Holographic Studies on Human Femur with Internal Fixations

Percival Almoro[1]*, Marienette Morales[2], Regency Gueco[2], Ronald Bundoc[3], and Marlon Rosendo Daza[2]
[1]Department of Physical Sciences and Mathematics CAS, U.P. Manila
E-mail: val@nip.upd.edu.ph
[2]National Institute of Physics,
University of the Philippines, Diliman, Quezon City 1101 Philippines
[3]Department of Orthopedics, UP Philippine General Hospital

ABSTRACT

Double-exposure holographic interferometry is used to investigate the response of the human femur, with and without fracture, subjected to mechanical forces. The femur without fracture experienced uniform tension in the lateral side and uniform compression in the medial side. Fractured femurs stabilized by different internal fixators were investigated and significant differences in the dynamics were observed. The fractured femur stabilized by a plate and screws experienced greater bending in the upper portion than in the lower portion of the fracture. In the fractured femur stabilized by an intramedullary nail, the load was absorbed completely by the lower portion of the fracture.

Key words: biomechanics, orthopedics, bone fractures, holographic interferometry, double-exposure method, laser application.

INTRODUCTION

Healing of fractured bones may proceed under conditions of maintained stable contact using internal fixations like plates and screws and intramedullary nails (Muller et al., 1992). The effect of these fixators is to reduce (not abolish) fracture mobility (Muller et al., 1992). Thus pain is reduced and the limb is protected from excessive deformation. Internal fixation of fractured bones, therefore, requires a good knowledge of the dynamics of stresses and strains, in order to provide an optimal fixation for undisturbed fracture healing.

Pauwels (Muller et al., 1992) postulated that eccentrically (off-axially) loaded bones have one cortex loaded in tension and the other in compression (Fig.1).

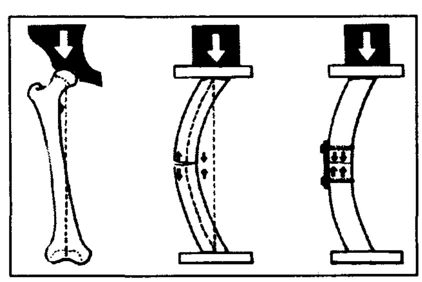

Fig. 1. (A) Eccentric loading of a bone results in one side being loaded in tension and the other in compression. (B) Under an eccentric load, the gap will open first on the tension side. (C) A plate applied to the tension side will prevent the deformity.

**Corresponding Author; Current Address: Laser Physics Laboratory, NIP, UP Diliman, Quezon City; Tel. No.: 434-4243; Fax No.: 434-4244.*

The eccentrically loaded bone is subjected to bending stresses, which results in a typical distribution of stresses with the tension coming on the convex side and compression on the concave side of the bone. Pauwels demonstrated its application using an engineering technique called tension band fixation (Muller et al., 1992). This postulate has also been proven *in vivo* using strain gauges (Schatzker, 1980).

In this study, double-exposure holographic interferometry (DEHI) was used to determine the dynamics of bending and compression on a human femur with internal fixations under eccentric loading. The advantages of DEHI are the following: it is non-contact, extremely sensitive, and a full-field displacement distribution is readily obtained (Kreis, 1996). Three bones were used in this study: a femur without fracture, a femur with fracture stabilized by a plate and screws, and a femur with fracture stabilized by an intramedullary nail.

INTERPRETATION OF THE HOLOGRAPHIC INTERFEROGRAMS

The holographically reconstructed object from a doubly-exposed hologram is covered with dark and bright fringe patterns called "holographic interferogram" (Kreis, 1996). These patterns were generated by the slight variations in the shape of the object induced by mechanical or thermal loading (Kreis, 1996). The contour and density of the holographic interferograms indicate the nature and extent of compression and/or tension occurring in the object. Each fringe contour represents a region of equal displacement (Rastogi, 1994). Uniform compression results in the appearance of a set of equally spaced parallel fringes (Rastogi, 1994). Generally, the displacement is perpendicular to the fringe contour, and the greater the fringe density the greater is the displacement (Hariharan, 1989). When bending occurs, the slopes of the fringes change. The actual three-dimensional (3-D) displacement of a point can be calculated by using the dynamic method of fringe analysis wherein fringe shift is detected as the direction of observation is changed (Pryputniewicz, 1978). For automatic fringe analysis of the holographic interferograms, a digital image processing technique called the Fourier transform method can be used to obtain 3-D surface deformations (Almoro & Daza, 1998). In this study, the eccentric loading of the human femur resulted in microscopic deformations and the appearance of the characteristic interferograms. The emphasis of this study is on the qualitative interpretation of the interferograms. The direct visualization of the displacement distribution gives a lot of useful insight on the dynamics of the femur under mechanical loading.

MATERIALS AND METHODS

The eccentric loading on the femur was simulated by putting a 1-kg weight on the head of the femur with its shaft naturally oriented about 10° from the vertical. The bottom part of the femur was clamped to the optical table. The bones used in the experiment were relatively fresh so that they still exhibit visco-elasticity (Muller et al., 1992). The implants (plates, screws, nail) were made of steel alloy, the same type used in actual orthopedic surgery. The region of interest is the shaft of the femur where the experimentally induced fracture is located.

The experimental setup is a typical double exposure setup (Almoro & Daza, 1998). The first exposure was made with the femur in its initial state. The femur was then loaded for 15 seconds. The second exposure was made with the femur in its deformed state. For each femur, one hologram was made facing the anterior side (front) and another hologram facing the medial side (inner side).

RESULTS AND DISCUSSION

Fig. 2(A) shows the basic parts of the human femur. Figs. 2(B) and 2(C) show the actual fractured femurs used in the experiment. Indicated in each femur are the locations of the induced fractures that were cut diagonally across the shafts. The plate was fastened to the femur by 6 screws (Fig. 2 (B)). One of the middle screws was applied transversely across the fracture for compression. Fig. 2(C) shows a femur with implanted intramedullary nail that extends down to the distal line of capsular reflection.

Fig. 2(D) is the holographically reconstructed femur without any fracture and any applied load. Fig. 2(E)