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Aging: Its Effects on Strength, Power, Flexibility, and Bone Density

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WITH THE ONSET OF THE YEAR 2000, the average American is living an extended life span of 3 decades. Are these years to be lived out in a nursing home? People generally do not end up in nursing homes because they are sick but because they are physically weak. They lack the muscular strength and motor ability to live a functional, independent life. When people reach 50, they begin to pay the price of a sedentary lifestyle. The predictable consequences are detrimental changes in body composition, including loss of lean body mass, strength, flexibility, and bone density, along with an increase in body weight and body fat. Inactivity with aging is the primary factor in these changes, because physical activity levels are one of the most important factors affecting body composition from childhood through old age.

Research studies have shown that age-related changes in body composition can be retarded and even reversed through resistance training. This review of literature examines the extensive studies published over the past 2 decades pertaining to the intervention of resistance training in managing the loss of functional capacity associated with aging. The review addresses the effects of aging on strength, power, flexibility, and bone density and the controversy of machines versus free weights in training older individuals. The review provides effective guidelines for writing a strength fitness prescription for the older adult, one that will enhance his or her ability to live an independent lifestyle well into late life.

Strength and Aging

Strength is a crucial component of the quality of life. Without adequate strength levels, even the most basic tasks become difficult or impossible to perform without assistance (36). As life expectancy grows, the decline in muscle strength with aging becomes a matter of increasing importance (36, 76). Research suggests that from ages 30 to 80 years, back, leg, and arm strength decrease 30 to 40% (29, 73). Israel (36) observed an approximate 30% decline in strength and muscle mass in male subjects between age 30 and 70 years. In another study, muscle mass, expressed as creatinine excretion per kilogram of bodyweight, decreased by 6% per decade in male subjects aged 22 to 87 years (51). According to Borkan et al. (13), muscle tissue declines with age, while fat is redistributed. In their study of men aged 41 to 76 years, computed tomography (CT) scans revealed that fat moves inward with age. There was increased intra-abdominal and decreased subcutaneous fat in the older male subjects and also fat infiltration within and between muscles.

Viitasalo et al. (76) studied 308 men in 3 age groups: 31 to 35, 51 to 55, and 71 to 75 years old. In the 71- to 75-year-old group, maximum strength declined in the quadriceps (47%), biceps (35%), hand grip (42%), trunk extension (42%), and trunk flexion (35%). Interestingly, the 51- to 55-year-old group had the greatest body weight and fat weight. Ankle joint movements involved in walking were studied in men and women aged 20 to 100 years by Vandervoot and McComas (75). They found that by the age of 60, strength levels began to significantly decline, were about 80% of younger adults' strength levels by age 70, and further decreased to only 50% by age 90. Electrical stimulation of the motor nerves produced increases in strength in older subjects, indicating that neuromuscularly, these subjects were capable of complete nervous facilitation of their muscles. Vandervoot and McComas' data suggested that decrease in excitable muscle mass is responsible for the lower strength in the elderly (75). In contrast, Kallman et al. (41) suggested that other factors besides muscle mass decline influence strength loss with age. In their study involving subjects 20 to 100 years old, residual analysis showed that muscle size alone failed to explain the strength of the young subjects or the weakness of the old. Klitgaard et al. (43) also observed an inability of the elderly to activate all muscle mass present. Moritani (50) and Sale (65) have demonstrated the importance of the neural aspect of strength performance.

Kallman et al. (41) found that strength increases into the fourth decade and then decreases thereafter at an accelerated rate. Interestingly, 29% of the middle-aged and 15% of older subjects in their study showed no decline in grip strength. Men 11 to 70 years old were studied by Larsson et al. (46). Isometric and dynamic strength increased to the third decade, remained stable to the fifth decade, and thereafter decreased with age. The strength decrease was not related to visual muscle atrophy, which could be a result of the fat infiltration into muscle masking visual muscle loss (13). Quadriceps muscle biopsy revealed decreased proportions and selective atrophy of type II fibers with age. A significant correlation between the strength decrease and type II fiber area was determined, but multiple regression failed to support fiber area as a predictor of muscle strength. A reduction in type I and II muscle fiber area with age was observed in men and women 20–70 years old by Essen-Gustavsson and Borges (24). This change was most evident after age 60. Proportionally, type I and II fibers experienced no relative change in the vastus lateralis with age. This is supported by Aniansson et al. (6), who studied biopsies of the vastus lateralis from subjects with fresh hip fractures who were clinically healthy before the accident. Results indicated that the proportion of type I to type II fibers remained the same but that there was an advanced reduction in muscle fiber size, especially in type II fibers. Aniansson et al. (6) observed high muscle quality in these subjects, suggesting that disuse is a reversible phenomenon responsible for the observed muscle fiber atrophy and strength loss.

Reed et al. (64) observed loss of strength per unit of muscle with increasing age. They suggested that to maintain muscle efficiency, people should make a special effort to resistance train as they get older. After measuring manual laborers at retirement and at 1 year after, Patrick et al. (62) suggested that maintenance of physical activity in the elderly is important. A 4% reduction in thigh muscle area and a 5% reduction in the ratio of muscle to body mass was observed.

Research by Clarkson and Dedrick (20) suggested that the elderly are capable of participating in a properly designed resistance training program. Active women over 60 were compared to active college-age women on the parameters of exercise-induced muscle damage and the ability of older muscle to repair and adapt to this damage. Exercise resulted in similar damage, repair, and adaptability patterns in young and old. Interestingly, no significant differences in isometric strength occurred between young and old subjects, suggesting that physical activity counteracts the age-related decline in strength. Bortz (14), after reviewing the similarities of deterioration caused by aging and physical activity, concurred, stating that people should live by the philosophy of "use it or lose it."

Strength Training and Aging

In order to maintain fat-free weight with age, resistance training appears to be a critical component of an exercise regimen (59, 63). We found that regardless of age, aerobically trained master athletes who resistance trained were the only ones to maintain fat-free weight.

According to Jette and Branch (38), after age 74, 28% of men and 66% of women in the United States cannot lift objects greater than 4.5 kg. Many people believe strength loss to be an inevitable fact of aging, but this is not so (34). In a case study, O'Shea (57) investigated how much strength

Figure 1. **For healthy individuals 50 and over, strength acquired through the power lifts has a high transfer value to dynamic, functional living.**

developed in a 13-year weight-lifting career could be regained 16 years later at the age of 51. A 1-year, periodized powerlifting program was instituted, with full squats as the cornerstone of training. Squats placed the training emphasis on the large muscle groups of the hips, thighs, and lower back, while periodization helped avoid the pitfalls of a hit-and-miss training program. Dynamic strength increased to levels comparable to lifts performed during the subject's competitive days, with a full squat, bench press, and deadlift of 215, 105, and 250 kg, respectively, at a bodyweight of 85 kg. No serious discomfort or joint soreness inhibited training, and the increased strength readily transferred to other physical activities (competitive cycling and triathlons). Again, at the age of 60, O'Shea, after engaging in no serious powerlifting for 8 years, undertook specialized high-intensity training in the form of functional isometric lifting combined with dynamic free weight lifting (59, 61). For a 6-week period functional isometric lifting loads of 100 to 150% of the 1-RM free squat and deadlift were used. At the conclusion of the training period and at a body weight of 83 kg, O'Shea squatted 215 kg and deadlifted 240 kg. The posttest results represented an increase of 12 and 15%, respectively, over the pretest results. Also, the lifts were 27% less than O'Shea's best at the age of 30, when he weighed 90 kg (59). In general, the results suggest that this type of high-intensity training can produce significant strength gains for healthy, middle-aged individuals. However, it should be noted that functional isometric lifting is not recommended for individuals 30 or older with little or no background in powerlifting.

In another unpublished case study, a 48-year-old subject with no previous background in powerlifting committed himself to a long-term training program. Competing in the U.S. Masters Powerlifting Championships at the age of 52 at a body weight of 82 kg, he squatted 227 kg, bench pressed 138 kg, and deadlifted 215 kg. These lifts represented a 30% strength gain over the 4-year period. Although powerlifting is not recommended for every middle-aged man or woman, the results show the strength potential for those having the desire to train at a high level.

The importance of resistance training in an exercise program was demonstrated by Klitgaard et al. (42, 43). Swimmers, runners, and resistance-trained athletes, aged 69 to 70 years old, who had trained on average for 14 years, 3 days per week, were compared to each other, age-matched controls, and 28-year-olds. Maximum isometric torque and muscle cross-sectional area, as measured by CT scans, were equal in the endurance-trained swimmers, runners, and age-matched controls, while the resistance-trained group was identical to the 28-year-olds. Furthermore, the swimmers and runners demonstrated selective atrophy of type II muscle fibers, while type II fibers were maintained in the resistance-trained subjects. The results demonstrate the specific effect of resistance training on muscle force and mass, suggesting that endurance-based swim and run training cannot counteract the age-related decrease in muscle force mass, whereas short, intense, high-load resistance training has a marked positive effect.

Larsson (45) investigated men aged 22 to 65 years involved in a low-intensity, high-repetition, 10-station circuit 2 days per week for 15 weeks. Before training, the proportion of type I fibers increased with age, while the area of type I and II fibers decreased, with type II decreasing most significantly. Also, strength decreased with age. After training, the type I and II fiber areas increased, eliminating the age-related decline in muscle area, and strength increased in all ages. Larsson (45) suggested that the observed fiber atrophy was due to disuse and that a higher intensity resistance-training program would have resulted in greater muscle mass and strength.

Barnes and Donovan (9) observed in hip fracture patients that decreased strength of the lower body was a significant factor in not reaching independence with ambulation. They suggested that specifically designed resistance-training programs could counteract this functional loss of strength.

Men aged 60 to 72 years were resistance-trained by Frontera et al. (26). Subjects performed quadriceps and hamstring exercises on a Universal machine for 12 weeks at 80% of their 1-repetition maximum weight (1 RM). Training frequency was 3 days per week, and volume was 3 sets at 8 repetitions. Muscle biopsies and CT scans of the thighs were performed, along with dynamic and isokinetic strength tests. Dynamic strength of the quadriceps and hamstrings increased by 107% and 226%, respectively. Isokinetic strength gains were significant but were 10 times less than dynamic strength gains, suggesting a specificity of training response from the dynamic training to the dynamic testing (26, 50, 65). Total thigh area increased 4.8%, with total muscle area and quadricep area increasing 11.4% and 9.3%, respectively. Muscle biopsy revealed a 33.5% increase in type I fiber area and a 27.6% increase in type II fiber area. The authors suggested that neurological factors combined with muscle hypertrophy to significantly improve strength. These results also demonstrate that a significant and rapid gain in functional strength can be obtained in the elderly with a properly designed resistance-training program (26). Studies by Hakkinen (30), Moritani (50), and Sale (65) demonstrated that the initial gains in strength from resistance training are predominantly caused by neural factors, with hypertrophy becoming the dominant factor as time goes by. This supports Frontera et al. (26), Larsson (45), and Klitgaard et al. (42), who found that hypertrophic factors influence strength gains in longer training programs.

The feasibility and physiological consequences of high-intensity resistance training in the frail elderly was investigated by Fiatarone et al. (25). Institutionalized subjects, aged 86 to 96 years, performed progressive-resistance weight training of the quadriceps 3 days per week for 3 sets of 8 repetitions at 80% of 1 RM. Quadricep strength increased by an average of 174%, with a 32% strength loss occurring after only 4 weeks of detraining. Gait speed increased by 48%. Two subjects no longer needed canes to walk, and one could now rise from a chair without assistance. Muscle hypertrophy occurred in some subjects. The authors stated that the risks of weight training are far overshadowed by the known hazards of immobility and falls. Fiatarone suggested that despite the evidence of positive outcomes, there has been a reluctance to apply progressive resistance, high-intensity resistance training to older individuals. Conroy et al. (21) suggested that the elderly and their physicians overrate the benefits of light and sporadic exercise and underrate their own abilities.

Conclusions

Resistance training is essential for individuals 50 and older who are wanting to maintain an independent lifestyle and are wanting to avoid the possibility of ending up in a nursing home (Figure 1). The magnitude of response to resistance training depends to a great extent on the training modality—machines or free weights. In reviewing the literature, it was found that a majority of the studies utilized machines, rather than free weights. The reason for this might have been that the investigators lacked knowledge and experience in the applied science of free-weight training. While the machines produced a statistically significant increase in strength, it is possible that the increase would have been better had free weights been used. As will be addressed later in this review, free weights offer many advantages over machines in terms of improving neuromuscular function, balance, and flexibility.

Another important conclusion drawn from the literature is that the aging human body is highly resilient in its capacity to cope and adapt to high-intensity resistance training. Confirmation of this statement can be seen in the case studies of the 2 middle-aged master power lifters. In both studies, the subjects subjected themselves to a level of training intensity normally associated with younger strength athletes, with no negative effects.

Finally, a common weakness found in many of the reviewed studies was the lack of sufficient training intensity, volume, and frequency. Controlling these variables is essential to writing a training prescription that utilizes the periodization concept. Periodization provides for a systematic stepwise increase in training intensity and volume (60). Also, only a few studies followed the progressive overload principle, which is one of the cornerstones of resistance training. Whether one is training young athletes or the elderly, to optimize results, scientific principles and concepts must be applied. Otherwise, all you have is a hit-and-miss training program that produces minimal results.

Muscle Power and Aging

Power represents the amount of work a muscle can produce per unit of time, the product of force and velocity (45, 60). An increase in power enables a person to improve performance in tasks that require strength with speed (1, 60), which relates to many of the functional and recreational activities of the older adult. For the master athlete, power is a crucial component of peak performance. The literature review revealed no studies dealing specifically with power performance in the aging adult; however, it is possible to make some inferences from other strength-related research.

The ability of the neuromuscular system to develop high action velocities, or power, depends on the recruitment and firing frequencies of the motor units and the contractile characteristics of the respective muscle fibers (60, 66). The close working relationship between neuromuscular efficiency (e.g., multiple fiber recruitment and facilitation of the stretch reflex) and dynamic power performance was clearly demonstrated by Adams et al. (1). Sale (65) suggested that the increased neural adaptation as a result of resistance training may increase the recruitment of higher threshold, higher force motor units, thereby increasing muscular power. Observations of athletes unfamiliar with resistance training demonstrate their inability to recruit the highest threshold motor units (65).

Type II muscle fibers are associated with high-velocity, power movements (44, 55, 60). Significant correlations were found between type II fiber percentage and mechanical power output as measured by vertical jump (44). Type II fibers have been shown to decrease with age (24, 44, 46), suggesting decreased power capabilities. This age-related decline of type II fibers is reversible through resistance training, making resistance training a possible mechanism for maintaining and improving power in the aging adult (56, 60).

Scientifically based resistance-training programs also increase neuromuscular coordination, which leads to increased power (26, 59). This is especially critical in the elderly, for whom coordination and balance problems, together with mechanical efficiency declines, can affect basic functional tasks (26).

Resistance Training and Muscle Power

Power is the ability to apply force throughout a full range of multijoint body movement. Anatomically, power production involves torso kinetic energy (energy of motion) and torso rotational energy. And it is the combined interaction of these elements that exerts the greatest influence on the application of power in human movement (60).

Optimal development and transfer of power to functional tasks will result from lifting movements that allow power to exert itself to the greatest degree. Large muscle group power lifts, such as the squat, leg press, power clean, and deadlift, are key exercises because they strengthen the body's power zone (large extensors and flexors of the back, hips, and thighs). Strength acquired through powerlifting has a high transfer capacity because the lifts come closest to duplicating many of the gross physical tasks of daily living. During execution of a power lift, a summation of forces occurs within the multilinked muscle–skeletal system, which maximizes power output. Energy generated by the power zone muscle flows to smaller muscle groups of the upper body, resulting in a summation of torso kinetic energy, which is essential for carrying out daily living tasks (e.g., lifting, walking, climbing stairs, gardening, changing a car tire, and making general home repairs).

Another important aspect of power is power endurance. This is the ability of muscles to contract and produce force for extended periods of time without fatigue. Power endurance is a major factor in long-distance walking, hiking, cross-country skiing, and biking. To maximize power endurance, one needs a good level of cardiovascular fitness (aerobic power). Muscular strength combined with aerobic endurance equals power endurance. The most effective method for developing power endurance is through a cross-training program of circuit weight training and aerobic activities. A safe and productive intensity calls for 5 to 6 power-type lifts, performed in 15–20 repetitions for 2 sets 2 days a week, together with a 45-minute aerobic activity session 3 days a week (59, 60).

Conclusions

The age-related decline in body power can be slowed and even reversed through resistance training. However, neither machine nor free-weight upper body training is effective in controlling this decline. What are required are freestanding power-type lifts that train and develop the body as a functional unit through a full-range of multi-joint body movement. And here, the key exercises are the power snatch and power clean. They have the capacity to contribute most to peak-performance, functional living. Together, these 2 lifts develop strength, neuromuscular coordination, balance, and flexibility, which is the primary purpose of weight training for adults 50 and over. Once the lifting technique has been learned and mastered, the lifts are not dangerous for male or female adults. Light weights are all that is required for training with intensity set at 2 sets of 8 to 10 repetitions. For developing power endurance, a cross-training program is necessary for strength and endurance (59). Cross-training maintains a balance between strength and cardiovascular fitness for health and doing the chores of daily living.

Flexibility and Aging

Flexibility is defined as the range of motion of a joint (4). Adequate flexibility helps a person meet the functional demands of life as well as enhances the person's participation in leisure activities (4, 11, 35). Lack of flexibility may increase injury rate and may cause functional problems, particularly in the sedentary, middle-aged, and elderly (3, 22, 35).

Flexibility declines with age (18, 23, 67, 69). It appears that flexibility declines 20 to 30% between the ages of 30 and 70 years (18, 39, 67). Johns and Wright (39) determined that the relative contributions of soft tissue to total resistance encountered at a joint are as follows: joint capsules, 47%; muscle and its fascia, 41%; tendons and ligaments, 10%; and skin, 2%. Little evidence suggests that biological changes such as tendon stiffening, joint capsule changes, or muscle changes are responsible for the age-related decrease in flexibility (2, 5, 34). Goldspink (28) demonstrated that with age, collagen increases in solubility, becomes more cross-linked, and increases in content in the muscle, leading to decreases in range of motion. Immobilization or lack of activity increases collagen turnover and deposition in ligaments, shortens muscle fibers, and decreases muscle mass, further reducing flexibility.

Studies show that as people get older, the range of motion during walking of the lower extremity joints gets progressively smaller (53). In a study of men age 20 to 87 years old, Murray et al. (52) compared the gait patterns of older and younger men. The older men had shorter strides, a decreased range of hip flexion and extension, and reduced ankle flexibility. Interestingly, Johnson and Smidt (40) determined that squatting and shoe tying required the greatest range of motion among common daily activities. Goldspink (28) suggested that exercise may reduce this age-related fibrosis and help maintain flexibility with age. Many researchers agree that the decline in flexibility with age is due to disuse and is reversible through activity (2, 5, 18, 34).

Resistance Training and Flexibility

Physical exercise that routinely places joints through a full range of motion will produce an increase in flexibility over time (35). Comprehensive conditioning and sports activities usually result in flexibility improvements throughout the body (22, 34). Disuse due to lack of physical activity produces contractures and shortening of connective tissue, while increased flexibility of the entire musculotendinous unit results from repetitive, active contractions that increase circulation to a muscle and gradually increase the strength of the tendon (5, 28, 34). Resistance training requires a constant interplay of mobility and stability and is functionally similar to the natural pattern of movement (59). This allows for a safe and natural increase in flexibility over time. Interestingly, besides increasing flexibility, resistance training combats excessive joint laxity by strengthening the muscles surrounding the joint (22, 60, 77).

Flexibility scores of physically active women in their 60s were more similar to young women in their twenties than to inactive women their own age (22). Buccola and Stone (15) demonstrated an increase in flexibility of the trunk and leg in men aged 60 to 79 years with participation in a 14-week walking and jogging program. Chapman et al. (18) studied flexibility in men age 15 to 19 and 63 to 88 years old. Results demonstrated an age-related loss of flexibility. Progressive strength training, however, increased flexibility in both age groups, with the older people being as responsive to training as the young. Similar results were found by Hartley-O'Brien (31), who found that regular mobilization increased flexibility of the hip and suggested that resistance training through the full range of motion may increase flexibility.

The effect on flexibility of a progressive weight-training program was investigated by Leighton (47). Training took place for 8 weeks, consisting of exercises that covered the whole body, such as squats, deadlifts, presses, and curls. Resistance training resulted in significant flexibility increases in 27 of 30 measures, with 3 measures showing no change. Leighton (47) also compared a Mr. America and a World Champion Olympic lifter with a group of 16-year-old boys on 30 flexibility measures. Mr. America's flexibility was greater in 16, equal in 8, and less than in 6 tests, while the Olympic lifter was greater in 14, equal in 6, and less than in 10 tests. Interestingly, shoulder and arm measures accounted for the majority of the lower flexibility measurements, possibly as a result of the great accumulation of mass in the shoulder and upper pectoral regions of the weightlifters (5). Leighton (47) concluded that weight training for increased muscle strength and size appears to increase flexibility.

Resistance training utilizing a full range of motion (e.g., Olympic-style snatch and clean and jerk) may maintain and increase flexibility, resulting in greatly enhanced coordinated motions (5, 56, 60, 70, 77). The effects of an 11-week free-weight training program on range of motion was investigated by Thrash and Kelly (73). College-age men trained for 3 sets of 8 repetitions, with the core exercises consisting of squats and bench presses. A significant increase in ankle and shoulder flexibility was observed. The authors concluded that weight training does not impair flexibility and can increase range of motion in some joints. Wathen (77) suggested that strength training elicits many of the same responses as stretching, and Anderson et al. (5) suggested that properly employed resistance-training exercises are more effective than traditional flexibility exercises at improving range of motion. This point is further illustrated by sports medicine's practice of using rubber tubes to increase strength and flexibility throughout a range of movement. Jensen and Fischer (37) reported that among athletes, Olympic weightlifters were second only to gymnasts in a composite score of several flexibility tests. O'Shea (60) stated that resistance training emphasizing full squatting resulted in improvement in the flexibility of the hamstrings, hips, and lower back and, when combined with the added strength developed, increased control and stability in other activities. Free weight training emphasizing dynamic strength optimizes performance throughout the full range of motion (5, 49). This provides increases in flexibility that are both comprehensive in nature and joint specific and allows for increased performance in daily functional tasks.

Conclusions

Flexibility is an important component of fitness that older people need but often neglect. Flexibility as a safety factor in preventing falls is often overlooked. At any age, good flexibility = good mobility. Flexibility coupled with strength permit one to perform household activities with reduced risk of injury. People with arthritis, especially ankylosing spondylitis, must be very conscious of their need to fight pain and stiffness by managing their condition through proper exercise and stretching. Frequently, lower back pain is associated with stiffness in the hips and back and is corrected with stretching.

Free-weight training, in combination with a program of stretching and swimming, develops and maintains good joint flexibility (i.e., the ability of muscles to stretch, allowing the joint to move safely through a full range of movement). Areas of major focus are muscles of the hips, lower back, thighs, and hamstrings. Flexibility in these muscle groups contribute most to functional living. Recommended weight exercises are all types of squats, the stiff-legged deadlift, the leg curl, and the leg press.

While static stretching does improving flexibility, PNF (proprioceptive neuromuscular facilitation) training is a superior method (32). However, it must be done with a partner. It is essential that older people learn PNF because it is the safest method of stretching.

Aging and Bone Density

Beginning around age 50, there is a significant decline in bone mineral density (BMD), a condition called osteoporosis. Low BMD, coupled with a decline in strength (muscle mass), greatly increases the risk of injury and fractures due to falls. Osteoporosis is associated primarily with low dietary calcium intake and lack of physical activity (8, 11). Postmenopaual women are more prone to develop osteoporosis. Studies have shown a significantly greater decline in bone mass following menopause (8, 11, 13, 17). The decrease is significant during the first 5 postmenopausal years. Women with low estrogen and calcium intake do not seem to respond to resistance training (48).

Long-term resistance training has been proven to significantly BMD (10, 19, 48, 63, 68). A positive correlation exists between strength and BMD. Stronger individuals possess greater BMD, compared to weaker individuals (21, 69). Snow-Harter et al. (69) reported that muscle strength is a significant predictor of BMD. Several cross-sectional studies have shown that strength positively correlates with BMD (21, 69). Individuals who engage in heavy labor or physical activity (e.g., weight training) have greater bone density than less active age- and gender-matched individuals (16).

Resistance Training and Bone Density

Maddolozzo (48) studied the effects of a 6-month resistance-training program on total BMD in 28 healthy men (average age 54) and 26 healthy women (age 52). He compared the effects of a moderate intensity, seated-machine–based program utilizing leg presses, leg extensions, and leg curls with a high-intensity, free-weight program consisting of squats and deadlifts. Analysis of the results found that the high-intensity, free-weight training program significantly increased BMD at the hip and spine for both men and women, while moderate intensity training produced no significant changes in BMD. These findings suggest that a higher magnitude of free-weight, large muscle group exercises (squats and deadlifts) is necessary to stimulate osteogenesis.

Other studies have shown that master athletes engaged in strength- and power-oriented sports (weight-lifting and throwing events) have higher BMD than endurance athletes (swimmers and distance runners) (54, 74, 78). Conroy et al. (21) compared the BMD of elite junior Olympic-style lifters (average age, 17.4 years) to those of a nonactive group of men of similar age. The junior lifters had significantly greater BMD at the lower spine and femoral neck. In addition, Conroy found a significant relationship between BMD and lifting ability in the snatch and the clean and jerk. Lifters with the highest BMD were also the most successful lifters.

Conclusions

A review of literature dispels any doubts that resistance training is essential in offsetting musculoskeletal declines associated with aging. A reduction in cortical bone mass, coupled with a decrease in bone strength, makes the elderly extremely susceptible to broken bones. High-intensity free-weight training utilizing squats and deadlifts is necessary to significantly increase BMD. Machine training seems to have no impact on increasing BMD.

Free-weight training may help people with arthritis. The ability to live with osteoarthritic changes depends to a great extent on the degree of stress around the joint that is shared by the muscles and the remaining cartilage. Bone strength is associated with good muscle, ligament, and tendon strength. Together, these reduce the stress placed on the joint surface. Physical inactivity causes significant loss in ligament and tension strength and hence, in joint strength. While high calcium intake contributes to greater bone density, it does not contribute to greater joint strength. Only through high-impact, freestanding weight training is total joint strength developed and maintained.

Machine Versus Free-Weight Training

The controversy of machines versus free weights is a never-ending one. However, a review of the literature clearly supports the fact that free-weight training is superior in developing overall strength fitness (1, 56, 58, 60, 70, 71). What, then, does research have to say about the effectiveness of machine training in developing strength?

Biomechanically, the design of a machine is based on the ability to vary resistance in accord with the strength curve of a specific exercise (33). As yet, no strength curves have been reported for full-range, multiple-joint, athletic-type lifts (core lifts include the following: power clean, power snatch, parallel squat, and dead lift). By their very nature, these lifts offer the greatest value for the transfer of training to everyday functional living (60). Further, variable resistance machines were developed on the basis that optimal strength development would result from taxing the working muscles to capacity through the full range of movement (33). Studies testing the validity of this theory have repeatedly failed to demonstrate that variable resistance machines hold an advantage over free weights (7, 33, 48). In contrast, free weights, compared to variable resistance machines, have demonstrated greater improvement in strength and power (1, 7, 60, 70, 71). According to Tesch (72) and O'Shea (60), there is no reason to believe that any weight-training device is more effective than free weights, especially athletic-type lifts, in developing strength, power, and quickness.

The major negative aspect of machine training is that it hinders the development of neuromuscular coordination, since machines eliminate the balance factor by "tracking" the weight and providing constrained movement patterns (5, 27, 32). Machines also restrict acceleration, resulting in velocity profiles that deviate severely from dynamic functional movements (27). Further, many machines eliminate countermovements. This decreases ballistic impulses and stretch reflex factors, thus decreasing the training effect (1, 27, 44, 60). All these negative factors add up to the fact that machines are unable to develop free, natural biomechanical movement that can transfer to functional daily living.

Conclusions

The research data on machines versus free weights overwhelmingly supports the latter in developing overall strength, power, and flexibility (1, 56, 60, 70, 71). Free-weight training develops superior neuromuscular function, especially in the muscle sensory system. Strength physiologists agree that free weights provide proprioceptive kinesthetic feedback similar to that provided by functional living tasks, resulting in increased neuromuscular coordination among agonists, antagonists, and their synchronization (32, 60, 66, 68). For older people, this provides for the improvement or maintenance of motor skills critical to independent functional living. As important, free-weight training builds a state of mind that says "I'm strong, I'm capable, all systems say go!"

While the published research is rather negative regarding the use of machines for resistance training, they still have a role to play. Realistically, a training program consisting only of free weights would not be appealing to a majority of people. In the training of individuals of all ages, but especially those 50 and older, a balance needs to be established between the use of machines and free weights. Training variety is crucial in maintaining continuous long-term motivation. Also, there are individuals who, because of extreme age or physical handicaps, cannot train with free weights. For healthy individuals, however, machines should never substitute for free-weight exercises such as squats and deadlifts. These large muscle group lifts comprise the core exercises of every science-based resistance program. They are critical in developing strength in the body's so-called "power zone" (i.e., the large muscles of the lower back, abdominals, hips, and thighs). Having a strong power zone contributes most to dynamic functional living.

■ Summary

The review of research literature strongly supports the theory that resistance training can improve the physical qualities of life for the aging adult. A major goal of resistance training should be to maintain sufficient muscle function to last one's lifetime. While training should start at as early an age as possible, men and women who are 50 or older can greatly benefit from it.

The benefits of a resistance-training program depend upon the type and intensity of training as well as on the muscle groups that are trained. Research favors free weights over machines, high intensity over moderate intensity, and emphasis on full-range large muscle group exercises, with hip and leg exercises being the most critical for improving functional capacity. However, the use of machines is recommended for the elderly where balance is a problem.

The idea that the older adult can derive health benefits from resistance training is no longer considered theory but confirmed fact. A broad-based strength fitness program is a must for individuals 50 and over to build and maintain strength, coordination, flexibility, and strong bones. The training outcomes will be evidenced by an overall feeling of physical and mental well-being. ▲

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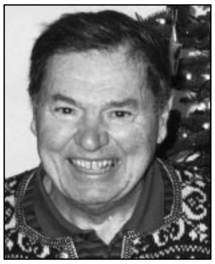 

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