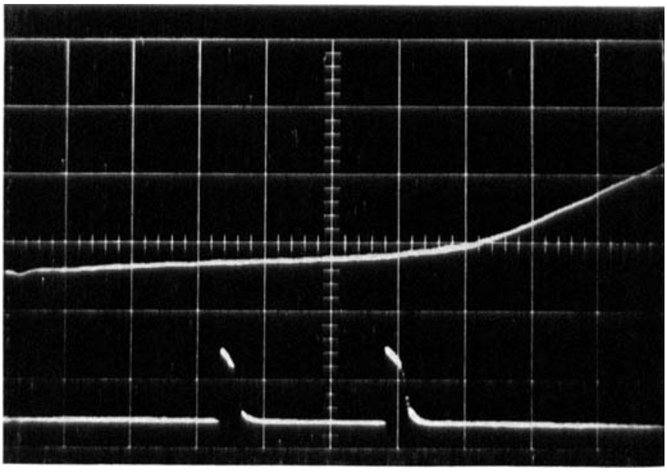
The subminiature force sensor in case II was positioned with the tip of the rod resting on the inclination of the palatal cusp of the tooth 26 during the experiment II:1. In the hologram a displacement of 26 could be recorded. The displacement was evaluated as <0.3 μm and recorded as just a slight change in the interference fringe pattern. According to the position of the sensor during the experiment, the displacement was interpreted as in palatal direction. The marginal bone contour was not retracted in this case and the teeth were very firmly attached to their sockets.

In the experiment II:2 the sensor was positioned in the mesial fossa of the tooth 24. No displacement could be evaluated.

In the experiments III:1 and IV:1 the reference fields reveal mobility patterns of certain types. In case III the extension part of the prosthodontic appliance was



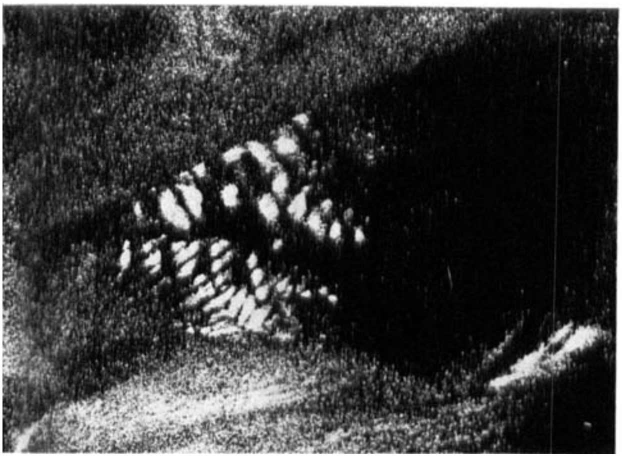
5a



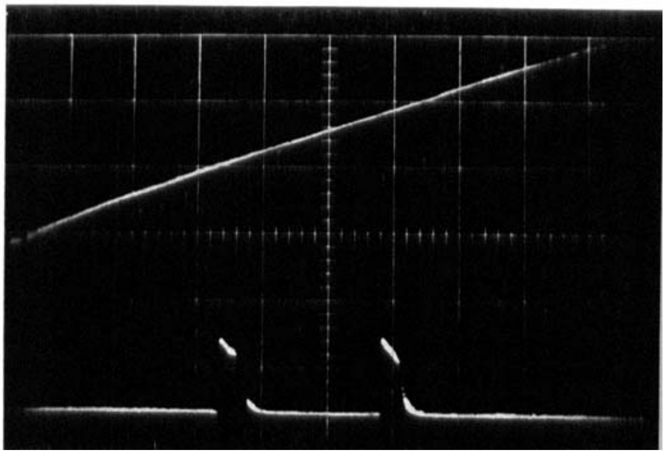
5b

Fig. 5a. Experiment II:1. Photographed reconstruction of a hologram. Reference fields: A: 27, B: 26, C: 21—25, D: 41, 31—36
A slight change in the interference fringe pattern revealed a horizontal displacement of the tooth 26 <0.5 μm.
Fig. 5b. Experiment II:1. Oscilloscope curves. Horizontal calibration 200 μsec/div. Vertical calibration 2.5 N/div.
The force increase was 0.6 N.

bended 3 μm upwards during the pulse separation delay (450 μsec). A simultaneous 2 μm labial displacement could be recorded. Probably the rigidity within the construction — improved by the palatal bar — has had an influence on the amplitude of the horizontal mobility. The roentgenological findings should be considered (Table I). The abutment teeth (especially 23) have a considerable retraction of the marginal

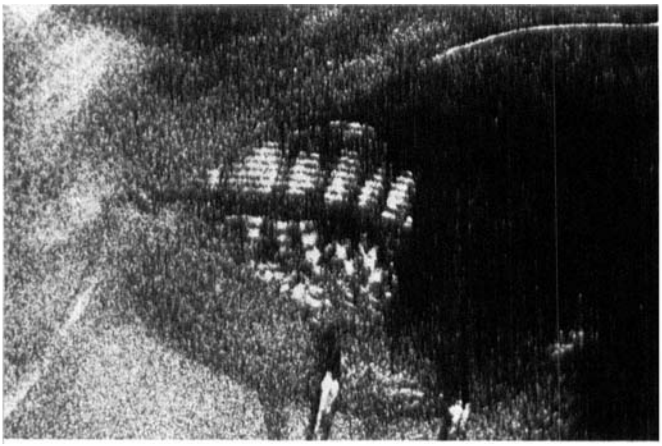


6b

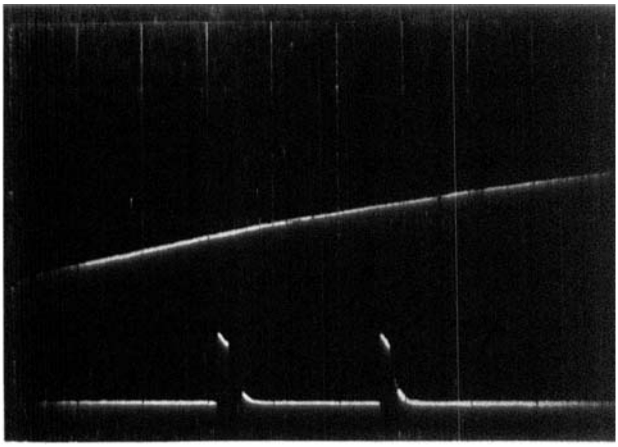


6a

Fig. 6a. Experiment II:2. Photographed reconstruction of a hologram. Reference fields: A: 21—26 B: 31—36
No relative displacement is recorded.
Fig. 6b. Experiment II:2. Oscilloscope curves. Horizontal calibration 200 μsec/div. Vertical calibration 4,9 N/div.
The force increase was 3.8 N.



7a



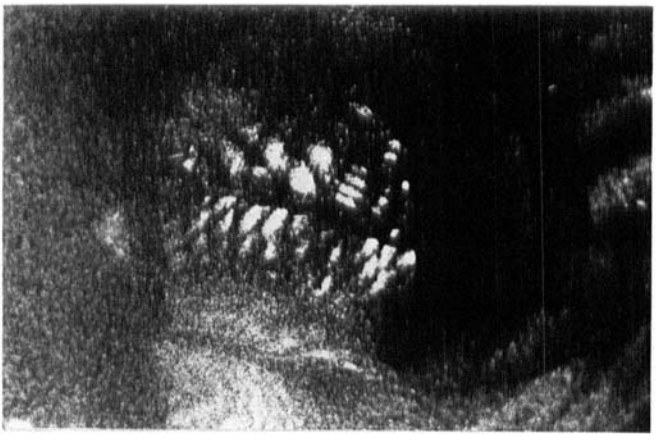
7b

Fig. 7a. Experiment III:1. Photographed reconstruction of a hologram. Reference fields: A: 24, 25, 26, B: 21, 22, 23, C: 31—35
A bending displacement is recorded within the bridge construction between the anchor part and the extension part.
Fig. 7b. Experiment III:1. Oscilloscope curves. Horizontal calibration 200 μsec/div. Vertical calibration 2.5 N/div. The force increase was 1.4 N.

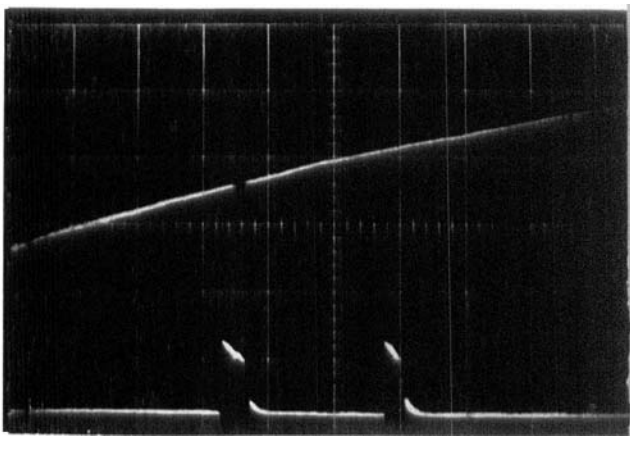
bone contour. A clearly visible difference between the reference fields A and B is seen in the hologram between 23 and 24, indicating that the bending mainly might have taken place within the construction.

The evaluation of the hologram in case IV shows that the patient might have bent his head slightly in the front direction during the experiment.

This was found when the interference



8a



8b

Fig. 8a. Experiment IV:1. Photographed reconstruction of a hologram. Reference fields: A: 21—26, B: 41, 31—36
No relative displacement was recorded.
Fig. 8b. Experiment IV:1. Oscilloscope curves. Horizontal calibration 200 μsec/div. Vertical calibration 4.9 N/div.
The force increase was 2.0 N.

fringe pattern on the glasses was taken into consideration and compared with other parts of the holographed region. A field of unitary interference fringes was found on the image of the bridge in the upper jaw. No tendency of bending within the bridge could be observed. The bridge was constructed with soldered joints of optimal quality. A slight intrusion was estimated due to the parodontal conditions shown in Table I. The tooth 25 had a considerable retraction of the marginal bone contour and the force application on 26 might have caused intrusion of 25. This was, however, not possible to observe during the evaluation.

DISCUSSION

Most of the abundant and detailed information is lost when three-dimensional holographic images are transformed into two-dimensional photographs.

The major variations in the interference fringe pattern in different parts of the holographed jaw section are, however, observable in photographs (Figs. 1—8).

A comparison between the interference fringe patterns in the presented cases revealed characteristic types of mobility. It was thus possible to correlate the mobility in different parts of the holographed jaw section to the experimental conditions. Some characteristic findings (Tables I, II and III) are listed below:

Displacements of separate teeth in horizontal as well as in axial direction were recorded.

Indirect displacements having an amplitude of about 0.5 μm were registered.

Intrusion and slight horizontal displacement of opposing teeth were recorded.

Rigidly connected parts of bridges acted as a functional unit when forces were applied.

Bending displacements between the anchor part and the extension part of the bridge-work were revealed by the interference fringe pattern. Considerations could be made about the inhibition in the last phase of the closing jaw movement.

The evaluations were made according to previously described static and dynamic principles (*Abramson*, 1972). As the sign (+ or —) of the displacement direction could not be determined directly by examining fringe patterns, supplementary considerations were necessary. The use of the plaster models of each patient's jaws as a simulator equipment facilitated the estimations as regards the direction of actuating forces and resulting displacements.

The roentgenographic findings in Table I were studied and related to the positions of the reference fields.

The present experiments indicated that the influence of the abutment teeth, eg. their position and fixation in the jaw, should be considered.

It should be kept in mind that the triggering force (2.0 N) in the ruby laser experiments was at the average level of the positioning forces in the simulator experiments in laboratory installation (1.0 N for one-end screw-vice fixation and 3.0 N for two-edge support. *Wedendal & Bjelkhagen*, 1974b).

The force increase in the ruby laser experiments (eg. 0.5 N for I: 1, 3.4 N for I: 2) correspond to the working forces in the He-Ne laser study (eg. 0.3 N and 1.0 N for one-end screw-vice fixation; 1.5 N for two-edge support. *Wedendal & Bjelkhagen*, 1974b).

The resulting deflection could be compared, if considerations are taken to the scale of distance in the test bars and in clinical bridge-work, respectively.

The purpose of the present investigation was to follow up the earlier developed method in some clinical applications. Further systematic experiments might elucidate different problems concerning the intra alveolar tooth mobility and the functional displacement of fixed bridgework as an important part of the masticatory function.

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REFERENCES

Abramson, N. 1972. The holo-diagram V: A device for practical interpreting of hologram interference fringes. Applied Optics. 11, 1143—1147

Henrikson, C. O. & Lavstedt, S. 1974. Precision and accuracy in intraoral roentgenographic determination of marginal bone loss. Acta Odont. Scand. (in print)

Izikowitz, L. & Wedendal, P. 1968. Sattelextensionsbrücken (SE-brücken). Schweiz. Mschr. Zahnheilk. 78, 850—868

Wedendal, P. R. & Bjelkhagen, H. I. 1974a. Dental holographic interferometry in vivo utilizing a ruby laser system. I. Introduction and development of methods for precision measurements on the functional dynamics of human teeth and prosthodontic appliances. Acta Odont. Scand. 32, 131—145

Wedendal, P. R. & Bjelkhagen, H. I. 1974b. Holographic interferometry on the elastic deformation of prosthodontic appliances as simulated by bar elements. Acta Odont. Scand. 32, 189—199.