CHAPTER 39

Exercise Prescription for People with Osteoporosis

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EPIDEMIOLOGY

Osteoporosis is a skeletal disorder characterized by compromised bone strength that results in an increased susceptibility to fracture (35,85). It is estimated that more than 200 million people worldwide currently have osteoporosis (20), and the prevalence is expected to increase with the increasing lifespan and aging population (21). In the United States alone, an estimated 44 million individuals (55% of the population older than 50 years) have low bone mass or osteoporosis. This number is predicted to increase to 61.4 million by the year 2020 (82). Because osteoporosis is seen mainly as a disease that affects women, men often go undiagnosed and untreated, yet men are increasingly at risk for osteoporotic fractures.

The clinical relevance of osteoporosis is the dramatic increase in risk of fracture. More than 1.5 million fractures are associated with osteoporosis each year. **Osteoporotic fractures** are low-trauma fractures that occur with forces generated by a fall from a standing height or lower and are most common at the spine, hip, and wrist. Regardless of fracture site, adults who fracture are at much greater risk of fracturing again at any location (25). It is estimated that one in two women and one in four men

> > > KEY TERMS

Bone balance: The amount of bone formed in a remodeling pit compared to the amount resorbed. When the bone balance is zero, no bone is lost. With menopause and advancing age, bone balance becomes negative and bone is lost.

Bone mineral density (BMD): A surrogate measure of bone strength that is typically measured by dual-energy x-ray absorptiometry (DXA) as the amount of mineralized tissue per area of bone area expressed in $g \cdot cm^{-2}$.

Cortical bone: Dense bone that comprises the shaft of long bones and provides a protective shell around the ends of long bones and vertebrae.

Modeling: Formation or resorption of bone along a surface that changes the size and shape of bones in response to bone growth.

Mechanotransduction: The process by which bone cells convert mechanical stimuli (i.e. load from physical activity) into a chemical response.

Osteoblasts: Cells involved in the formation and mineralization of new bone.

Osteoclasts: Multinucleated cells involved in resorbing old, damaged, or excess bone.

Osteocytes: Osteoblasts that become entombed in the matrix they helped secrete. These are thought to be the main mechanosensory cells of the skeleton.

Osteopenia: Low bone mass; designated as a bone density between 1.0 and 2.5 standard deviations less than the mean peak value for young normal adults.

Osteoporosis: A skeletal disorder characterized by compromised bone strength that results in an increased susceptibility to fracture; diagnosed by a bone mineral density more than 2.5 standard deviations less than the mean peak value for young adults.

Osteoporotic fracture: A low-trauma fracture that occurs with trauma generated by a fall from a standing height or lower; most common at the spine, hip, and wrist.

Remodeling: A dynamic process of bone resorption and subsequent formation that occurs throughout life.

Strain: The deformation of a material; refers to the relative change in bone length in response to an applied load.

Trabecular bone: Porous bone found in flat bones, the ends of long bones, and in cuboidal bones (e.g., vertebrae).

older than 50 years of age will suffer from an osteoporotic-related fracture in their lifetime. To put this in perspective, a woman's risk of hip fracture is equal to her combined risk of breast, uterine, and ovarian cancers (82), and men have a greater risk of developing osteoporosis than prostate cancer. Hip fractures are considered to be the most devastating consequences of osteoporosis because they are associated with severe disability and increased mortality (77). Furthermore, the economic burden of hip fractures is substantial, with an estimated worldwide annual cost of $131.5 billion (42). The combination of all osteoporotic fractures cost the U.S. healthcare system approximately $17 billion per year, and these annual costs are projected to reach $50 billion by the year 2040 (59).

Osteoporosis is a silent disease: if not detected early, fractures may occur without warning because of reduced bone strength and increased load on the bone at a given time. Therefore, much attention is focused on early prevention, detection, and treatment of osteoporosis. The purpose of this chapter is to provide a brief overview of the pathogenesis, diagnosis, risk assessment, prevention, and treatment of osteoporosis—with special emphasis placed on the role of exercise in building and maintaining a strong skeleton and thereby offsetting skeletal fragility.

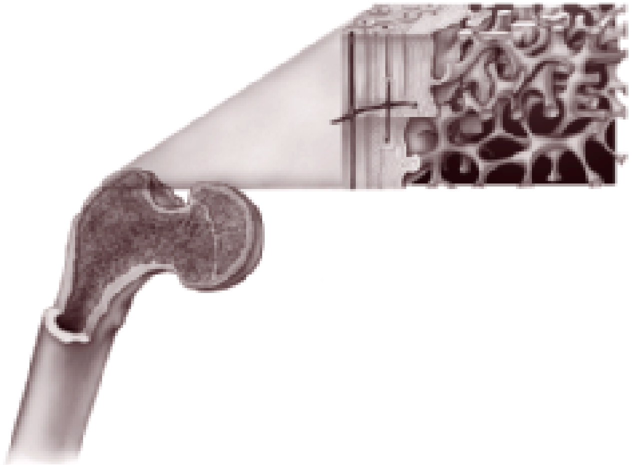

FIGURE 39-1. Bone is a dynamic tissue that is vascularized and innervated. *Cortical* bone is dense and stiff and makes up the shaft of long bones. Cortical bone also provides a shell of protection around *trabecular* bone, which is more porous and flexible and is found at the ends of long bones and in vertebrae. The external surface of bone is called the *periosteal* surface. The inner surface of long bones lining the medullary canal (containing bone marrow) is called the *endocortical* surface. The distance between the endocortical and periosteal surfaces in any given cross section is referred to as the *cortical thickness*. (Adapted from DAMS.)

BONE PHYSIOLOGY

Bone is a bisphasic material with crystals of hydroxyapatite (calcium-phosphate mineral) incorporated in a collagen matrix. The collagen gives bone flexible properties, and the mineral adds stiffness. This material is fashioned into two types of bone. **Cortical bone** (also referred to as compact bone) is dense and stiff and comprises the shaft of long bones as well as provides a shell of protection around **trabecular bone** (Fig. 39-1). Trabecular bone (also referred to as *cancellous* or *spongy bone*) is more porous and flexible and is found in flat bones, the ends of long bones, and in cuboidal bones (e.g., vertebrae). In trabecular bone, the bone material is in the form of plates and struts called *trabeculae*.

The characteristics of bone that determine its strength include the *quantity* of bone material present (the "mass" component), the *quality* of the material (i.e., material properties), and the distribution of the material in space (*structure* or *geometry*). These factors are determined by the dynamic cellular activities known as bone **modeling** and **remodeling**, which are regulated by bone's hormonal and mechanical environments. Modeling is the *independent* action of **osteoclasts** (bone-resorbing cells) and **osteoblasts** (bone-forming cells) on the surfaces of bone, whereby new bone is added along some surfaces and removed from others. Modeling affects the size and shape of bones and is especially important for reshaping long bones as they grow in length during adolescence or in response to changing mechanical load throughout life. Remodeling (Fig. 39-2) is a localized process that in-

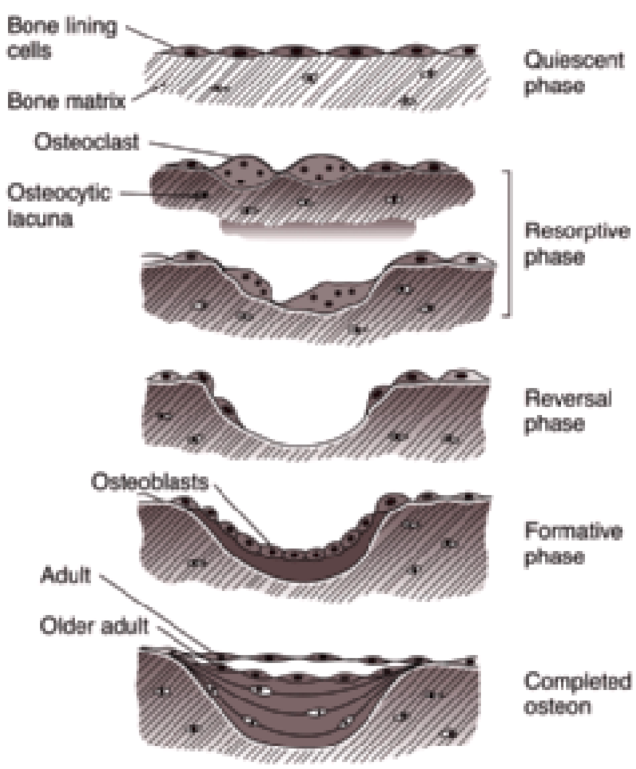

FIGURE 39-2. Bone remodeling is the *coupled* actions of osteoclasts and osteoblasts whereby a portion of older bone is resorbed by osteoclasts and replaced with newly formed bone by osteoblasts. The new bone begins as unmineralized matrix (osteoid). Eventually, the osteoid incorporates mineral. (From DAMS.)

volves the *coupled* action of osteoclasts and osteoblasts, in which osteoclasts first resorb a pit of older bone and osteoblasts are subsequently recruited to the site to form and mineralize new bone. This process happens throughout the lifespan and occurs diffusely throughout the skeleton. Like any material subjected to repetitive loading, fatigue damage is incurred. However, unlike inert materials, bone is able to replace damaged bone with new bone through the process of remodeling (87).

PATHOPHYSIOLOGY

Although osteoporosis denotes skeletal fragility, osteoporotic fractures are the result of *both* skeletal fragility and increased rate of falls. Osteoporotic fractures are a function of the reduced strength of a bone and the load on the bone at any given time, where the load must exceed bone strength for the fracture to occur. A majority of hip and wrist fractures occur as a consequence of falling. Thus, factors influencing both bone strength *and* risk of falling are important for fracture prevention.

SKELETAL FRAGILITY

Many skeletal characteristics contribute to bone strength, and consequently, bone fragility, including the quantity of bone material present, the quality of the material, and the distribution of the material within the bone structure.

Bone Quantity

Bone "quantity" refers to the amount of bone material present (i.e., the bone mass). The average pattern of change in bone mass across the lifespan is displayed graphically in Figure 39-3. The actual pattern of bone change is more dynamic than shown, both during growth and in later life. For example, approximately 26% of total adult bone mass is accrued in a 2-year period during adolescence (9). This is approximately equivalent to the amount lost in later life (26). Overall, global bone formation continues at a faster pace than bone resorption until peak bone mineral accretion is attained sometime in the second or third decade (depending on site, region, and gender). In later life, the process of bone formation in each remodeling site no longer equals the bone that was resorbed, and thus, a small amount of bone is lost with each new remodeling cycle. This is referred to as a negative **bone balance**.

In later life, gonadal hormones (testosterone, estrogen) decrease in both men and women. Estrogen suppresses activation of new remodeling cycles, and thus, low estrogen levels partially contribute to an increased rate of remodeling (108). As resorption precedes formation in the process of remodeling, and formation and subsequent mineralization are time-intensive processes, an increase in the rate of remodeling results in temporary decreases in bone mass. Although temporary losses in bone mass lead to a transient increase in bone fragility, increased rates of remodeling with a negative bone balance lead to sustained bone loss of approximately 9% to 13% (91) during the first 5 years after menopause. Bone turnover eventually slows to a rate similar to premenopausal years. Men also experience age-related bone loss but without the rapid period of loss (16).

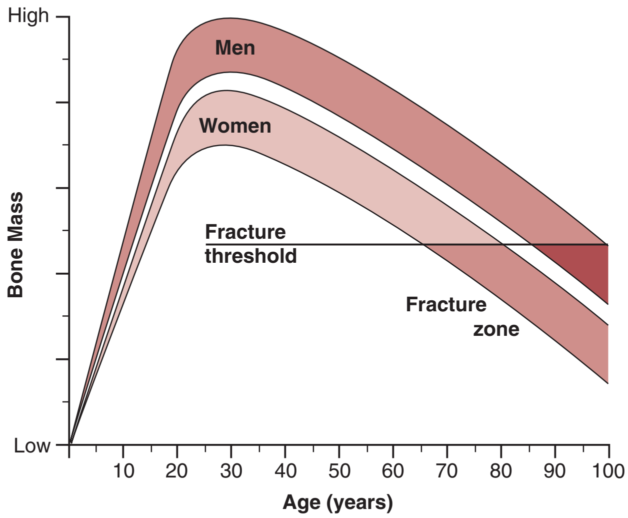

FIGURE 39-3. Normal pattern of bone mineral accretion and loss throughout the lifespan in men and women. (Permission requested.)

Bone Material Quality

Although the amount of bone in the human skeleton decreases with menopause and advancing age, there is evidence that properties of the remaining bone material may change with age in a way that increases susceptibility to fracture. Bone material from older individuals is less able to absorb energy before failure, likely because of increased mean tissue mineralization and changes in collagen properties that are associated with advancing age (22). Bone, like all loaded structural materials, is subject to fatigue damage in the form of microcracks that increase in number and length with advancing age (113). Microdamage accumulation is associated with reduced bone strength (81).

Bone Structure

Another important component of bone strength is the structure and geometry of bone—that is, how the material is distributed in space. Subtle changes in cross-sectional geometry can markedly increase bone strength with little or no changes in bone mass or density. Structural differences in cortical bone geometry may partially explain some of the differences in fracture rates between men and women. During growth, boys have greater gains in periosteal (outer) diameter, while girls have a narrowing of the endocortical (inner) surface, resulting in a greater overall bone size in boys that remains throughout life (33,99). In later life, bone is lost primarily from the endosteal surfaces (inner surface of long bones and intracortical surfaces within the cortex). Thus, the cortex becomes more porous and the cortices become thinner and more fragile. To offset these losses, bone may be added to the periosteum (outside surface of bone), thereby increasing the diameter of bone and maintaining the strength of the structure in bending (13,100,101). However, as more bone is resorbed from the endocortical surface than is formed on the periosteal surface, the cortices continue to thin, becoming fragile and more likely to fracture.

Microarchitecture of trabecular bone is also an important contributor to skeletal fragility (50). For example, if the resorption phase of remodeling is too aggressive, as is seen at menopause and thereafter, trabeculae may be penetrated and entire trabecular elements lost (Fig. 39-4). In these cases, the loss in structural strength is exaggerated far out of proportion to the amount of bone lost (92). Furthermore, trabeculae that remain intact may be thinned by excessive remodeling, creating a weakness in the ability to bear loads.

FALLS

Although skeletal fragility increases susceptibility to fracture, it would be of little concern if damaging loads, such as those generated in a fall, were prevented. A majority of hip fractures occur after a sideways fall and landing on the hip (36,110). The incidence of falls increases with age because several sensory systems that control posture (vestibular, visual, and somasensory) become compromised with advancing age. Furthermore, muscle mass and strength, which prevent instability and correct imbalance, decline 30%–50% between the ages of 30 and 80 (51).

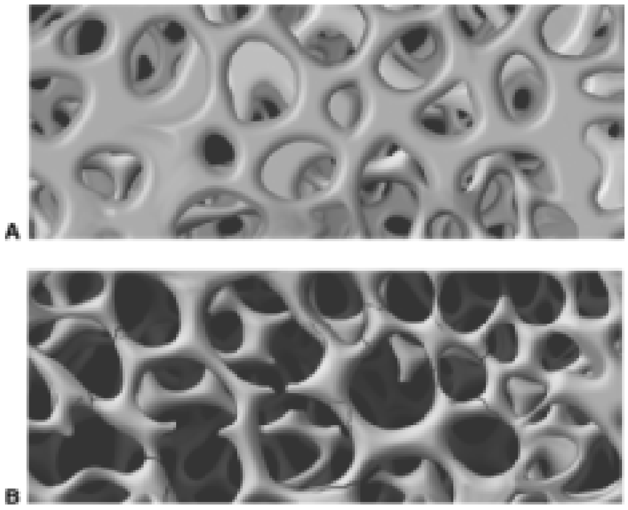

FIGURE 39-4. Slice of trabecular bone in normal **(A)** and osteoporotic **(B)** individual showing loss of trabecular connectivity and increased microcracks with ageing. (From DAMS.)

DIAGNOSIS OF OSTEOPOROSIS

There is currently no direct method to measure bone strength noninvasively. Therefore, identification of individuals with osteoporosis relies on the use of noninvasive technology to measure surrogates of bone strength. A measurement of **bone mineral density** (BMD) by dual energy x-ray absorptiometry (DXA) is the primary factor involved in the diagnosis of osteoporosis (1). BMD represents the amount of bone per unit *area* and is currently the most commonly used surrogate of bone strength in clinical settings. The World Health Organization (WHO) has defined **osteopenia** (low bone mass) as a site-specific bone density between 1.0 and 2.5 standard deviations less than the mean for young white adult women, and **osteoporosis** as a bone density that is 2.5 standard deviations less than the mean for young white adult women (85,112). Expressing an individual's BMD relative to the young adult mean is referred to as a T-score (i.e., $T \leq 2.5 =$ osteoporosis). These criteria were developed based on population data of primarily white women. Controversy exists among experts as to how this criterion applies to men, children, and various ethnic groups (5,85). Furthermore, as these categories were derived from BMD data at the hip, the application of these criteria to other skeletal sites is questionable (44,45). Despite these issues, BMD measurements have been shown to predict 60%–70% of a patient's risk for fracture (80), therefore making them better predictors of fracture than the measurement of lipids in predicting heart disease (44,80,112).

New software such as the Hip Structure Analysis Program and new technology such as quantitative computed tomography (QCT), peripheral QCT (pQCT), and magnetic resonance imaging (MRI) are used to better assess important components of bone strength such as bone geometry and cortical and trabecular volumetric density and, therefore, provide better estimates of bone strength. However, these technologies are currently used primarily in research settings, and their clinical utility is not yet clearly established.

RISK FACTORS FOR OSTEOPOROTIC FRACTURE

Despite the appreciable capabilities of BMD measurements in predicting fracture, combining multiple risk factor assessment with a measure of BMD may more accurately determine overall fracture risk (44,80,112). This notion is strengthened by the observation that the presence of multiple risk factors is a better predictor of hip fracture than low bone density alone (44). Many risk

BOX 39.1 Osteofit: A Community-Based Physical Activity Program for Women with Osteoporosis

1.7.7-ES: Prescribe exercise using nontraditional modalities (e.g., bench stepping, elastic bands, isodynamic exercise, water aerobics, yoga, tai chi, etc.) for individuals with cardiovascular, pulomonary, or metabolic diseases.

1.7.17-ES: Design strength and flexibility programs for individuals with cardiovascular, pulmonary, and metabolic diseases, the elderly, and children.

AN EFFECTIVE EXERCISE PROGRAM IN OSTEOPOROTIC WOMEN: OSTEOFIT

Osteofit is an exercise-based program designed by the staff of the British Columbia Women's Hospital Centre Osteoporosis Program in Vancouver, Canada (http://www.osteofit.org/) (51). In a study of the efficacy of Osteofit in women aged 65–85 with osteoporosis, the women who completed the Osteofit program had (a) increased ability to undertake ADLs, (b) decreased back pain, (c) increased general health, (d) decreased fear of falling, and (e) improved falls risk profiles (18, 61). Importantly, the benefits of this program have been shown to persist even 1 year postintervention (62). This community-based program for women and men with osteoporosis aims to reduce participant's risk of falling and improve their functional ability, thereby enhancing quality of life. It differs from typical senior exercise classes by specifically targeting posture, balance, gait, coordination, and hip and trunk stabilization rather than general aerobic fitness. A typical class consists of a warm-up, a workout, and a relaxation component, all of which are outlined here (Fig. 39-5).

Warm-up: The general 10- to 15-minute warm-up is done to music and commences with gentle range of motion exercises for the major joints, which are performed either seated or standing. Static stretching exercises are usually not included. The warm-up ends with walking and simple dance routines with tempos of between 110 and 126 beats per minute so that participants can remain in control.

Workout: The workout consists of strengthening and stretching exercises intended to improve posture by combating medially rotated shoulders, chin protrusion (excessive cervical extension), thoracic kyphosis, and loss of lumbar lordosis. Exercises to improve balance and coordination may progress from heel raises and toe pulls to the mildly challenging two-legged heel-toe rock and the more challenging tandem walks and obstacle courses. Hip stabilization is trained using leg exercises (e.g., hip abduction and extension) or balance exercises. Trunk stabilization is addressed when the participant is cued and positioned to do all standing exercises with resistance for the arms (e.g., biceps curls) and shoulders (e.g., lateral arm raises). The abdominal muscles strengthened in their function as stabilizers rather than as prime movers. Exercises to improve functional ability include chair squats and getting up and down from the floor. Exercises are arranged so that upper and lower body activities are alternated to reduce the risk of tendon pain. If the class includes more than one set of an exercise, the sets are separated by a short rest period. Repetitions are kept to between 8 and 16, and weights are relatively light so that participants do not work to fatigue with each set. The exercises are arranged so that the less strenuous exercises, such as hamstring stretching, are at the end of the workout.

Relaxation: The last few minutes of the class are devoted to relaxation techniques such as deep breathing, progressive muscle tensing and relaxing, and visualizations to a background of soft music and/or nature sounds.

factors for osteoporosis and fracture have been identified, including age, family history of fracture, previous fracture, physical inactivity, and medication use, among others (Table 39-1). Advancing age is perhaps one of the best predictors of fracture because the risk of a hip fracture increases three to six times from 50 to 80 years, independent of BMD status (21,46).

Because of estrogen's effect on suppression of remodeling, hypogonadism is an important risk factor in both men and women. In men, hypogonadism can be caused by several conditions including hypopituitarism, hyperprolactinemia, overtraining, and inadequate energy intake. In young women, hypogonadism secondary to amenorrhea may be associated with inadequate energy intake (67). When taken to the extreme, the so-called female athlete triad syndrome (amenorrhea, disordered eating, and osteoporosis) is thought to be associated with increased risk for osteoporosis (2), although the prevalence of all three components of the triad is low (52). Menopause, whether spontaneous or due to surgery, chemotherapy, or radiotherapy, is also associated with increased risk of osteoporosis and fracture.

History of fracture is another important risk factor for subsequent fragility fractures, with a twofold increase in

FIGURE 39-5. Women participating in the Osteofit class community-based program for falls prevention that includes strength and agility training. (Photos courtesy of K. Khan.)

risk of hip fracture following a previous hip or spinal fracture (53). Several medications can increase risk of osteoporosis, including glucocorticoids, which result in greater losses in spine bone mass. However, bone loss can be reduced by use of inhaled glucocorticoid therapy (109). Use of medications such as anticonvulsants, glucocorticosteroids and adrenocorticotropin, gonadotropin-releasing hormone agonists, immunosup- pressants, and heparin (long term) have also been associated with osteoporosis and fracture risk (83). Furthermore, several conditions are associated with secondary osteoporosis, including hyperthyroidism and gastric surgery (44).

As discussed previously, factors related to risk of falls have important considerations. Exercise professionals should pay close attention to neuromuscular deficits, balance, and coordination in older individuals, particularly those with osteopenia or osteoporosis, who would be at increased risk of fracture in the case of a fall. Improving these deficits is equally (if not more) important in older individuals than attempting to increase bone integrity.

TABLE 39-1. RISK FACTORS FOR OSTEOPOROTIC FRACTURES

AGE	NEUROMUSCULAR DISORDERS	EXCESSIVE ALCOHOL CONSUMPTION
Previous fragility fracture	**Cigarette smoking**	Long-term immobilization
Glucocorticoid therapy	**Low body weight**	Low dietary calcium intake
High bone turnover	Premature menopause	Vitamin D deficiency
Family history of hip fracture	Primary or secondary amenorrhoea	Female sex
Poor visual acuity	Primary or secondary hypogonadism in men	Asian or white ethnic origin

Bold text indicates characteristics that capture aspects of fracture risk over and above that provided by bone mineral density. Adapted from Kanis, 2002 (14).

Falls are correlated with physiological impairments associated with aging such as slow reaction time, loss of balance, and muscular weakness (17,65). Psychological factors, such as fear of falling, are also associated with falls (17). Other risk factors associated with fall risk include orthostatic hypotension, Parkinson disease, stroke, depression, epilepsy, eye diseases, osteoarthritis, peripheral neuropathy, delirium, anemia, diabetes mellitus, depression, cognitive impairment, vitamin D deficiency, syncope, and many medications. Therefore, these factors should all be considered when determining risk, treatment, and preventative strategies regarding osteoporotic fracture (51).

CLINICAL MANAGEMENT

Although prevention of osteoporosis is important, once an individual is diagnosed with the disease, attention is turned to treatment to offset initial and subsequent fractures. Management strategies involve both pharmacological therapy and lifestyle modifications.

PHARMACOLOGICAL THERAPY

1.5.3-ES: Recognize medications associated in the clinical setting, their indications for care, and their effects at rest and during exercise (i.e., beta-blockers, nitrates, calcium channel blockers, *Digitalis*, diuretics, vasodilators, antiarrhythmic agents, brochodilators, antilipemics, psychotrophics, nicotine, antihistimes, over-the-counter cold medications, thyroid medications, alcohol, hypoglycemic agents, blood modifiers, pentoxifylline, antigout medications, and anorexiants/diet pills).

Several pharmacological agents (listed in Table 39-2) have been approved by the U.S. Food and Drug Administration (FDA) for the treatment of osteoporosis. These agents can be categorized by whether they act on remodeling (antiremodeling drugs) or directly on formation (anabolic drugs). Antiremodeling agents include bisphosphonates, salmon calcitonin, hormone replacement therapy (HRT), and selective estrogen receptor modulators (SERMs, raloxifene). These drugs act by suppressing the resorption phase of the remodeling cycle and thus allow existing cavities to fill, resulting in an increase in bone density. Also, by suppressing resorption, these agents can reduce loss of connectivity and trabecular thinning associated with menopause and aging. One of the major hormones regulating calcium homeostasis is parathyroid hormone (PTH), which is secreted in response to falling serum calcium levels. PTH helps to regulate serum calcium levels by (a) stimulating bone resorption in

TABLE 39-2. MEDICAL THERAPIES AVAILABLE FOR THE TREATMENT OR PREVENTION OF OSTEOPOROSIS

DRUG CLASS	NAME OF DRUG	BRAND NAME
Estrogens[a]	Estrone sulfate	Ogen
	Conjugated estrogen	Premarin
	Transdermal estrogen	Estraderm
	Estropipate	Ortho-Est
	Esterified estrogen	Estratab
	Conjugated estrogen + medroxyprogestrone acetate[b]	Premphase
		PremPro
		Activella
Calcitonin[c]	Synthetic salmon calcitonin	MiaCalcin
		Calcimar
Bisphosphonates	Alendronate[d]	Fosamax
	Risedronate[d]	Actonel
	Etidronate[e]	Didronel
SERMs	Raloxifene[f]	Evista
	Tamoxifene	Nolvadex
Others	Isoflavones (natural flavonoids)	
	Tibolone or ipriflavone (synthetic flavonoids)	
	Calcitriol or other vitamin d metabolites	
	Teriparatide[f] or other parathyroid hormones[g]	
	Sodium fluoride[g]	

SERM, selective estrogen receptor modulator.

[a]All estrogens have FDA approval for prevention of osteoporosis, but only Premarin is approved for treatment.

[b]Premphase, PremPro, and Activella are estrogen and progesterone taken in combination. Premphase and PremPro are FDA approved for the treatment of osteoporosis; Activella is approved for prevention of osteoporosis.

[c]Both calcitonins are approved for prevention, but only MiaCalcin is approved for treatment of osteoporosis.

[d]Alendronate and risedronate have FDA approval for both prevention and treatment of osteoporosis. Alendronate is also approved for treatment of osteoporosis in men.

[e]Etidronate has FDA approval but not with an osteoporosis indication in the United States.

[f]FDA-approved treatment of osteoporosis.

[g]Approval pending for an osteoporosis indication.

the presence of adequate vitamin D, (b) increasing intestinal calcium absorption, and (c) enhancing resorption of calcium in the kidney (51). Although PTH can stimulate both bone formation and bone resorption, when administered intermittently it results in net bone formation, and it is thus classified as an anabolic agent (83). Recombinant PTH is an anabolic drug that works by stimulating an increase in osteoblastic bone formation.

Because of the role of estrogen in suppression of osteoclast function and progestins in stimulating osteoblast activity, HRT has been shown to increase BMD at the spine and hip in women during the postmenopausal years when substantial losses are typically observed. However, approximately 40% of women who begin HRT treatment choose to stop taking the medication because of its many side effects (29). Furthermore, HRT is associated with an increased risk of coronary disease, stroke, and breast and ovarian cancer (34). For women unable to take HRT because they are at high risk of ovarian and breast cancer, the SERM raloxifene is a treatment option because it does not stimulate breast or endometrial tissues (58).

LIFESTYLE MODIFICATIONS

Because of difficulty implementing long-term lifestyle changes, the exercise professional can play a large role in facilitating adherence to these changes in the patient with osteoporosis. All postmenopausal women and older men, regardless of fracture risk, should be encouraged to engage in behavior modifications, including adequate calcium (1000–1500 $mg \cdot d^{-1}$) and vitamin D (400–800 $IU \cdot d^{-1}$) intake, regular exercise, smoking cessation, avoidance of excessive alcohol intake, and visual correction to decrease fall risk. Of these lifestyle modifications, exercise is the only one that can simultaneously ameliorate low BMD, augment muscle mass, promote strength gain, and improve dynamic balance—all of which are independent risk factors for fracture (47,84). However, there is currently no direct evidence that exercise reduces the risk of osteoporotic fracture, and there likely will not be until large, well-funded trials are conducted. Nevertheless, clinicians and exercise professionals should embrace the theoretical basis behind exercise prescription in osteoporosis prevention and treatment (51). Exercise prescription for individuals diagnosed with osteoporosis is outlined at the end of the chapter.

EXERCISE AND OSTEOPOROSIS

PHYSIOLOGICAL RESPONSE TO EXERCISE

This section reviews both the acute and chronic physiologic responses to exercise in those with osteoporosis.

Acute Physiological Response

Bone is a dynamic tissue capable of continually adapt to its changing mechanical environment. When a bone is loaded in compression, tension, or torsion, bone tissue is deformed. Deformation of bone tissue, or the relative change in bone length, is referred to as **strain**. Bone tissue strain causes fluid within the bone to move past the cell membrane of **osteocytes**—the bone cells that are embedded throughout bone tissue and are connected with one another, to other bone cells, and with the bone marrow through slender dendritic processes. The current prevailing theory in the bone field is that this fluid flow along the osteocyte and its cell processes causes a release of molecular signals that lead to osteoclast and osteoblast recruitment to (re)model bone to better suit its new mechanical environment. This process of turning a mechanical signal into a biochemical one is called **mechanotransduction**.

Chronic Physiological Response

It has been suggested by Harold Frost that the response of bone to its mechanical environment is controlled by a "mechanostat" that aims to keep bone tissue strain at an optimal level by homeostatically altering bone structure (31). Indeed, when bone is subjected to lower than customary loads (as in space flight and immobilization), bone will adapt by ridding itself of excess mass. Alternately, when bone is subjected to higher loads such as uncustomary exercise, bone will become stronger by altering its structure and increasing in mass. Although mechanotransduction is an acute response to exercise, the adaptation of bone structure through modeling and remodeling takes up to several months to complete. Bone does not respond to exercise by solely adding mass randomly to the skeleton. Rather, from animal studies, it is clear that bone is added where strains are the highest—typically on the periosteal surface in long bones (95). This has the effect of increasing the diameter of long bones, making them stronger in bending, because small increases in bone mass applied to appropriate locations can increase bending strength dramatically.

Remodeling is a process that not only performs the task of removing excess bone or adding bone on trabecular surfaces in youth but also repairs fatigue-damaged bone. With the increase in bone tissue strain that occurs with exercise, damage in the form of microcracks results. This damage is targeted for removal by osteoclasts, and new bone is formed in its place (87). Thus, one of the chronic effects of exercise on the skeleton involves the maintenance of bone strength through targeted remodeling.

Traditional imaging techniques such as DXA are unable to capture fine structural changes in bone and therefore may underestimate the benefits of exercise on the skeleton (41). Furthermore, mineralization of newly formed bone is an ongoing process on the order of months to years. Recall that resorption precedes formation in remodeling; therefore, the effects of exercise on the skeleton may take up to several months to be fully realized.

OSTEOGENIC ACTIVITIES

1.7.16-ES: Describe the principal of specificity as it relates to the mode of exercise testing and training.

Bone responds to loading in a site-specific manner. That is, bone will be added in locations where adequate strain is generated. Thus, to optimize bone health at the hip, for example, physical activity should load the hip region through muscle force or ground reaction forces. Evidence from animal studies suggests that effective exercise programs for bone health should result in high strain rates and unusual strain distributions (i.e., loading in directions the bone is unaccustomed to). In practical terms, an osteogenic (bone-forming) exercise regimen should require high mechanical forces at high rates of force application produced in versatile movements (95,106). New evidence also suggests inserting rest between loading cycles can optimize the bone response to loading (94,105). That is, bone cells seem to saturate after a short loading period. In animal studies, bone loses more than 95% of its mechanosensitivity after only 20 loading cycles (95,106). For example, doing 10 jumps three times per day with 2–4 hours of rest between sets should be more effective for bone health than doing 30 jumps all at one time.

Although generally high magnitude and high strain rate lead to an optimal bone response, strain patterns can be altered to stimulate bone adaptation. For example, low magnitude strains that were otherwise ineffective stimulated an osteogenic response in mature animals if 10 seconds of rest were inserted between loading bouts (105) or if they were generated at a very high frequency (>20 Hz or cycles $\cdot$ s^{-1}) (43,96,97). These novel strain applications have important implications for interventions in individuals with low bone mass such as osteoporotic adults (discussed later).

PHYSICAL ACTIVITY DURING ADOLESCENCE: PREVENTION OF OSTEOPOROSIS

Although osteoporosis is a disease associated with advancing age, there is almost universal consensus that early-life experiences are important in reducing the risk of osteoporosis in later life (26). The amount of bone mineral accrued during growth is recognized as an important predictor of bone mineral status in older adults (26,66). The observation that more than 25% of adult bone mineral is laid down during the 2 years surrounding the age of peak linear growth emphasizes the importance of the adolescent years in optimizing bone mineral accrual (8). It is estimated that as much bone mineral is laid down during this period as an adult will lose from 50 to 80 years of age (4,8). Thus, optimizing bone mineral accrual during the growing years would seem to be an essential ingredient for the prevention of osteoporosis later in life (24).

A number of excellent reviews have all concluded that appropriate physical activity augments bone development (7,10,11,68,74). Retrospective human studies clearly indicate that bone responds more favorably to physical activity undertaken during childhood and adolescence than during adulthood (6,7,28,88). Mechanical loading studies using animal models lend strong support to these human studies (9,23,27,28,37,40,49,56,63,90, 95,106).

Numerous randomized controlled intervention studies aimed to investigate the change in bone mass or strength in children secondary to an exercise intervention. In general, these demonstrate a positive effect for physical activity during growth and development. Interventions were diverse, and activities ranged from moderate (running) to high (jumping) impact performed for 10–40 minutes, two to three times per week. In all studies of pre- and early-pubertal children, BMD increased more in the intervention group than in controls at various regions of the proximal femur and/or lumbar spine (15,32,39,70,71,76,79). Generally, the magnitude of the augmented response over 7–10 months varied from 1% at the trochanteric region of the proximal femur (76) to ~3% at the femoral neck for a high-impact jumping intervention (32,79). When moderate activity was increased through daily physical education, a positive effect on bone accretion in prepubertal girls was also noted (107). In a school-based intervention with a 10-minute moderate-impact circuit training three times per week, the benefit doubled if the intervention continued for a second school year. Bone mass benefits increased from 2% to approximately 4% at the femoral neck and lumbar spine in both boys and girls (69,72). These and other studies suggest that the bone response to loading is optimized in pre- and early-puberty (premenarche in girls) (14,39,48, 111,94).

Exercise Prescription for Optimizing Bone Development in Youth

1.7.4-ES: Design, implement, and supervise individualized exercise prescriptions for people with chronic disease and disabling conditions and people who are young or elderly.

The ACSM position stand on physical activity and bone health (54) states that exercise to optimize bone health in children and adolescents should involve 10–20 minutes, three days per week, of impact activities such as plyometrics, jumping, moderate-intensity resistance training, and participation in sports that involve running and jumping (soccer, basketball). Since the publication of this position stand, a new trial of exercise in youth has further elucidated the appropriate anabolic dose of exercise to strengthen the growing skeleton. A pilot study of a simple jumping intervention, "Bounce at the Bell," showed that 10 jumps, three times per day, over 8 months was associated with a significant increase in proximal femur (+2.3%) and intertrochanteric region (+3.2%) BMD (75). To perform their jumps, children simply stood next to their desk and jumped for <1 minute, three times per day when the bell rang. The intervention took <3 minutes per day and required no equipment or special training from teachers. Although more work is needed to confirm these results, these data suggest that interventions can be very simple and short and still be effective at improving bone development; they may be excellent adjunctive exercises to those recommended in the ACSM position stand.

EXERCISE AND BONE HEALTH IN ADULTHOOD

The goal of exercise in adulthood should be to offset bone loss that is observed during this time in life, rather than adding bone mass to the skeleton as in youth. Trials of exercise lasting 8–12 months in premenopausal women generally show increased BMD by 1%–3% at the loaded sites (spine and hip) compared to controls (30,38,64, 102–104). Differences between exercisers and controls in the premenopausal cohorts are attributed to gains in bone mineral of exercisers (12,38), attenuation of bone loss in exercisers, or a combination of bone gain in exercisers and bone loss in controls (30). Trials of exercise in premenopausal women (ages 22–49) with favorable outcomes involved jogging, strength training, aerobics, and jumping exercises (51).

Traditionally, there is far less research attention regarding the effects of exercise on bone health in men versus women (86). This paucity of research is not justified by the observations of the exponential increase in incidence of hip fracture in men as they age (although this happens 5–10 years later than for women) (86). Of the few studies performed in older men, most found positive effects of resistance training on BMD at loaded sites. Menkes et al. report that 16 weeks of resistance training in 59-year-old men resulted in a 3.8% increase in femoral neck BMD compared with controls (78). Similarly, Ryan et al. found that 16 weeks of resistance training in 61-year-old men resulted in a 2.8% increase in femoral neck BMD compared with controls (98). Overall, studies in adults indicate that exercise, if done with adequate load such as resistance (weight training) and impact (i.e., jump) training, are effective at attenuating bone loss observed with advancing age (51).

Exercise Prescription to Preserve Bone Health during Adulthood

1.7.9-ES: Identify patients who require a symptom-limited exercise test prior to exercise training.

1.7.40-ES: Ability to explain and implement exercise prescription guidelines for apparently healthy clients, increased risk clients, and clients with controlled disease.

Prior to beginning a new exercise program, all individuals with osteoporosis or who are at risk should be encouraged to consult with their physician. No special recommendations for performing an exercise evaluation exist for this population, and the recommendation is to consider the need for an exercise evaluation as one would for any individual.

The ACSM position stand on physical activity and bone health states that exercise to preserve bone health during adulthood should involve 30–60 minutes per day of a combination of moderate-to-high intensity weight-bearing endurance activities (three to five times per week), resistance exercise (two to three times per week), and jumping activities (54). Weight-bearing endurance activities include tennis, stair climbing, and jogging at least intermittently during walking. Activities should involve jumping, including volleyball and basketball, and resistance exercises, such as weightlifting, and these should target all major muscle groups (54).

EXERCISE IN ELDERLY AND OSTEOPOROTIC INDIVIDUALS

Exercise Testing in Osteoporosis

5.2.1-HFI: Knowledge of musculoskeletal risk factors or conditions that may require consultation with medical personnel before testing or training, including acute or chronic back pain, osteoarthritis, rheumatoid arthritis, osteoporosis, inflammation/pain, and low back pain.

1.3.9-ES: Instruct the test participant in the use of the RPE [rate of perceived exertion] scale and other appropriate subjective rating scales, such as the dypsnea, pain, claudication, and angina scales.

1.3.22-ES: Describe the differences in the physiological responses to various modes of ergometry (e.g., treadmill, cycle and arm ergometers) as they relate to exercise testing and training.

1.7.18-ES: Determine appropriate testing and training modalities according to the age, functional capacity, and health status of the individual.

Exercise testing is not contraindicated for those with osteoporosis. However, because of the nature of the disease, if an exercise test is indicated, certain measures must be taken into consideration to ensure maximal safety. As with any exercise test, instruct the test participant in the use of the RPE and pain scales. Because the majority of individuals with osteoporosis are older in age and sedentary, they should be considered as moderate risk for atherosclerotic disease (see GETP8 Table 2.1). Based on this, it is recommended that a physician be present if a maximal exercise test is performed (see GETP8 Fig. 2.4). When exercise tests are performed in individuals with osteoporosis, the following should be considered:

- Use of cycle ergometry as an alternative to treadmill exercise testing to assess cardiovascular function may be indicated in patients with severe vertebral osteoporosis for whom walking is painful.
- Vertebral compression fractures leading to a loss of height and spinal deformation can compromise ventilatory capacity and result in a forward shift in the center of gravity. The latter may affect balance during treadmill walking.
- Maximal muscle strength testing may be contraindicated in patients with severe osteoporosis, although there are no established guidelines for contraindications for maximal muscle strength testing.

1.7.10-ES: Organize GXT [graded exercise test] and clinical data to counsel patients regarding issues such as ADL [activities of daily living], return to work, and physical activity.

As with all patient populations, the trained exercise professional should work in consultation with the physician or other referring licensed healthcare provider to counsel patients regarding activities of daily living (ADL), return to work, and physical activity. The results of an exercise test are useful in determining the safety of performing these activities and the maximal metabolic equivalent (MET) threshold for activities that a person should be allowed to perform.

1.5.2-ES: Describe the mechanisms and actions of medications that may affect exercise testing and prescription, i.e., beta-blockers, nitrates, calcium channel blockers, *Digitalis*, diuretics, vasodilators, antiarrhythmic agents, brochodialators, antilipemics, psychotrophics, nicotine, antihistimes, over-the-counter cold medications, thyroid medications, alcohol, hypoglycemic agents, blood modifiers, pentoxifylline, antigout medications, and anorexiants/diet pills.

The effects of any of the FDA-approved medications for the specific prevention and treatment of osteoporosis (e.g., calcium, vitamin D, calcitonin, bisphosphonates, fluoride, estrogens, and androgens) on acute or chronic exercise responses have not been extensively studied. However, there is no evidence that any of these agents would affect exercise response during testing with the possible exception of estrogen, which has an acute vasodilator effect and may alter electrocardiographic responses to exercise during an exercise test. This effect has been seen in studies using large doses of estrogen but has not been demonstrated in doses used with estrogen or HRT (3,55).

1.7.15-ES: Describe common gait, movement, and coordination abnormalities as they relate to exercise testing and programming.

Osteoporosis can preclude detection of abnormal responses associated with heart diseases during an exercise test because performance may be limited by the symptoms of osteoporosis, thus preventing the individual from achieving an adequate heart rate and blood pressure response necessary for an accurate diagnosis. Severe kyphosis (rounding of the upper spine) is one such example unique to osteoporosis that may limit an exercise test because of an imposed mechanical limitation on respiratory muscle function. Ideally, a maximum effort test should be used, assuming no contraindications exist and the appropriate supervision is provided. A maximal capacity test is preferred so that more accurate exercise heart rates can be prescribed based off of the heart rate reserve method. If a maximal test is contraindicated or cannot be performed, the rating of perceived exertion (RPE) to guide exercise intensity is appropriate for this population. However, if the population is at moderate or high risk for cardiovascular disease, it would be prudent to closely assess the patient for indications of ischemia (e.g., angina equivalents) or excessive exercise intensity (e.g., excessive heart rate or blood pressure responses).

Exercise Prescription in Patients with Osteoporosis

1.7.41-HFI: Ability to adapt frequency, intensity, duration, mode, progression, level of supervision, and monitoring technique in exercise programs for patients with controlled chronic disease (e.g., heart disease, diabetes mellitus, obesity, hypertension), with musculoskeletal problems (including fatigue), during pregnancy and/or postpartum, and with exercise-induced asthma.

1.7.4-ES: Design, implement, and supervise individualized exercise prescriptions for people with chronic disease and disabling conditions and people who are young or elderly.

1.5.8-ES: Recognize patient clinical need for referral to other (non-ES) allied health professionals (e.g., behavioralist, physical therapist, diabetes educator, nurse, etc.).

1.5.9-ES: Recognize patients with chronic pain who may be in a chronic pain management treatment program and who may require special adaptations during exercise testing and training.

1.7.8-ES: Demonstrate exercise equipment adaptations necessary for different age groups, different

physical abilities, and other potential contributing factors.

1.5.10-ES: Recognize exercise testing and training needs of patients with joint replacements or prostheses.

Prior to prescribing exercise for the patient with osteoporosis, especially those who have recently experienced a fracture, an exercise professional should consult with the clients' physician. For patients with debilitating osteoporosis and severe pain or recent joint replacement, exercise program options will be limited. These patients should typically work with a physical therapist or rehabilitation specialist until mobile. There is a high prevalence of back pain in patients with osteoporosis, which is related to limited functional ability (60). Thus, pain management may be an important part of the care for osteoporotic individuals. It may be necessary to begin exercise prescription with a warm-pool-based program (e.g., hydrotherapy), which, although non-weight-bearing, can improve flexibility and muscle strength. In light of the rapid and profound effects of immobilization and bed rest on bone loss, and the poor prognosis for recovery of bone mineral content after remobilization, even the frailest elderly people should remain as physically active as their health permits to preserve skeletal integrity. If a person cannot tolerate active exercises, functional electrical stimulation may improve vital muscle strength in preparation for active strengthening as pain diminishes (51).

1.3.30-ES: Discuss the appropriate use of static and dynamic resistance exercise for individuals with cardiovascular, pulmonary, and metabolic disease.

1.2.3-HFI: Knowledge of risk factors that may be favorably modified by physical activity habits.

As stated in the ACSM position stand on physical activity and bone health (54), "exercise programs for elderly women and men should include not only weight-bearing endurance and resistance activities aimed at preserving bone mass, but also activities designed to improve balance and prevent falls." However, few well-designed trials have tested the efficacy of such programs. A 20-week strength, posture, and balance program, Osteofit, improved dynamic balance in females with osteoporosis. In a study of females with a history of spinal fracture, a 10-week balance, strengthening, stretching, and relaxation program resulted in a significant reduction in pain and use of analgesia and increased quality of life (73). In both men and women with osteoporosis, 12 months of balance and strength training resulted in improved BMD, balance, and aerobic capacity (57). Although these trials indicate that exercise has beneficial effects on *surrogates* of osteoporotic fracture, well-designed studies with fracture endpoints are needed to further guide exercise prescription in men and women with osteoporosis.

1.7.11-ES: Describe relative and absolute contraindications to exercise training.

1.7.6-ES: Knowledge of the concept of "activities of daily living" (ADLs) and its importance in the overall rehabilitation of the individual.

Contraindicated Exercises for Individuals with Osteoporosis

Several general types of exercise are contraindicated for people with osteoporosis because they can generate large forces on relatively weak bone. Twisting movements (e.g., golf swing), dynamic abdominal exercises (e.g., sit-ups), and excessive trunk flexion should all be avoided because they can all result in vertebral fracture. Osteoporotic individuals should be taught correct form for ADLs such as bending to pick up objects to avoid vertebral fractures. Furthermore, exercises that involve abrupt or explosive loading, or high-impact loading, are contraindicated in persons with osteoporosis.

Flexibility Training for Individuals with Osteoporosis

A program to increase flexibility can also benefit osteoporotic patients because decreased flexibility can cause problems with posture. However, many of the commonly prescribed exercises for increasing flexibility, especially of the hamstring muscles, involve spinal flexion and must be avoided. There is little consensus on the optimal training program for increasing flexibility in individuals with osteoporosis, but good suggestions are available from many sources including Chapter 7 of the ACSM's eighth edition of the *Guidelines for Exercise Testing and Prescription* and Pearlmutter et al. (89). As with resistance training, slow and controlled movements should be the rule with stretching; ballistic-type stretching should be avoided.

Aerobic Training for Individuals with Osteoporosis

The primary reasons for prescribing aerobic exercise for those with osteoporosis are to increase aerobic fitness and work capacity, decrease cardiovascular disease risk factors, help maintain bone strength, and improve balance. Aerobic exercise for those with osteoporosis should primarily involve weight-bearing modes of exercise such as walking. For those with more significant osteoporosis-induced pain who cannot tolerate weight-bearing activities, cycling, swimming, or water aerobics are possible alternatives. Aerobic exercise should be performed according to the ACSM's eighth edition of the *Guidelines for Exercise Testing*, approximately 3–5 days per week at an intensity of 40% to 70% of $\dot{V}O_2$ reserve or heart rate reserve (HRR). An initial goal of 20–30 minutes per session is reasonable but may be shorter at the beginning in cases of extreme deconditioning. Orthopedic limitations may slow progress or mandate the use of additional supports, such as handrails for walking. Once 20–30 minutes becomes well tolerated, the duration can slowly be increased in much the same fashion as with healthy populations. If the individual is severely limited by pain, the physician should be consulted prior to exercise participation. Aerobic exercises that involve forward flexion of the spine such as rowing should be avoided.

1.7.20-ES: Discuss the appropriate use of static and dynamic resistance exercise for individuals with cardiovascular, pulmonary, and cardiovascular disease.

Resistance Training in Patients with Osteoporosis

Resistance training offers a good option to meet both the bone health and falls prevention criteria on an individual basis. Resistance training requires little skill and has the added advantage of being highly adaptable to changes in both magnitude and strain distribution. In addition, increases in strength and muscle size have been demonstrated after resistance training, even in elderly individuals, which has the added benefit of reducing these patients' risk of falls (17,19,93).

Improving muscle strength helps to conserve bone and muscle mass and enhance dynamic balance. Resistance training with free weights, machines, calisthenics, and elastic bands are recommended for osteoporotic populations with the loads ideally being directed over the long axis of the bone (axial loading). A resistance exercise prescription, for individuals at risk for osteoporosis, should follow the FITT principal outlined in the ACSM's *Guidelines for Exercise Testing* that recommends 2 to 3 days per week, of 8–12 repetitions, at a moderate (60%–80%) or high (80%–90%) intensity of one time the repetition maximum (1-RM). For those with established osteoporosis, the only limitation in this exercise prescription should be to limit the resistance training intensity to the moderate level because of the risk of fracture. Additionally, those with osteoporosis should avoid any ballistic or jumping activities that are recommended for those who are at risk. The overall goal for both groups is to perform weight-bearing and resistance exercise for 30–60 minutes each exercise session.

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INTERNET RESOURCES

- Action Schools BC: http://www.actionschoolsbc.ca/Content/Home.asp
- American Academy of Physical Medicine and Rehabilitation: How PM&R Physicians Use Exercise to Prevent and Treat Osteoporosis: http://www.aapmr.org/condtreat/other/osteotreat.htm
- American Society of Bone and Mineral Research: Webcast on Bone Quality: What Is It and Can We Measure It?" http://aap2capital-reach.com/esp1204/servlet/tc?cn=asbmr&c=10169&s=20292&e=4521&& American Society of Bone and Mineral Research: Bone Curriculum: http://depts.washington.edu/bonebio/ASBMRed/ASBMRed.html
- Mayo Clinic: Exercise and Osteoporosis: http://www.mayoclinic.com/ health/osteoporosis/HQ00643
- National Institutes of Health: Osteoporosis and Related Bone Diseases National Resource Center: http://www.niams.nih.gov/bone/
- National Osteoporosis Foundation: http://www.nof.org/
- Osteofit: http://www.osteofit.org/
- Prevention of Falls Network Europe (ProFaNE): http://www.profane.eu.org/
- U.S. Bone and Joint Decade: http://www.usbjd.org/