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Interferometry in the Assessment of Biomechanical Features of the Masticatory System Hard Segments

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ABSTRACT

Biomechanical studies have found wide application and solved many problems in dental medicine. An interdisciplinary approach has allowed an ever-faster progress in the field. The aim of this study was to point out the advantages of holographic interferometry. With the use of this method, the study object is observed as a whole rather than as a substrate, thus providing a three-dimensional holographic image visualizing the load transmission from one jaw to another, tooth pressure against the alveolus, and strain of Sharpey's fibers, and yielding precise data on deformities, dislocations and force distribution.

Introduction

Biomechanical studies have provided new fundamentals and found wide application in numerous fields of dental medicine. A fast progress of the method is warranted by its interdisciplinary nature. Because of its complex structure and function, the masticatory apparatus is subject to the laws of biomechanics, whereby great forces are produced[1]. Numerous studies on the issue have provided valuable data[2–5], however, many problems and unknowns have yet remained to be elucidated.

The transmission of forces in the masticatory apparatus should be observed in full complexity of its elements, including the jaw, bone, tooth, periodontium and root as well as the force transmission by occlusion contact to the other jaw. The main principle is that the sum of all

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forces within the orthogonal three-dimensional system must always be in a static or dynamic balance. The analysis of forces acting during the stomatogenic system function is even more difficult, as a large number of hardly definable individual morphological and functional factors should be taken in consideration. Therefore, each case should be individually approached as an open system with an indefinite number of the degrees of freedom.

Holographic interferometry is one of non-invasive methods which does not act on the study substrate itself (it is neither prepared nor dried), but the study object is observed as a whole.

Gabor initially proposed the idea of the holographic recording of spatial three-dimensional images on photographic plate as early as 1948[6]. However, the wide use of holography occurred after the discovery of laser[7,8]. Various methods of holographic interferometry suitable for use in biomedicine to analyze minimal dislocations and deformities due to mechanical load upon an anatomical or biological specimen or in vivo, have been developed from the original method of photographing holograms.

The aim of the study was to evaluate the applicability of the method of holographic interferometry to visualize the distribution of forces in human teeth and jaws. The method has first found use in technical sciences[9,10], followed by its application in biomechanical studies of the locomotor system on both static and dynamic load[11–18]. As the use of holographic interferometry in biomechanical studies has recently been neglected, one of the objectives of the present study is to reconsider the possibilities and place of holographic interferometry in the studies and solutions of biomechanical problems related to the stomatogenic system in humans, all this in the light of the latest concepts and achievements[20–22].

Material and Methods

The analyses were performed on the anatomical preparations of the maxilla and mandible of a 40-year-old man, where all permanent teeth were present in the maxilla (n = 8), while the first and

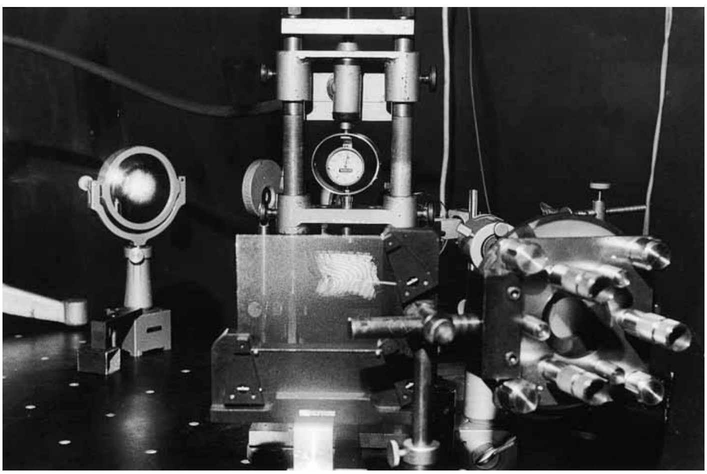

Fig. 1. A holographic device with a hydraulic press.

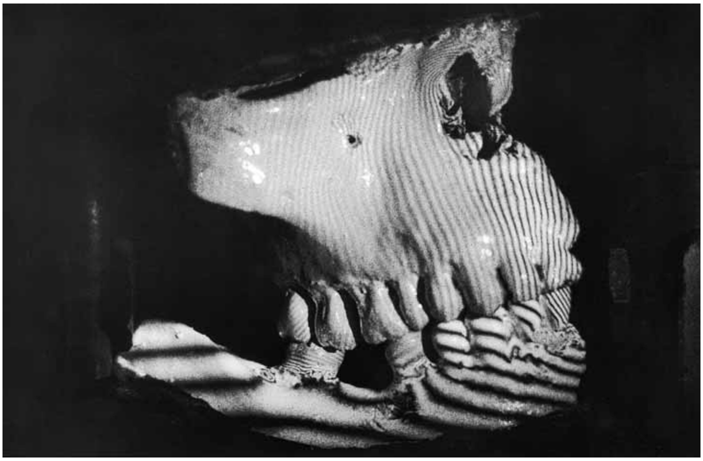

Fig 2. Interferogram of a preparation with load difference of 10 kP (65 and 75 kP).

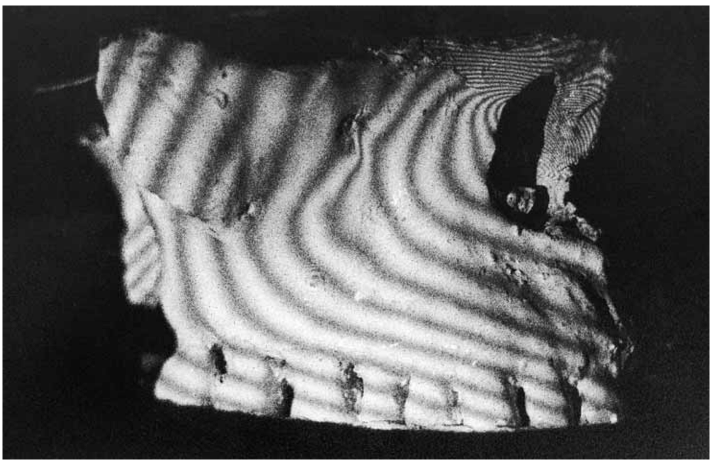

Fig. 3. Interferogram of a maxilla with a check bite with a load of 3 kP and without preload.

second molars were missing in the mandible. The jaws were separated from other parts of the skull and from soft tissues except for periosteum. The jaws were mounted onto a specially constructed support, and placed into a hydraulic press with sliding screws (Figure 1). A loading device with a load range of 0–1500 N was placed above the holographic table. A dynamometer to measure the level of pressure was placed between the teeth and pressure-exerting part of the press. A helium-neon laser, 15 mW, emitting a red beam at 6328 A, served as the source of light. Upon the laser light splitting, the jaw was illuminated by a broadened beam, i.e. subject beam, whereas reference beam was directed to dry plate. In order to determine the area of load and deformities required for holographic analysis, the initial, unloaded condition of the preparation was taken first in the

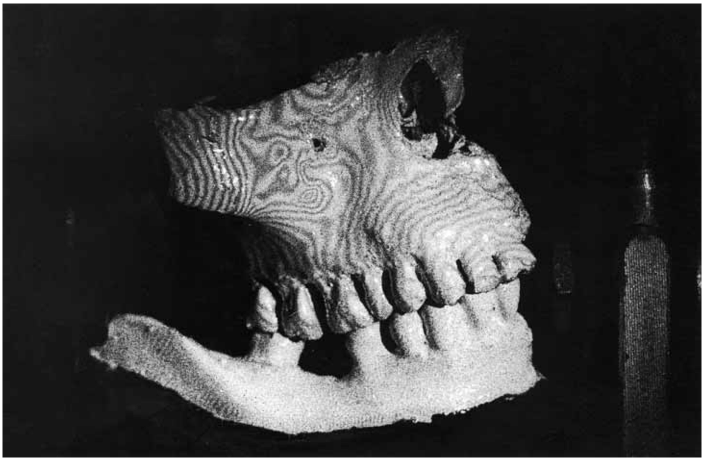

Fig. 4. Interferogram of a maxilla after compensation for its dislocation as a hard object.

form of hologram on dry plate, while changes from this initial state with loading manifested as interference lines. Thereafter, the preparation was photographed and analyzed by the method of double-exposition holographic interferometry.

Results

The results of the study pointed to reproducibility of deformities for various loads of the mandible (Figure 2), showing that tooth pressure caused the outer alveolar wall to move inward, i.e. toward the root. The medial incisor was found to be most severely loaded, followed by the second premolar and second molar.

Figure 3 shows the distribution of deformities on the preparation load through a check bite. The pressure was found to be uniformly transmitted. The formed interference lines represented the first dislocation 'contour lines' (Figure 4).

The incisors pressed into the alveolus, with an anterior dislocation. The distal parts of the alveolar process protruded beneath the lower root of the zygomatic process. The deformity of a part of the maxilla, corresponding to the second premolar and molars, caused lateral dislocation of the rough zygomatic process. This clearly demonstrated that the zygomatic and alveolar processes are the main trajectory in transmission of the facial skeleton forces. In this experiment, the other major trajectories of transmission of maxillary load forces, i.e. the one bypassing the piriform aperture and proceeding along the lower edge of the orbit toward the zygomatic process, and the other running along the edge of the orbit and the piriform aperture toward the frontal prominence of the maxilla, were also demonstrated.

Discussion

As differentiated from other methods used in biomechanics, holographic interferometry provides complete information on deformities of complex, load exposed preparations of a live body. The method is non-invasive, precise, accurate, and provides a three-dimensional visualization of the object. As demonstrated by our experiment, transmission of the load from

Fig. 5. X-ray of the preparation of a study model.

one jaw to another, and the mechanism of dislocation and deformation of the tooth – periodontium – alveolus – jaw complex were clearly visualized by holographic interferometry. The loading force was found to be distributed over a large area, while the masticatory energy was absorbed on elastic deformity of the complete system, explaining why and how the relatively thin bone plates of the maxilla can be used on biting or during the process of mastication. Anyhow, holographic interferometry currently is on the ascending pathway of its development, with numerous, as yet undiscovered possibilities.

A number of different methods have been used in biomechanical studies of the stomatogenic system, each of them associated with certain advantages as well as shortcomings. However, several methods have been generally used in order to cover the whole mosaic of the issue under study. As the problem usually is of a dynamic nature, and of individualized morphology and function, mathematical models that will allow simulation of a large number of different loading patterns and states, adjustable to individual conditions, will have to be designed in the future. The use of end models may be one of such applications[23].

Conclusion

The present study showed the mechanism of load transmission from one jaw to another and from the tooth via periodontal membrane to the alveolus. Holographic interferometry is the only method by which it could be experimentally demonstrated how the pressure of the tooth into the alveolus and straining of Sharpey's fibers resulted in a dislocation of the alveolar walls toward the root, thus reinforcing it. The comparison of the holographic interferogram and x-ray of the jaw (Figure 5) of the preparation used as a study model revealed the relationship between the mode of deformation and the inner structure of the jaw.

A Chinese proverb says: »One picture is worthy of a thousand of words«; we could say that one hologram is worthy of a thousand of pictures.

Holographic interferometry provides precise data on the structure deformity and dislocation. In combination with other methods giving data on the morphology, structure, occlusion, force and strain distribution, it will enable the creation of large data bases needed for programming of mathematical models as close as possible to the real stomatographic apparatus in vivo.

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PRIMJENA INTERFEROMETRIJE U ODREĐIVANJU BIOMEHANIČKIH SVOJSTAVA POJEDINIH KRUTIH DIJELOVA ŽVAČNOG APARATA

S A Ž E T A K

Biomehanička istraživanja u stomatologiji našla su široku primjenu i riješila mnoge probleme.Interdisciplinarni pristup osigurava njen još brži napredak. Ovim radom želimo svratiti pozornost na holografsku interferometriju, metodu kod koje se ne djeluje na sami ispitivani supstrat, nego se promatra ispitivani predmet u cjelini. Osnovu ove metode čini dobivanje holografske trodimenzionalne slika, koja prikazuje prijenos opterećenja s čeljusti na čeljust, utiskivanje zuba u alveolu i rastezanje sharpeyevih niti, te pruža precizne podatke o deformaciji i dislokaciji, te distribuciji sila.