Chapter 76
New Diagnostic and Monitoring Method for Osteoporosis

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ABSTRACT

Osteoporosis is chronic disease affecting most postmenopausal females and 30% of males with biological, behavioral and financial consequences. A non invasive method to assess bone structural integrity is presented, based on in-vitro or in-vivo measurement of bone dynamic characteristics (Modal Damping Factor) by applying vibration excitation in the range of acoustic frequencies, in the form of an acoustic sweep signal. This method has been applied on metallic structures and composites, including bones, and is supported by analytical and arithmetic tool based on model's theory. Experimental MDF results are compared to results acquired with conventional methods for bone quality assessment and show impressive correlations between damping factor and indices of bone quality in an advantageous manner. Evaluation of these research findings strengthens the potential of the proposed method to consist a valuable assessment tool for diagnosis and monitoring of bone integrity, in metabolic bone diseases, especially osteoporosis.

INTRODUCTION

A new non-destructive method is presented for bone integrity assessment. The method is based on measurement of bone dynamic characteristics (Modal Damping Factor - MDF), has been already applied on metallic structures and composites, including bones and has shown the potential to become a valuable assessment tool for monitoring bone structural changes. The measured characteristics are directly related with stress concentration due to discontinuities in the material of the bone, such as changes in porosity due to osteopenia. In turn, stress concentration is known to cause fracture in such materials. The method is supported by analytical and arithmetic tool based on model's theory. MDF experimental results are compared to data acquired with conventional methods for bone quality assessment. The comparison shows that changes in MDF correlate satisfactorily with all other measured conventional characteristics, something that does not always happen among them. The results of this research strengthen the potential of MDF method to consist a valuable assessment tool for in-vivo monitoring and diagnosis of bone integrity and osteoporosis.

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BACKGROUND

Bone is a composite formed by the mineralization of an organic matrix (largely collagen type I) by the deposition and growth of a carbonated calcium phosphate mineral (bio apatite), highly resembling hydroxy-apatite, $Ca_{10}(PO_4)_6(OH)_2$, within the matrix. Bioapatite provides the biomechanical properties needed for body support and movement, enabling it also to withstand stresses. Failure of mineralization of newly formed or bone remodeling results in an excess of unmineralized bone matrix (called osteoid tissue) comprising the clinical entity of osteomalacia. Main causative mechanisms are vitamin D deficiency and phosphate depletion (Mundy, 1995). In contrary, the decrease in the amount of normally mineralized bone and the disturbance in bone micro architecture (which increases the risk of fractures occurring in the absence of trauma or in response to trivial trauma) are known as osteoporosis (Melton, 1998). Some clinicians use the generic term osteopenia, which describes decreased mineralized bone mass with no reference in particular bone pathology responsible for the decrease in bone mineral density (Mundy, 1995). Osteopenia may be due to osteomalacia, primary hyperparathyroidism or malignant diseases, all of which may cause generalized bone loss.

Bone Mineral Density (BMD) is recognized as the most important single determinant of fracture risk in populations with bone disease (Cumings, 1990, 1993). Accordingly, measurement of bone density is currently the mainstay for the diagnosis and monitoring of osteoporosis, osteomalacia or osteopenia in general. However, many other skeletal and extraskeletal factors and conditions may influence the risk of developing a fracture, as in particular, a hip fracture (Cumings, 1995). Therefore, the ability of bone to withstand traumatic insults is the result of both the amount of mineralized tissue per unit of volume (density), and many other factors that are commonly referred to as bone quality. Loss of trabecular connectivity is considered one of the critical factors that weaken bone strength in osteoporosis (Parfitt, 1987). Although data are still limited, this architectural abnormality may independently constitute an important factor for predicting fracture risk (Kleerekoper, 1985).

In vitro studies have shown that bone strength is correlated not only to mineral content, but also to the modulus of elasticity (Petersen, 1977; Steele, 1984, 1988) and the natural frequency of bone vibration as Doemland (1979), Hiriyama (1979), Lewis (1975), Markey (1974), and Campbell (1971) discussed. Thus, transmission techniques based on ultrasound attenuation or velocity, have been developed as a clinical tool (Heaney, 1989).

It is known that the degradation of materials structural integrity is related to the decrease of their strength. The evaluation of the effect of these defects on the strength of materials, especially in fatigue and brittle fracture, is a very important consideration in engineering technology. Pre-existing pores, cracks and flaws, in addition to those produced during service due to fatigue or static loading, influence the behavior of a material towards mechanical stresses, namely, its fracture toughness and reliability, as well as other physical properties (optical, thermal and electrical conductivities, etc.).

Damping is a very important material property when dealing with vibrating structures from the point of view of vibration isolation in many applications: bearings, filters, aircraft parts, and generally structures made of porous materials or facing crack development. For a material there are many mechanisms generating damping, most of which contribute significantly to the total damping only over a certain small range of frequency, temperature or stress (Lazan, 1968).

In a material subjected to stress field there are always temperature fluctuations throughout its volume due to thermoelastic effect. The resulting irreversible heat conduction leads to entropy production, the cause of thermodynamic damping, which is due to thermal distribution within the material, is linearly