MEASURES OF BONE QUALITY AND THEIR RELATIONSHIP TO BONE MECHANICAL PROPERTIES

Abstract

by

Ziheng Wu

Measurement of bone mineral density (BMD) has been used as a method for diagnosis of osteoporosis. However, this method does not account for the influence of changes in bone quality. The objectives of this dissertation were to investigate viscoelastic properties of bone tissue using nanoindentation, identify the effects of disease, aging, gender and tissue compositions on bone mechanical properties, and study crack initiation and propagation in bone samples subjected to multiple loading modes.

We compared the viscoelastic behavior of human cortical bone between genders by using nanoindentation at a fixed load of 10 mN to measure the creep time constant. Bones from females had a significantly greater time constant than bones from males. The creep time constants decreased with increasing tissue modulus. The mineralization, collagen content, and collagen crosslink density were analyzed to determine if the differences in viscoelastic behavior were explained by compositional differences in the bone. However, none of the parameters differed between genders, nor were they correlated to the viscoelastic time constant.
The effect of ovariectomy on mechanical properties of ovine trabecular bone tissue was investigated using nanoindentation. Three groups of mature ewes were studied: one group was unoperated control and two other groups underwent bilateral ovariectomy and were sacrificed either 12 months (OVX-1) or 24 months (OVX-2) after surgery. Mineralization and elastic properties decreased and the creep time constant increased after ovariectomy. As the elastic properties recover as well as mineralization, the viscoelastic properties did not, indicating that there might be other factors in change of viscoelastic properties. Elastic modulus increased and creep time constants decreased with increasing mineralization, but the sensitivity to the change of mineralization depended on OVX status. This demonstrated that mineralization altered both elastic and viscoelastic properties, but may be in different extent for different OVX status.

Microdamage initiation and propagation in human trabecular bone was studied. The on-axis specimens were subjected to torsional, compressive and combined torsional and compressive overloading at 2% principal strain level. The combined overloading gave rise to 60.52% more microcrack density than torsional overloading and three times greater than compressive overloading. Both the density of induced and propagating microdamage depended on the density of pre-existing microdamage, suggesting that the pre-existing microdamage not only provide crack propagating sites, but also indicated high risk to new cracks. Taken together, the results indicate that microdamage burden may contribute to osteoporotic fractures by increasing the risk of further damage formation, which decreases modulus and strength.
Overall, this research provides insight into bone viscoelastic properties and microdamage by studying creep behavior, tissue composition, disease and crack initiation and propagation.