Introduction  Clinical evidence has shown that aseptic loosening of total hip replacements becomes more frequent with time since implantation and that reduced levels of activity improved survivorship rates [1]. These observations suggest that cumulative fatigue damage from activities of daily living may contribute to the eventual clinical loosening of total joint replacements. In the cemented hip implant system, aseptic loosening may be initiated by the mechanical failure of the stem-cement and cement-bone interface as well as fracture of the cement mantle. To date, the fatigue damage accumulation of the cement surrounding implants has been the focus of both experimental and computational models. Damage to the cement-bone interface has only been investigated using static loading [2]. But even with static loading, the post-yield softening of the interface suggests that the damage process to the cement-bone interface is very different from bulk cement.

The goal of this study was to determine the fatigue damage response of the cement-bone interface using carefully fabricated specimens from the proximal femur of cemented total hip replacements. Tensile fatigue loads were applied to the cement-bone interface and the results were examined for two different failure mode characteristics: (1) stiffness degradation during loading and (2) permanent or creep damage after unloading. Following this, a possible correlation equation was developed to predict the fatigue life of the interface.

Methods A total of 27 specimens containing cement, interdigitated cement-bone region, and bone were fabricated using a multi-step process. Three pairs of human proximal femurs were broached for a Charnley stem followed by water lavage and brushing. PMMA bone cement (Simplex P, Stryker-Howmedica-Osteonics) was vacuum mixed and inserted in retrograde fashion using a cement gun. An implant cemented in a constant rate region (Fig. 2b). During fatigue loading there was a decrease in stiffness and increase in a constant rate region (Fig. 2b).

The strain damage response with three distinct zones is consistent with the creep and stiffness damage. The main limitation of this study was that only the global fatigue process was considered. Local histological examination of failed specimens is needed to understand the detailed mechanism of the creep and stiffness damage.

Discussion The damage response of the cement-bone interface due to cyclic tensile loading exhibited typical fatigue behavior i.e. decreasing stiffness and increasing hysteresis and creep for the duration of the test. The strain damage response with three distinct zones is consistent with that found for trabecular bone and PMMA cement [3,4]. Cyclic creep damage dominated the failure response, accounted for nearly 80% of the total strain accumulation at failure. This level is substantially higher than that of trabecular bone (26%) [3] or PMMA cement (50%) [4]. This suggests that the damage mechanism for the cement-bone interface may be different from typical bulk constituents.

Eqn 1 clearly shows that the number of cycles to fracture (N_f) can be predicted if (de/dt) is known. This could serve as a useful tool to estimate fatigue life for specimens that do not fracture. Interestingly, this log-log relationship in fatigue creep response was found for both trabecular bone [3] and PMMA cement [4].

The main limitation of this study was that only the global fatigue response of the cement-bone structure was considered. Local histological examination of failed specimens is needed to understand the detailed mechanism of the creep and stiffness damage.