Introduction: Skeletal fragility with age, especially for women, is a health concern and is believed to be related to the formation of microcracking and diffuse damage in bone under cyclic loading during activities of daily life [1, 2]. Therefore, understanding the kinetics of fatigue crack propagation (FCP) in human cortical bone is fundamental to understanding fracture processes in cortical bone with respect to age and gender. Clinical evidence also indicates that the rate of fracture in irradiated allografts is higher than that in non-irradiated allografts [3]. Stawarz et al. [4] and Mitchell et al. [5] investigated the effects of age, gender, and radiation sterilization on the FCP resistance of human cortical bone. They found that the FCP resistance for older bone was reduced compared with younger bone. Radiation sterilization was found to reduce the FCP resistance of younger bone more so than older bone.

Hypothesis: We hypothesized that the FCP resistance of human bone is related in part to the formation of damage (microcracking and diffuse damage) at the crack tip during crack growth. That is, that the zone of damage formed at the crack tip is smaller for older bone vs. younger bone and smaller for irradiated bone vs. non-irradiated bone. We also hypothesized that the thickness of the damage at the crack tip increases with increasing cyclic stress intensity factor (increasing crack length).

Methods: Damage at the crack tip during fatigue crack growth was evaluated on notched compact tension specimens for which the FCP resistance has been previously reported [3, 4]. Briefly, five pairs of fresh frozen human femora were obtained (MTF; Anatom. Donations Prog., U. Mich.) to represent different age and gender groups: 1 younger male (18yr); 1 younger female (15yr specimens); 2 older males (60yr, 61yr); and 1 older female (75yr). Compact tension specimens were wet machined with the crack plane longitudinal to the osteonal orientation. Specimens were assigned from the left or right femur to an irradiated group or control group such that each irradiated specimen had a control specimen matched for bone position for each pair of femora. Irradiated specimens received an average dose of 31.7kGy of gamma radiation. Specimens were cyclically loaded to failure in a servohydraulic testing system. Three to 7 specimens were tested in each treatment group.

Discussion: Histological analysis of compact tension specimens tested with fatigue crack propagation longitudinal to osteon orientation showed that the damage formed about the fracture plane during fatigue crack propagation testing of human cortical bone was significantly reduced by increasing age and by radiation sterilization. The results are also consistent with the expectation that the damage or plastic zone ahead of the crack tip should increase in size with increasing cyclic stress intensity factor, according to linear elastic fracture mechanics principles.

The damage thickness measurements are consistent with the previously reported FCP behavior [4, 5]. For example, a greater loss in FCP resistance was found between younger and older bone in the non-irradiated condition than in the irradiated condition. It is speculated that damage to the collagen matrix as a function of aging or by radiation sterilization affects FCP through energy dissipation. In this regard, it is speculated that damage to the collagen matrix acts as a toughening mechanism to retard FCP. The results are also consistent with the expectation that the damage or plastic zone ahead of the crack tip should increase in size with increasing cyclic stress intensity factor, according to linear elastic fracture mechanics principles.

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