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Cortical Bone Remodeling and In-Service Damage Accumulation

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INTRODUCTION:

Bone's susceptibility to formation of microdamage is influenced by elevation or suppression of bone remodeling[1,2]. Remodeling suppression via bisphosphonates increases local bone mineralization which is believed to increase the susceptibility of bone to microcrack formation. However, mineralization of mature bone has been shown to decrease with age[3-5] while microdamage has been shown to increase with age.[6,7] Therefore, the effect of bone remodeling on bone's susceptibility to damage goes beyond the influence of mineralization alone. Intracortical porosity is also believed to play a significant role in bone damageability. Bone remodeling, which increases bone intracortical porosity, is also attributed to increased bone microdamage[2]. The objective of this research was to investigate the effect of bone morphometry and mineralization on the incidence of linear microcracks and diffuse damage density. It is hypothesized that intracortical porosity (i.e. bone density) is the primary determinate of bone's susceptibility to form microdamage, and that mineral percentage is secondary to the effects of porosity.

METHODS:

Fifty-seven fresh human femurs were harvested from 31 males (22 to 91 yrs.) and 28 females (24 to 94 yrs.). Bulk sections were cut from the proximal femur and stained with basic fuchsin from which 80μm thick transverse slices were removed and mounted for examination using a brightfield and fluorescence microscope at a magnification of 125x. Five fields were randomly chosen from each quadrant for damage measurements yielding a total of 20 fields per bone. Microcracks were identified as linear type morphology, typically on the order of 30-100um in length.[6,7] Crack density parameter (Cr.Dn.) was defined as the ratio of the total number of cracks (#cracks) and the bone area (B.Ar.)(Cr.Dn.= #cracks/B.Ar., #cracks/mm^2). Diffuse damage areas were identified as focal areas of diffuse staining. Diffuse damage area density parameter (Df.Dm.Ar.) was defined as the ratio of the total damaged area (Dm.Ar.) and bone area (B.Ar.)(Df.Dm.Ar.=Dm.Ar./B.Ar., mm^2/mm^2). Remodeling associated morphometric indices, i.e. osteon size, number and pore area (percent porosity) and mineral content were determined in previous studies[3,8]. Mineralization was determined from ashing. Correlations were made between crack density, diffuse damage area and morphometric indicies and mineralization. Simple regression analysis and generalized linear models using the statistical package JMP^{TM} (SAS Institute, Cary, NC) was used in the statistical analysis. Significance was set at $p<0.05$.

RESULTS:

Of the variables investigated, mineral percentage significantly correlated with Cr. Dn. ($p<0.0031$) and Df.Dm.Ar. ($p<0.0105$) (Figure 1) and porosity significantly correlated with Cr.Dn. ($p<0.0037$) (Figure 2). Mineral percentage significantly ($p<0.0001$) decreased with age while porosity was also found to significantly ($p<0.0001$) increase with age. Df.Dm.Ar. was significantly related to mineral percentage alone, independent of age.

DISCUSSION:

It has been proposed that as bone becomes more mineralized, or more brittle, that it becomes more damageable[9] possibly due to decreases in the amount of plastic deformation that can occur before failure[1]. It has also been reported that bone becomes more mineralized at the microscopic level when bone remodeling is suppressed using bisphosphonates[10,11]. Results of the current study show that crack density and diffuse damage area significantly decrease, rather than increase, when bone becomes more mineralized. This finding is consistent with studies investigating the effect of antiresorptive agents which slow intracortical remodeling. Clinical data show that antiresorptive agents reduce fracture risk within the first year of treatment and for as long as 7-10 years thereafter[1]. This implies that bone becomes less susceptible to damage with the slowing of intracortical remodeling. Results of the current study also show that Cr. Dn. increases with increases to intracortical porosity. This is consistent with the proposal that elevated intracortical remodeling can accelerate microdamage accumulation by increasing intracortical porosity and decreasing the stiffness of cortical bone [12].Results of this study suggest that the susceptibility of bone to form damage is more strongly influenced by porosity (i.e. bone density) than mineral content. It is concluded that elevated remodeling, which decreases mineralization and increases porosity, should increase bone's susceptibility to damage whereas remodeling suppression should not.

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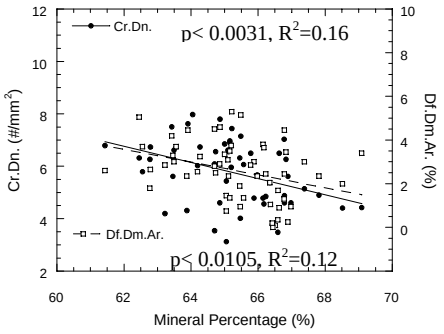

Figure 1. Variation of Cr.Dn. and Df.Dm.Ar. with mineral.

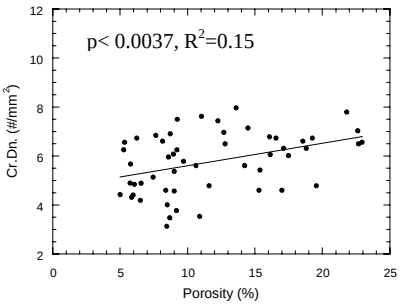

Figure 2. Variation in Cr.Dn.with porosity.