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Technology

Holographic interferometry of cerebral pulsations☆

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Abstract

Background: Holographic interferometry is a noninvasive method used to analyze the mechanical displacement affecting an object undergoing deformation. This technique has been primarily applied to inanimate entities owing to the difficulty in producing stress forces in living subjects. In this report, the possibility of harnessing cerebral pulsations as a displacement force to produce interferograms in neurosurgical patients was studied.

Methods: This work evaluates the application of this technology to patients with areas of calvarial defects. Using a pulse ruby laser, holographic interferograms were created in neurosurgical patients with areas of calvarial loss. The cardiac cycle was used to trigger the firing of the laser.

Results: The holographic interferograms were accurate up to within 0.5 mm in outlining the region of bony deficiency.

Conclusion: Holographic interferometry imaging was successfully accomplished using cerebral pulsations as a cyclic displacement-producing force. This method accurately outlined the area of bony loss. A discussion of this technology is included.

Keywords: Calvarial defect; Hologram; Holography; Interferometry; Pulsed laser

1. Objective

A hologram records the wavefront of light reflected from the surface of an object that has been illuminated with a coherent source such as a laser. Reconstruction of that wavefront reveals the object in full 3 dimensions. When an object undergoes displacement or is subjected to deformation after its initial hologram has been recorded, this second image superimposed upon the original hologram produces light and dark fringes or an interference pattern. In other words, a double-exposure hologram of a surface undergoing cyclic out-of-plane movement leads to the formation of a holographic interferogram [3,6,8] from which the behavior of that object under deformation can be studied.

Holographic interferometry applied to medicine has been traditionally used with rigid structures such as prosthetic appliances in dentistry and cadaveric bones including human skulls [1,4,7,9-11]. These objects are coupled to mechanical force–producing devices to introduce structural deformation. Using such studies, the reaction of these materials to the displacement forces could be evaluated. The challenge in applying this technology with patients has been in devising methods of safely producing repetitive strains in living subjects. The current report departs from earlier work with cadavers by harnessing, for the first time, naturally occurring physiologic forces, cerebral pulsations, as a displacement-producing mechanism in neurosurgical patients.

Using cerebral pulsations as a deformational force for interferometric evaluation would normally be impossible because of the overlying skull. Therefore, patients with calvarial defects were studied in consideration of whether the cerebral pulsations can be used to produce holographic interferograms in living subjects and, if so, how accurate

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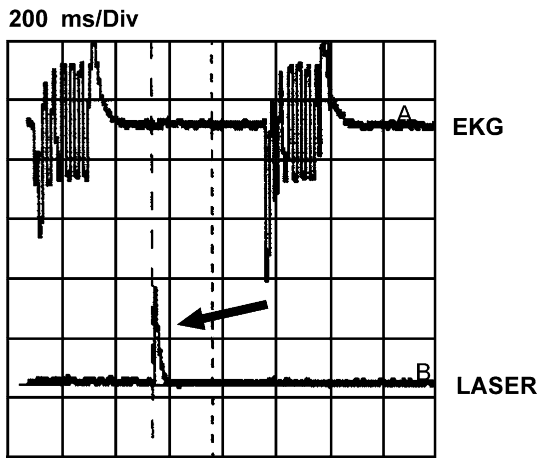

Fig. 1. Oscilloscope trace depicting the double firing of the pulse laser and the patient's electrocardiogram tracing (arrowhead). The double pulse of the laser is seen as one impulse (arrow) because of the greater order of magnitude of the time scale (200 milliseconds per unit) compared with the repetition interval of the laser (800 microseconds).

these interferograms will be in depicting the area of bone loss?

2. Methods

Five patients with cranial vault defects underwent holographic interferometry. Four of whom had a postmissile wound in the head with the initial injury occurring, on the average, 4 months previously and one of whom developed a postoperative infection after tumor removal. All were anticipating cranioplastic procedures that would reestablish each of their calvarial contours. The mean age of the patients was 30 years. The defects were located in the following regions: supraorbital-frontal in 2 patients, temporal-parietal in another 2 patients, and occipital in 1 patient. The widest dimension of the area of bone loss ranged from 2.2 to 7.5 cm. All patients were presumed to have normal intracranial pressure (ICP) at the time of imaging.

2.1. Holographic interferometry

The holographic camera used was a prototype portable pulsed ruby laser system (Holographics, Inc, Long Island, NY), which has a wavelength of 694.3 nm, a pulse duration of 25 nanoseconds, and a power output of 75 mJ. Two pulses are extracted from a single excitation of the ruby crystal. The interpulse width or repetition interval between the 2 pulses of the ruby laser can be set to vary from 300 to 1000 microseconds in multiples of 100 microseconds. The repetitive firing of the laser within this period produces a double-exposed image on a single sheet of holographic film that is the basis for the formation of the interferogram.

The patients were positioned approximately 18 inches from the holographic camera to provide an optimal view of the area with bony loss. Standard electrocardiogram electrodes were placed on each patient. A signal from the QRS complex of the cardiac cycle triggered the circuit for the firing of the laser. The trigger circuit introduced a delay of 350 milliseconds before the first pulse of the ruby laser. The electrocardiogram and laser responses were recorded on an oscilloscope (ScopeMeter 97, Fluke Manufacturing, Everett, Wash; Fig. 1).

The scalp overlying the regions of bony loss moves in response to the cerebral pulsations between the 2 firings of the laser. The area of the scalp above the intact cranium experienced virtually no displacement because of the dampening effect of the underlying bone. Fig. 2 illustrates the phase relationships for points on a surface illuminated with coherent laser light undergoing displacement (Δd) between time 1 and time 2, as in our patients. At time 1, the surface contained points A, B, and C, while at time 2, the surface was displaced such that the new surface points became A', B', and C', respectively. In this instance, the surface had undergone simple displacement toward the observer. The illuminating laser light impinged on the surface at some angle α, and it was reflected toward the viewer at the angle β. The phase shift superimposed between time 1 and time 2, when recorded by holography, reflected as interferometric fringe patterns.

Two synchronized images separated in time were exposed on a single filmstrip (Agfa 10E75AH, Agfa, Ridgefield Park, NJ) using a holographic technique, resulting in an interferogram [5,12]. The interferograms were developed and the patterns evaluated. For the calibration of spatial measurements, a plastic scale in millimeters was included in the field of view of each interferogram. The reconstructed holograms were captured using a high-resolution Megaplus camera (Kodak,

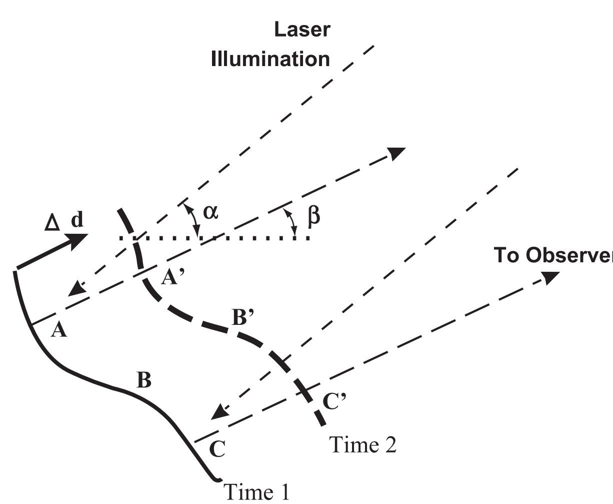

Fig. 2. Schematic diagram of the surface displacement of an object. At time 1, the surface contains points A, B, and C. After undergoing displacement toward the observer at time 2, the new surface points become A', B', and C'. The illuminating laser light impinges on the surface at angle α and is reflected toward the observer at angle β.