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Circumferential Creep of Human Cortical Bone Suggests Threshold for Press - Fit Stems

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CIRCUMFERENTIAL CREEP OF HUMAN CORTICAL BONE SUGGESTS THRESHOLD FOR PRESS-FIT STEMS

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Introduction: The degree of contact between a press-fit hip implant and the endosteal surface of the femoral canal is important for achieving initial fixation and clinical success where greater contact improves load transfer and lessens micromotion [1-5]. If the stem initially applies excessive stresses to the surrounding bone, the bone may fracture [6]. Sufficient contact without excessive stress must be achieved to maintain initial stability and allow new bone growth. However, the contact stresses at the time of implant insertion may result in creep, time-dependent deformation under constant load [7]. Creep due to hoop stress is an under-appreciated phenomenon that may threaten initial stability by reducing the contact area for load transfer between bone and implant before new bone growth can occur [8].

The objective of this study is to examine the time-dependent hoop response of femoral bone to an intramedullary radial load. The relationship between hoop creep strain, creep rate and permanent hoop strain to hoop stress is examined to understand how femoral cortical bone deforms due to stresses that may occur as a result of a press-fit hip prosthesis.

Methods: Ten fresh human femora were obtained from 8 male and 2 female cadavers (mean age 39 ± 13 years). From these femora a total of 15 right circular cylinders 19 mm in length, with a 19 mm inner wall diameter and a mean wall thickness of 2 ± 0.05 mm were wet machined. Four unidirectional strain gages were mounted on the outer surface of the specimen on the anterior, posterior, lateral and medial aspects; all gages were oriented to measure hoop strain. A test fixture applied internal pressure to the specimen while submerged in saline at 37°C [9]. A multi-phase loading protocol was followed to observe the creep behavior [7]. The specimens were initially loaded to a pressure of 50 psi. The load was increased in 15 psi increments during successive load phases. The internal pressure load was applied in less than 2 seconds and was held constant for 1 minute, released and the specimen unloaded for 2 minutes while strain was monitored (Figure 1). The creep strain was calculated as the difference between the hoop strain measured at the beginning and at the end of the 1-minute loading phase. The creep rate was determined for each constant pressure phase by linear regression analysis of creep strain data during the last 40 seconds of the 1-minute load phase. Permanent strain was measured as the amount of strain remaining at the end of the 2-minute unloading phase.

Results: Measured hoop strain values from the posterior cortex were used from each specimen because this quadrant consistently displayed the greatest strain and was the location of the point of failure. To account for differences in material properties among specimens, the hoop stress was normalized using hoop stiffness determined at every load level during the tests. A linear regression of the creep strain data against normalized hoop stress was used to model the initial behavior (σ_H/E_H<0.0005) (Figure 2). The line was offset, similar to the procedure to determine the yield strength of materials, to the upper bound of the initial data. The offset line passes through the strain data after the behavior has become nonlinear. An exponential fit was used to model the combined creep strain data for all specimens. The intersection of the linear offset and exponential fit provides a value of normalized hoop stress, 0.00111, and creep strain, 189με, at which the creep strain begins to increase nonlinearly. The increase in stress also caused a similar change in behavior for the creep rate at 1.2με/s and permanent strain at 93με.

Discussion: The creep strain, creep rate and permanent strain all initially exhibit linear behavior, until a particular stress level, or threshold, where it begins to exhibit nonlinear exponential behavior. Creep strain is occurring at very low levels of hoop stress, as low as 1.5 MPa. This is much less than the longitudinal stress level, approximately 50 MPa, needed to cause creep strain found by Fondrk et al. [7]. Jasty et al. [6] report a range of assembly hoop strains between 100-2400με for a press-fit prosthesis; the results of this study suggest that hoop creep strain may occur at or below this level.

The creep rate threshold determined in this study, 1.2με/s, is less than the value of 10με/s determined by Fondrk et al. [7]. Differences are most likely due to the anisotropy of bone. Our creep rate is similar to the creep rate of approximately 1με/s that can be deduced from Pattin et al. [10] for longitudinally oriented bovine bone specimens. To determine whether creep rates below, at or above our threshold will eventually lead to failure will be the subject of long-term creep tests.

This study, using a simplified loading environment, provides knowledge of the extent and rate of hoop deformation. This deformation occurs at low hoop stress levels and therefore may threaten initial fixation. The change in contact area between the implant and bone may reduce the contact stresses and result in a relaxing mechanism. The creep threshold evident in this study may be useful as a design parameter and for evaluating the potential success of press-fit hip prostheses.

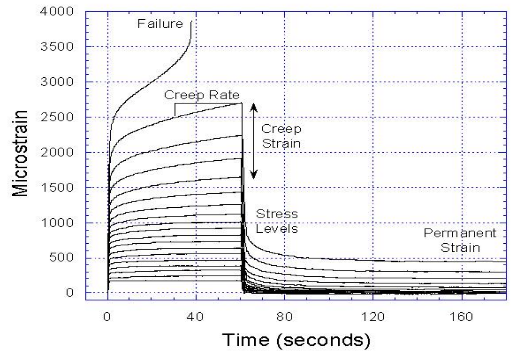

Figure 1. The multi-phase cycles for a typical specimen.

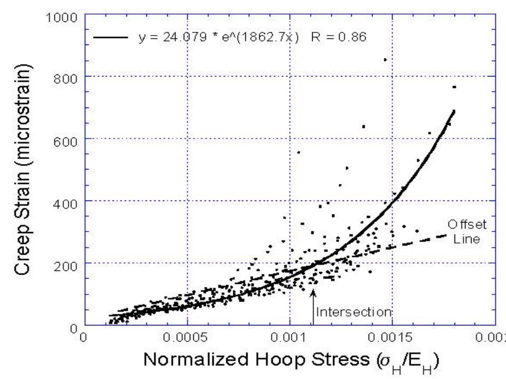

Figure 2. Creep strain accumulated during the 1-minute load phase for all specimens.

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