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Editorial

Muscle Strength and Skeletal Competence: Implications for Early Prophylaxis

The erosion of the bony skeleton, which afflicts people worldwide, requires many decades of bone loss before it manifests as the skeletal fragility of osteoporotic fractures. Because of the multi-decade evolvement of osteoporosis, specific strategies, differentially adapted to the issues of the periods under consideration, can be selectively applied to the control of the condition. The treatment of symptomatic osteoporosis, encountered primarily in the elderly, should preferably differ from the treatment designed to stem the perimenopausal acceleration of bone loss, and both should differ from strategies designed to support the optimal maturation and subsequent preservation of the skeletal mass, as a safeguard against the inevitable decrements of old age.

No agent or combination of agents has yet emerged that will replete the eroded bone mass of the osteoporotic skeleton [1]. Thus, the aim of the therapeutic intervention in the clinically overt *primary osteoporosis* of late adulthood and old age is currently limited to the alleviation of discomfort and the containment of further skeletal deterioration. On the other hand, during the *perimenopausal period* the therapeutic issues revolve around the accelerated rate of bone loss, brought about by the withdrawal of ovarian hormones from the regulatory systems of the organism. Estrogen replacement became, therefore, the target of treatment for this period of the life cycle. Though effective in counteracting the accelerated postmenopausal bone loss, estrogen treatment is not risk free: estrogen as an endogenous constituent has receptors in many tissues, which by interacting with the exogenously administered hormones may generate undesirable side effects. The currently prevalent view, therefore, is that estrogen treatment should be limited to women who are at an increased risk of fractures [1] on account of family history, predisposing medical problems, and/or unfavorable life-style elements.

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Although early postmenopausal estrogen treatment can be correctly viewed as prophylaxis, it is initiated after a variable period of decline from the peak skeletal mass (PSM) reached in early adulthood [2]. Yet, for optimal effectiveness, prophylactic measures should reach earlier into the life cycle in order to maximize the maturation of the skeleton and subsequently preserve it. An optimized PSM provides a protective margin for later years when age-related decrements tend to exact penalties from skeletal balances. By definition, early prophylaxis must rely on modifications of life-style elements because pharmacologic intervention without an imminent threat to health is not feasible. The two life-style elements that can impact the development and maintenance of a competent skeleton are adequate consumption of calcium and adequate levels of mechanical loading.

The Role of Calcium

Since two-thirds of bone by weight is composed of mineral, of which calcium constitutes a constant fraction of 38%, and since serum calcium homeostasis takes precedence over skeletal homeostasis, an adequate consumption of calcium is an irreducible requirement for an optimal skeletal growth as well as for the subsequent maintenance of its structural competence. Yet, consumption of excessive amounts of calcium per se will apparently not prevent the postmenopausal erosion of the skeletal mass. This was shown in the Copenhagen study in which women in the early stages of menopause had their diets supplemented with 2,000 mg of calcium per day for 2 years without experiencing decrements in the rates of trabecular bone loss [3]. One can conceptualize, therefore, that calcium functions in an "*enabling*" mode in that it permits the skeleton to respond appropriately to genetic, physiologic, and mechanical cues.

The Role of Mechanical Loading

It appears that in a supportive metabolic environment the skeleton can optimize its genetically proscribed bone mass only through an adaptive remodeling in response to the dynamic loading by muscle contractions. One of the objectives of skeletal remodeling is to produce a mass and an arrangement of bone tissue that is capable of bearing functional loads without suffering incapacitating trauma [4]. Since skeletal loading is mediated by muscle contractions, it follows that muscles of high strength relative to sex, age, and body habitus would indicate that the remodeling processes are habitually influenced by high levels of mechanical loading, and weak muscles would indicate the obverse. It is therefore submitted that the development of normative data for muscle strength may provide the standards for the assessment of the adequacy of mechanical loading, and by extension, of the prevailing balances in skeletal remodeling, and thus guide the design of prophylactic measures to be initiated prior to the onset of bone losses.

The above assumptions are based on a synthesis of published data that document (1) the skeletal effects of mechanical loading by physical activity, (2) the comparable changes in muscle and bone parameters induced under diverse clinical and experimental settings, and (3) the comparable rates of decrements observed in muscles and bones in the course of the aging process.

Collectively, these studies have shown that:

1. Skeletal adaptation to mechanical loading is achieved primarily by adjustments of bone mass and of bone geometry, whereas the qualitative material properties of the bone remain essentially unchanged; moreover, it is the dynamic and not the static loading that provides the functional stimulus to remodeling.

2. Mechanical loading below the habitual level for the given organism causes bone loss, and conversely, bone accretion is induced when the mechanical loading rises above the habitual level [4]. Thus, paucity of mechanical loading, which can be caused by confinement to bed by paralysis or by lack of gravity in space is associated with severe losses of bone mass [5]. By contrast, a broad range of physical activities, extending from moderate exercises to rigorous athletic activities, have been found not only to protect against bone losses but even cause increases in bone mass [6]. Yet, despite the many studies, the parameters of effective exercise programs for use in osteoporosis prophylaxis still need to be defined [6]. Moreover, an examination of generalized and distant skeletal effects of exercise as distinct from the well-documented, site-specific effects should be further explored [7, 8].

3. Since skeletal loading by physical activity is mediated by muscle contractions, muscle parameters have been shown to correlate with the parameters of the bony skeleton. This was demonstrated in broadly differing experimental settings and will be selectively illustrated with three examples. Significant correlations were found (1) between the isometric strength of back extensors and the bone mineral content of the lumbar vertebrae [9] and (2) in autopsy samples, between the weight of the psoas muscle and the ash weight of the third lumbar vertebral body [10]; moreover, (3) aerobic dancing and walking were found to increase both the arm strength as well as the cross-sectional moment of inertia of the ulna [8]. The above findings were interpreted to mean that muscle mass and/or muscle strength reflect the forces the muscle exerts on the bone to which it is attached, and that muscle is, therefore, an important determinant of bone. This conclusion is further reinforced by the parallel decrements of muscle and bone parameters observed in the course of the aging process. This is most convincingly illustrated by the constancy of ratio of total body calcium to total body potassium (TBCa/TBK) maintained by women throughout their adult life-span, despite a 30–40% reduction in bone mass by the age of 80 [11].

The findings, that contracting muscles are important determinants of the mass, the geometry, and the strength of the bones to which they are attached, have a direct bearing on the proposed strategy for early prophylaxis.

Strategy for Early Prophylaxis

Adult bone loss, the precursor of osteoporosis, is a polyfactorially induced phenomenon because of the key role the skeleton plays in calcium metabolism. Risk factors that contribute to a negative calcium balance include heavy smoking, excessive coffee consumption, and alcohol intake as well as a variety of diseases and drug treatments that impinge on calcium bioavailability [11]. Barring the above risk factors, two key elements emerge as the mainstay of early prophylaxis: an adequate calcium consumption and an adequate mechanical loading of the skeleton. Moreover, an early intervention that precedes the onset of bone losses is of essence, because effective prophylaxis, instituted early, optimally preserves the PSM and thus provides a maximal leeway against the inevitable physiological decrements of old age.

The levels of adequate calcium intake have been defined for the various stages of the life cycle. Compliance with the relevant RDAs can be roughly determined with relative ease, because calcium is found largely in milk and milk products. In cases of nutritional inadequacy of calcium consumption, calcium supplementation does not present undue difficulties.

The issue of physical activity is more complex. In all technologically advanced countries, physical activity has been largely eliminated from occupational pursuits and mechanized transportation and the great distances involved in negotiating daily activities has reduced opportunities for walking. Moreover, passive viewing of the easily accessible TV entertainment has replaced, for large segments of the population, participation in more active pastimes. Consequently, adequate levels of physical activity can be introduced into the modern life-style largely through a determined dedication of leisure time to physically active pursuits.

For the vast majority of people, a pursuit of physical activity clearly does not represent an attractive option, and if anything, it too often conflicts with the natural preferences for design of leisure time. However, should muscle strength norms, adjusted for age, sex, and body habitus, become available and should muscle strength measures become a standard component of the medical checkup for adults, they could be used as an indicator of the habitual level of physical activity. Popularly publicized principles of maintaining wellness could then incorporate the inadequacy of mechanical loading on the skeleton in addition to such standard risk factors as obesity and high blood pressure, and combine it with emphasis on the importance of adequate calcium consumption. The advantage of this kind of strategy is that it could be applied as early as age 30–35, the presumed time of the attainment of the PSM [2]. This would tend to optimize the maintenance of PSM, and thus would improve the skeletal odds against aging-related physiologic and pathologic decrements that can impinge deleteriously on skeletal balances.

The benefits stemming from muscle strength measures as indicators of the habitual level of physical activity will by no means be limited to osteoporosis. It is believed that some of the functional decrements attributed to aging can be partially ascribed to sedentary life-styles, and that exercise can significantly improve a broad range of functional capacities in the aged. Moreover, increased levels of physical activity have been shown to be associated with reduced risks of coronary heart disease, peripheral arterial insufficiency, noninsulin-dependent diabetes, cancer, and depression [12]. An association between reduced muscle strength and an increased incidence of low back pain and falls has also been documented.

Yet, despite the clear benefits of physical activity, exercise added to a busy life-style is viewed by many as intrusive and burdensome. Normative values of muscle strength could therefore be used as a tool of persuasion to indicate the medical necessity for increasing physical activity. The high prevalence of osteoporosis among the aged, who constitute the fastest growing segment of the population, justifies the considerable effort required for establishing muscle strength norms. The benefits, as indicated above, will be far reaching and not limited solely to the skeleton.

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