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Biomechanical investigation of the hyoid bone using speckle interferometry

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Summary. Speckle interferometry is a non-destructive measurement technique using a laser. The principles of the method are described. Human hyoid bones ($n = 10$) were investigated. Loads were applied to individual points on the anterior surface of the body of hyoid bones. All hyoid bones showed an asymmetric displacement. The displacement was greatest in a plane vertical to the load. An evaluation of fracture behavior is possible due to the displacement pattern.

Key words: Speckle interferometry – Hyoid bone

Zusammenfassung. Die Speckle-Interferometrie ist eine zerstörungsfreie laseroptische Meßmethode. Das Prinzip der Methode wird dargestellt. 10 menschliche Zungenbeine wurden untersucht. Die Kraft wurde von vorn punktförmig auf den Zungenbeinkörper geleitet. Alle Zungenbeine zeigten eine asymmetrische Auslenkung, in Richtung senkrecht zur Belastung war sie am größten. Aufgrund des Bewegungsmusters ist eine Aussage über das Frakturverhalten möglich.

Schlüsselwörter: Speckle Interferometrie – Zungenbein

Introduction

Modern testing and measurement techniques are becoming increasingly important. They are used for example in the optimization of constructions, quality control and production control and increasingly in medicine. In this context non-destructive measurement techniques play an ever-increasing role. One of these techniques, the holographic interferometry has, been successfully used for many years for the analysis of changes in form [3, 7, 11]. This method is also being used to solve biomedical problems, e.g. the biomechanics of bones and the evaluation of osteosynthetic methods [1, 4, 6, 8, 9]. The aim of this study was to investigate the biomechanical properties of the hyoid bone with this method.

When the rough surface of a substance is illuminated with a laser light a so-called speckle-pattern is produced in the space in front of the object. This pattern originates as a result of the microscopical interference between the light waves which are reflected from single points on the surface of the rough object. In the field of coherent optics the speckles are considered to be unavoidable interferences. The granulations of the coherent light are especially suitable for the measurement of movement of objects because the speckle pattern moves in front of the object in the same way as the surface of the object. In order to photograph the speckle interferogram a double exposure of the object is made on the same film before and after deformation of the object. For this it is important that the camera is exactly focussed on the surface of the object. In this manner an interference pattern is obtained between two speckle fields which corresponds to the two separate conditions of the object. If the developed film is viewed with a laser beam the interference fringes can be seen in the Frauenhofer plane. These striations contain the information on the coordinates of movement of one point on the surface of the object. Each point on the object is then analysed with a laser beam and the movement curves of the total surface can be calculated in a direction perpendicular to the plane of observation. This method of investigation is called speckle photography and belongs to the speckle measurement techniques [2].

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Materials and methods

Materials. The hyoid bone was investigated in 10 subjects (5 female and 5 males, age 20–60 years) taken from medico-legal autopsies.

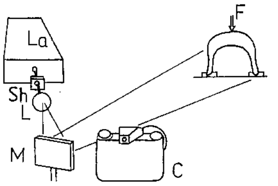

Fig. 1. Photographic documentation of speckle interferogram of the hyoid bone. *La* – laser, *Sh* – shutter, *L* – lens, *M* – mirror, *C* – camera, *F* – F-force

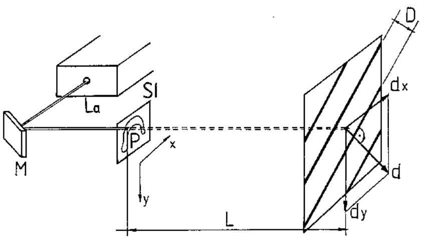

Fig. 2. Analysis of speckle interferogram in the Frauenhofer plane with laser beam. *La* – laser, *SI* – speckle interferogram, *L* – distance between SI and Frauenhofer plane, *D* – distance between the bands, d_x, d_y – vectors in x and y direction, *d* – resulting vector, *M* – mirror, *P* – Frauenhofer plane

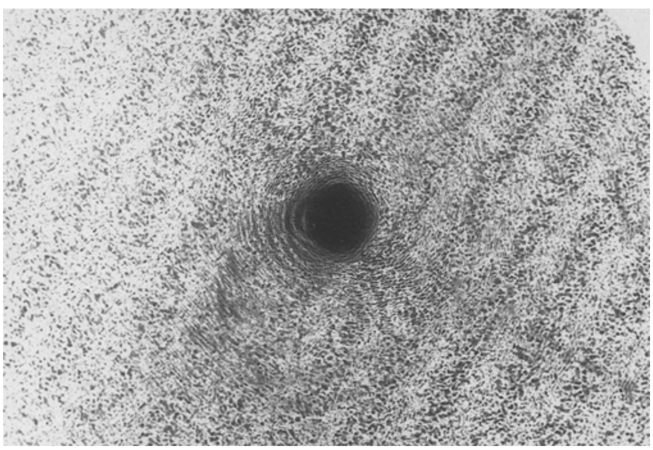

Fig. 3. Interference patterns due to diffraction of the laser beam in the Frauenhofer plane

The hyoid bones were fixed in 4% formalin together with the soft tissues and later properly prepared. The anatomical form of the hyoid bone was not taken into consideration for the investigation [5].

Methods. For the experiment the hyoid bones were mounted with the horns underneath (Fig. 1). The horns were either free or were mounted on the substrate with dental acrylate.

The axial load (F) was applied from above at single points on the hyoid bone using a special piston perpendicular to the plane of the support. The experiment was carried out with a preload Fo = 0.1 N and with a differential load F = 0.1 N. The deformation can be detected even with the smallest load because the optical measurement technique is generally very sensitive. The selected differential load is sufficient to achieve a satisfactory resolution in the striation pattern.

An argon laser (La) (wave-length lambda = 514.5 nm, 200 mW) was used as a source of coherent light. The laser beam was deflected through a lens (L) and directed on the object with a mirror (M). The shutter of the camera (C) was not used because of the specificity of the speckle interferogram photographs. Therefore it is necessary to use a separate shutter (Sh). The exposure times were 0.1 ms and the exposure intervals 3 s. The single speckle interferograms were recorded on Agfa 8E56 high-sensitivity film.

The first speckle photograph was taken with a preload of 0.1 N and a second photograph was taken on the same film after an increase in load of 0.1 N.

The speckle interferogram was analysed using the set up shown in Fig. 2. The exposed film was examined with an argon laser beam. The interference bands were viewed on a screen in the Frauenhofer plane at a distance L from the film. A typical speckle interference picture in this plane is shown in Fig. 3. The interference picture contains information on the coordinates (dx, dy) of the displacement of the speckle field for a point P on the object surface in a plane perpendicular to the observation axis. The vector d describes the displacement of the point P due to the load and can be calculated with the following formula: $d = \lambda L/MD$. Where D is the distance between the fringes at a distance L from the film, lambda (λ) is the wave length of the laser beam used for the analysis and M is the magnification of the film.

Results

The results of an analysis of speckle interferograms of 3 selected points on the hyoid bone are shown in Fig. 4. The vectors d demonstrate that the hyoid bone moves asymetrically. Furthermore it can be clearly recognised that the component of deformation (dy) runs in the same direction as the load F.

As an example the dx and dy components from two hyoid bones have been calculated and are shown in Figs. 5 and 6. They correspond to a line approximately in the middle of the hyoid bone (dotted line). Different horizontal and vertical displacement vectors were found for each hyoid bone dependant on the configuration of the bone and the mounting. In all investigated preparations a greater displacement to one side was found because of the anatomical configuration. In most cases a larger displacement between the body and the horns of the hyoid bone could be found in the vertical axis of the displacement curve. This distortion was therefore located in the region of articulation of the hyoid bone. However, similar distortions were also found in the horizontal axis of the displacement curve (Fig. 6a). In both cases described, the y-component of the body of the hyoid bone is greater than in the region of the horns. A demonstration and

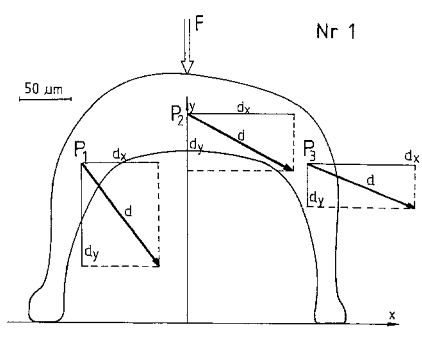

Fig. 4. Analysis of the speckle interferogram at 3 selected points on the hyoid bone. The resulting vector d can be calculated from d_x and d_y

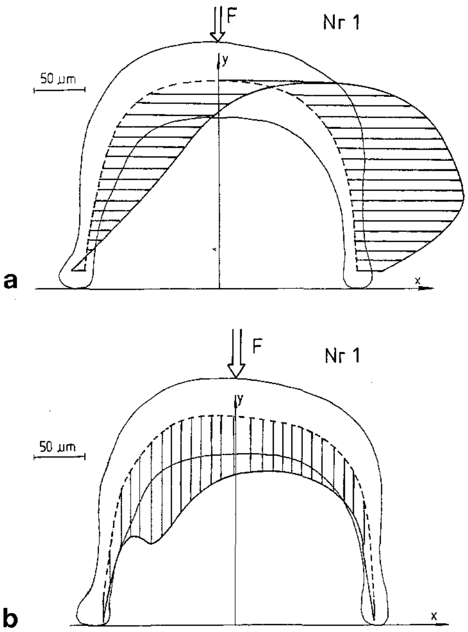

Fig. 5a,b. Schematic representation of the vector d_x (**a**) and vector d_a (**b**) in case 1. Asymmetric displacement especially in the x-direction. Fracture of the right horn on the outside, of the left horn on the inside. Large displacement in the y-direction in the junction between the body and the horn of the hyoid bone on the left side

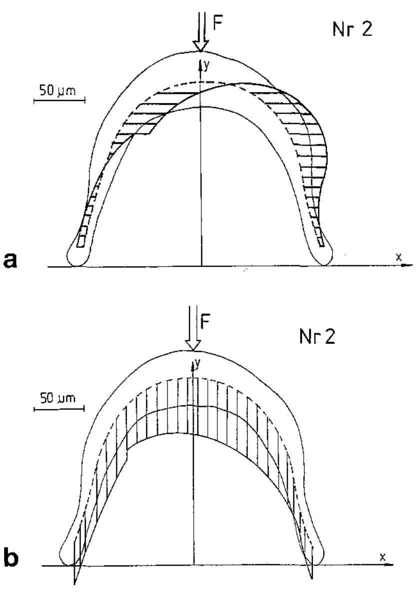

Fig. 6a, b. The same representation as Fig. 5 (case 2). The asymmetric displacement is weaker than in case 1. A large displacement is found at the junction between horn and body on the left side

evaluation of the elastic properties in various parts of the hyoid bone is therefore possible.

Discussion

Damage to the larynx and hyoid bone is a typical finding in specific causes of death, such as hanging, throttling and strangulation. The cause of fractures to the hyoid bone is thought to be either a direct mechanism by pressure on the horns of the hyoid bone against the spine or an indirect mechanism by muscle tension. According to the available literature only Saternus and Koebke [10] have investigated the behaviour of the hyoid bone in photo-elastic experiments. They could differentiate 3 basic types in the form of the hyoid bone (hyperbolic, parabolic and horseshoe forms). The photo-elastic results and the bone tissue density in the hyoid bone demonstrated that the position and type of the fractures were dependent on the basic type.

With speckle interferometry the tension can be measured directly in the hyoid bone due to the magnitude of the displacement vectors. The greater the difference in distortion between adjacent points the greater the tension. Because of the analysis of distortion an estimation of the risk of fracture at a definite point in the bone is therefore possible.

These results were confirmed by a further increase in pressure. The horns of the hyoid bone broke at the expected place. In most cases a one-sided fracture occurred due to a frequent asymmetry in the form of the hyoid bone horns.

This investigation showed that speckle interferometry is a suitable method for the investigation of biomechanical parameters in bones. Measurements can be carried out directly on the original bone and investigations using models are not necessary. The method is very sensitive and can detect even the smallest distortions.

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