Resistance Training for Older Adults: Position Statement From the National Strength and Conditioning Association

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Abstract

Fragala, MS, Cadore, EL, Dorgo, S, Izquierdo, M, Kraemer, WJ, Peterson, MD, and Ryan, ED. Resistance training for older adults: position statement from the national strength and conditioning association. *J Strength Cond Res* XX(X): 000–000, 2019—Aging, even in the absence of chronic disease, is associated with a variety of biological changes that can contribute to decreases in skeletal muscle mass, strength, and function. Such losses decrease physiologic resilience and increase vulnerability to catastrophic events. As such, strategies for both prevention and treatment are necessary for the health and well-being of older adults. The purpose of this Position Statement is to provide an overview of the current and relevant literature and provide evidence-based recommendations for resistance training for older adults. As presented in this Position Statement, current research has demonstrated that countering muscle disuse through resistance training is a powerful intervention to combat the loss of muscle strength and muscle mass, physiological vulnerability, and their debilitating consequences on physical functioning, mobility, independence, chronic disease management, psychological well-being, quality of life, and healthy life expectancy. This Position Statement provides evidence to support recommendations for successful resistance training in older adults related to 4 parts: (a) program design variables, (b) physiological adaptations, (c) functional benefits, and (d) considerations for frailty, sarcopenia, and other chronic conditions. The goal of this Position Statement is to a) help foster a more unified and holistic approach to resistance training for older adults, b) promote the health and functional benefits of resistance training for older adults, and c) prevent or minimize fears and other barriers to implementation of resistance training programs for older adults.

Key Words: strength training, elderly, frail, seniors, exercise, resistance exercise

Summary Statements

The purpose of this Position Statement is to provide an overview of the current and relevant literature, evaluate exercise program variables, and provide evidence-based recommendations for resistance training for older adults. Current research has demonstrated that countering muscle disuse through resistance training is a powerful intervention to combat muscle strength loss, muscle mass loss (sarcopenia), physiological vulnerability (frailty), and their debilitating consequences on physical functioning, mobility, independence, chronic disease management, psychological well-being, and quality of life.

A list of 11 summary statements for effective resistance training in older adults is presented in 4 parts below. The goals of these recommendations are to (a) help foster a more unified and holistic approach to resistance training for older adults, (b) promote the health and functional benefits of resistance training for older adults, and (c) prevent or minimize fears and other barriers to implementation of resistance training programs for older adults.

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Part 1: Resistance Training Program Variables

1. A properly designed resistance training program with appropriate instructions for exercise technique and proper spotting is safe for healthy, older adults.
2. A properly designed resistance training program for older adults should include an individualized, periodized approach working toward 2–3 sets of 1–2 multijoint exercises per major muscle group, achieving intensities of 70–85% of 1 repetition maximum (1RM), 2–3 times per week, including power exercises performed at higher velocities in concentric movements with moderate intensities (i.e., 40–60% of 1RM)
3. Resistance training programs for older adults should follow the principles of individualization, periodization, and progression.

Part 2: Positive Physiological Adaptations to Resistance Exercise Training in Older Adults

4. A properly designed resistance training program can counteract the age-related changes in contractile function, atrophy, and morphology of aging human skeletal muscle.

5. A properly designed training program can enhance the muscular strength, power, and neuromuscular functioning of older adults.
6. Adaptations to resistance training in older adults are mediated by neuromuscular, neuroendocrine, and hormonal adaptations to training.

Part 3: Functional Benefits of Resistance Exercise Training for Older Adults

7. A properly designed resistance training program can improve mobility, physical functioning, performance in activities of daily living (ADL), and preserve the independence of older adults.
8. A properly designed resistance training program can improve an older adult's resistance to injuries and catastrophic events such as falls.
9. A properly designed resistance training program can help improve the psychosocial well-being of older adults.

Part 4: Considerations for Frailty, Sarcopenia, or other Chronic Conditions

10. Resistance training programs can be adapted for older adults with frailty, mobility limitations, cognitive impairment, or other chronic conditions.
11. Resistance training programs can be adapted (with portable equipment and seated exercise alternatives) to accommodate older adults residing in assisted living and skilled nursing facilities.

Introduction

Effect of Age on Skeletal Muscle Mass and Strength

Aging, even in the absence of chronic disease, is associated with a variety of biological changes that can contribute to decreases in skeletal muscle mass, strength, and function, leading to a general decrease in physiological resilience (ability to tolerate and recover from stressors) and vulnerability to catastrophic events (355). As a complex and multidimensional phenomenon, aging manifests differently between individuals throughout the lifespan and is highly conditional on interactions between genetic, environmental, behavioral, and demographic characteristics (52). The growth of the older adult population (often defined by chronological age of age 65 years of age and older), due to lower mortality and increasing lifespan, has led to a diversification and growth in chronic disease morbidity (49). Such growth includes an increased prevalence of aging-related mobility impairments and a substantial reduction in the number of nondisabled years in the United States (32,233,649). Even with healthy aging (aging in the absence of disease), reductions in physiological resilience often lead to physical disability, mobility impairment, falls, and decreased independence and quality of life (638). Chronic health conditions, that commonly accompany aging, such as cardiovascular or metabolic disease, may exacerbate the vulnerability to such conditions and loss of physiological resilience.

Age-related loss of muscle mass (originally termed sarcopenia) (395,519) has an estimated prevalence of 10% in adults older than 60 years (538), rising to >50% in adults older than 80 years (39). Prevalence rates are lower in community-dwelling older adults than those residing in assisted living and skilled nursing facilities (139). Loss of muscle mass is generally gradual, beginning after age 30 and accelerating after age 60 (413). Previous longitudinal studies (199,225) have suggested that muscle mass decreases by 1.0–1.4% per year in the lower limbs, which is more than the rate of loss reported in upper-limb muscles (207,298). Sarcopenia is considered part of the causal pathway for strength loss (200,494), disability, and morbidity in older adult populations (518). Yet, muscle weakness is highly associated with both mortality and physical disability, even when adjusting for sarcopenia, indicating that muscle mass loss may be secondary to the effects of strength loss (124).

The contribution of age-related losses in muscle mass to functional decline is mediated largely by reductions in muscle strength (409,456,632). The rate of decline in muscle strength with age is 2–5 times greater than declines in muscle size (155). As such, thresholds of clinically relevant muscle weakness (grip strength of <26 kg in men and <16 kg in women) have been established (14) as a biomarker of age-related disability and early mortality. These thresholds have been shown to be strongly related to incident mobility limitations and mortality (409). In addition, the European Working Group on Sarcopenia in Older People recently updated their recommendations to focus on low muscle strength as the key characteristic of sarcopenia and use detection of low muscle quantity and quality to confirm the sarcopenia diagnosis (138). Given these links, grip strength (a robust proxy indicator of overall strength) (192) has been labeled a "biomarker of aging" (526). Losses in strength may translate to functional challenges because decreases in specific force and power are observed (155,225,292,412). Declines in muscle power have been shown to be more important than muscle strength in the ability to perform daily activities (37,292). Moreover, a large body of evidence links muscular weakness to a host of negative age-related health outcomes including diabetes (469), disability (407,409), cognitive decline (13,74,85,590), osteoporosis (406), and early all-cause mortality (367,409,470,653).

Age-related changes in skeletal muscle mass, strength, and function may be attributable to a variety of mechanisms, including disuse, impaired protein synthesis, and chronic inflammation. In regard to muscle disuse, individuals who are physically inactive have been found to have double the risk of future mobility limitation compared with those who meet the US Surgeon General's recommendations for physical activity (634). Moreover, several studies have demonstrated impaired protein synthesis and decreased muscle anabolism with aging (145,247,253,325,511,628,640). Declines in protein synthesis impair muscle contractile function, strength, and protein quality (26,123,253). There is also a growing consensus that the low-grade chronic inflammation in aging (inflammaging) is a strong risk factor for both morbidity and mortality in older adults (193) and may represent a strong mechanism linking age-related increases in adiposity and metabolic dysregulation with sarcopenia and muscle weakness (41,311).

Resistance Training to Counter Consequences of Aging and Disuse

Given the undesirable physical consequences of aging, strategies for both prevention and treatment are necessary for the health and well-being of older adults. Among the contributors to the aging process, muscle disuse is a preventable and reversible factor. Muscle "use" in the form of resistance exercise training has been consistently shown as a feasible and effective means of counteracting muscle weakness and physical frailty (184), attenuating age-related intramuscular adipose infiltration (223), improving physical performance (61,242), increasing muscle fiber area (242), improving muscle quality (174,184,223), bone density (397), metabolic health and insulin sensitivity (146), management of chronic health conditions (268), quality of life (152), psychological well-being (108,119,660), extended independent living (567), and reduced risk for falls and fractures in older adults (553). Moreover, resistance exercise may improve metabolic capacity of skeletal muscle by improving glucose homeostasis, preventing intramuscular lipid accumulation, increasing oxidative and glycolytic enzyme capacity, enhancing amino acid uptake and protein synthesis, and shifting the anabolic/catabolic milieu toward anabolism through release (173,304,364).

Resistance training is considered an important component of a complete exercise program to complement the widely known positive effects of aerobic training on health and physical capacities (480,541). There is strong evidence that resistance training can mitigate the effects of aging on neuromuscular function and functional capacity (66,88,91,465,553,573). Various forms of resistance training have potential to improve muscle strength, mass, and power output (243,291). Evidence reveals a dose-response relationship where volume and intensity are strongly associated with adaptations to resistance exercise (573). In addition, chronic resistance exercise improves bone mineral density and decreases abdominal and visceral fat mass (142,438,539,543,643); in adults with type 2 diabetes, resistance exercise reduces hemoglobin A1c (HbA1c) compared with aerobic training (87). For these reasons, resistance exercise is often considered a "medicine" (542,643).

Despite the known benefits of resistance training, only 8.7% of older adults (>75 years of age) in the United States participate in muscle-strengthening activities as part of their leisure time (570). Reported barriers to participation in resistance exercise for older adults include safety, fear, health concerns, pain, fatigue, and lack of social support (86). The low participation rates and broad health benefits underscore the need for evidence-based guidelines and recommendations for resistance exercise for older adults to safely and beneficially incorporate strength training into their lives.

When performed regularly (2–3 days per week), and achieving an adequate intensity (70–85% of 1RM) and volume (2–3 sets per exercise) through periodization, resistance exercise results in favorable neuromuscular adaptations in both healthy older adults and those with chronic conditions. These adaptations translate to functional improvements of daily living activities, especially when power training exercise is included. In addition, resistance training may improve balance, preserve bone density, independence, and vitality, reduce risk of numerous chronic diseases such as heart disease, arthritis, type 2 diabetes, and osteoporosis, while also improving psychological and cognitive benefits.

Process

Using an evidence-based practice approach, the authors integrated scientific evidence, professional expertise, and end-user considerations to develop recommendations for the interests, values, needs, and choices of older adults. Key steps in the evidence-based practice approach involved: (a) framing each statement as a hypothesis, (b) collecting the evidence, (c) assessing the evidence, (d) integrating the evidence with practical aspects, and (e) making each recommendation based on the evidence (21). As evidence was drawn from a variety of research-based methodologies, no single approach was ideally suited for assessing the strength of all existing scientific evidence (642). Thus, the Position Statement presents a critical review of the major relevant published work using a scoping review of the literature (610) according to the specified inclusion criteria. As there is broad biological variation among older adults of similar chronological age and age-related changes in skeletal muscle generally begin during middle age, no standard definition of "older age" based on chronological age was deemed adequate. Instead, due to the broad physiological and functional diversity, and onset of age-related consequences to skeletal muscle, studies included subjects aged 50 years and older.

Inclusion Criteria for Publications

1. Full-article publication (not just an abstract)
2. Peer-reviewed publication
3. Years of publication (1965–2018)
4. English language publication
5. Study subjects 50 years of age and older
6. Random assignment to intervention groups
7. Presence of comparison group
8. Use of validated method of outcome measurement

Evidence for Summary Statements

Part 1: Resistance Training Program Variables

A Properly Designed Resistance Training Program With Appropriate Instructions for Exercise Technique and Proper Spotting Is Safe for Healthy Older Adults. Both research and clinical experience indicate that resistance training is safe for healthy older adults (404), frail (physiologically vulnerable) older adults (94,621), and individuals with disease (404). A systematic review on the effects of resistance training in physically frail oldest-old (70–92 years of age and older) reported only one case of shoulder pain with resistance training out of 20 studies and 2,544 subjects (96). On the other hand, some cases of injuries associated with resistance training have been reported in older individuals, mainly in those non-experienced subjects. These injuries are mainly related to a combination of heavy and repetitive workload, unfavorable positioning or incorrect technique, and exercise selection (563). Special care should be taken with the shoulder complex, due to its susceptibility, as well as hip, knee, and spine structures (334,361). To maintain safety, proper program design is required, and special care and consideration is needed in resistance exercise training for some older adult populations to reduce the risk associated with their specific condition. For example, exercise prescription for an older adult with uncontrolled hypertension should consider acute elevations in blood pressure, which occur with resistance training. As with aerobic training, cardiovascular risks associated with resistance training may increase with age and are also dependent on habitual physical activity and fitness level, and intensity of training (647). Interestingly, some evidence indicates that resistance training may result in a more favorable balance in myocardial oxygen supply and demand than aerobic exercise because of lower heart rate and higher myocardial (diastolic) perfusion pressure (179). Resistance training should be prescribed in combination with aerobic training because both types of exercise elicit distinct benefits, such as improvements in neuromuscular and cardiovascular functions (91), respectively, and both muscle strength and aerobic fitness are inversely associated with all-cause mortality in older individuals (521).

Engaging in resistance exercise performed until concentric failure will elicit a marked increase in the blood pressure, heart rate, and cardiac output (404), and thus, this type of resistance training approach should be avoided in older adults with uncontrolled high blood pressure. Research has supported resistance exercise as generally safe in individuals with controlled hypertension (217,227), and training may assist in managing high blood pressure. When hypertension is controlled and medical examination and clearance precede exercise, resistance exercise is safe. In a study of more than 26,000 healthy subjects 20–69 years of age (all of them whom had resting blood pressure <160/90 mm Hg) who underwent a preliminary medical examination (227), no significant cardiovascular events were reported with 1RM strength testing.

Despite the reported safety, medical screening can help to evaluate appropriateness for resistance exercise training and may identify older adults with unstable medical conditions who may be at increased risk. Because of the potential risk of dangerous elevations in blood pressure, especially during the Valsalva maneuver, some absolute and relative contraindications to resistance training exist. Absolute contraindications include unstable coronary heart disease (CHD), decompensated heart failure, uncontrolled arrhythmias, severe pulmonary hypertension (mean pulmonary arterial pressure >55 mm Hg), severe and symptomatic aortic stenosis, acute myocarditis, endocarditis, or pericarditis, uncontrolled hypertension (>180/110 mm Hg), aortic dissection, Marfan syndrome, and high-intensity resistance training (80–100% of 1RM) in patients with active proliferative retinopathy or moderate or worse nonproliferative diabetic retinopathy. Relative contraindications (should consult a physician before participation) include major risk factors for CHD, diabetes in any age, uncontrolled hypertension (systolic blood pressure >160 mm Hg and/or diastolic blood pressure >100 mm Hg), low functional capacity (<4 metabolic equivalents), musculoskeletal limitations, and individuals who have implanted pacemakers or defibrillators (110,217,644). Exercise progression from low to moderate intensity before attempting vigorous or high intensity allows exercise tolerance to be evaluated more effectively. In addition, training intensity and progression should be established through individualization and consideration of training experience. Besides being safe, resistance exercise is relatively free of potential unwanted side effects caused by common medications that are prescribed in patients with multiple comorbidities (90). Special considerations should be also taken regarding joint pain or instability from osteoarthritis (OA) or other causes. These conditions require alternative ways to train the same muscle groups, considering different exercises (for example, leg press rather than squats in knee OA), lower intensities, different type of contraction, reduced range of motion (transitory or permanent), among others. All these strategies must be applied to avoid worsening in pain and clinical condition (392,442).

A Properly Designed Resistance Training Program for Older Adults Should Include an Individualized and Periodized Approach Working Toward 2–3 Sets of 1–2 Multijoint Exercises per Major Muscle Group, Achieving Intensities of 70–85% of 1 Repetition Maximum, 2–3 Times per Week, Including Power Exercises Performed at Higher Velocities in Concentric Movements With Moderate Intensities (i.e., 40–60% of 1 Repetition Maximum): Intensity (Table 1). Intensity of resistance training is classically defined as the training load (i.e., in percentage or absolute value) relative to maximal dynamic strength (i.e., 1RM) (16,18). Some original studies have shown similar strength gains between moderate- to high-intensity resistance training (i.e., >70% of 1RM) compared with moderate resistance training (i.e., 51–69% of 1RM) (78,629). Yet, some meta-analyses and systematic reviews have suggested greater effects of high-intensity resistance training on strength compared with moderate- and low-intensity resistance training, as well as greater effects of moderate intensity on muscle strength compared with low-intensity resistance training (66,465,553,573), even in frail older adults (621). Physiologically, human motor units are recruited in order of increasing motor neuron size, according to the "size principle" to accommodate increasing intensity or load (148,169).

Steib et al. (573) performed a meta-analysis including 22 articles that compared the effect of different resistance training protocols (i.e., direct dose-response investigation) on muscle strength and functional tests of performance in older adults (aged 65 and 80 years of age). These authors observed that intensities higher than 75% of 1RM achieved greater effect on maximal strength enhancement than moderate (55–75% of 1RM) or lower intensities (less than 55% of 1RM). In addition, moderate intensity (55–75% of 1RM) achieved greater effects on maximal strength than low (55% of 1RM) intensities (573). In this meta-analysis, only 3 studies comparing different intensities of functional tests were included, and no differences in functional outcomes among different training intensities were observed (573). In addition, a meta-analysis, including 25 randomized clinical trial (RCT) investigating the effects of resistance training in sedentary older adults (mean age of 65 years of age and older), found that intensities of 70–79% of 1RM induced larger effects on muscle strength (standardized mean differences [SMD] between groups = 1.89) than lower intensities (66).

However, the same was not observed when assessing resistance training effects on muscle morphology (size and shape): moderate intensities of 51–69% of 1RM (SMD = 0.43, 9 studies included in analysis) yielded larger effects than either lower or higher intensities (66). Petersen et al. (465) conducted a meta-analysis including 47 studies that investigated resistance training effects of lower- and upper-body strength of older subjects (mean age of majority of studies was 60–75 years of age). These authors observed that the only between-study predictor that had a significant association with strength improvement was training intensity (i.e., incremental increase in intensity subgroup induced change in maximal strength gains of 5.3%) (465). Moreover, in a meta-analysis comparing the effects of resistance training between high intensities (i.e., intensities progressing until 80% of 1RM) and low to moderate intensities (i.e., intensities progressing until 60% of 1RM), Csapo et al. (140) found that increases in strength were 43% for high intensity and 35% for low to moderate intensity, and average increases in muscle size were 11 and 9%, respectively (mean age of 67 years of age, only 2 of 15 studies included subjects aged 50–60 years of age).

In summary, in healthy adults older than 60 years of age, resistance training intensity should achieve 70–85% of 1RM during training periodization to optimize strength gains. Changes in muscle morphology and functional performance may also be achieved at low to moderate intensities (approximately 50–70% of 1RM). Although periodized and nonperiodized resistance training programs may elicit similar neuromuscular adaptations, lower (or sometimes higher) intensities may be used to vary the training, prevent boredom, and also promote training adaptations in periodized programs as intensity progresses up to 85% of 1RM.

Volume. Training volume refers to the total amount of weight lifted during a training session (449). More specifically, volume-load refers to the summation of the total number of sets multiplied by the number of repetitions per set, multiplied by the weight lifted for each repetition (449). This subsection will provide evidence regarding the most effective number of sets per exercise, repetitions, and time under tension to optimize muscle strength and size.

In early phases of resistance training, the number of sets per exercise does not seem to be the primary variable responsible for muscle strength increases in older adults. Similar results have been shown in older women when comparing 1–3 sets during short-term training periods (i.e., 6–12 weeks of training) (6,486). However, an advantage has been observed in favor of 3 sets during longer resistance training periods (209,486).

The results of a meta-analysis investigating the effects of resistance training on lean body mass of aging subjects showed that a higher number of sets per session were associated with greater increases in lean body mass (465). In addition, in a meta-analysis by Borde et al. (66), 2–3 sets per exercise and 7–9 repetitions produced the greatest effects on muscle strength and muscle morphology (mean SMD of 2.99 and 1.98 for muscle strength, and 0.78 and 0.49 for muscle morphology, respectively). In addition, a metaregression analysis revealed that moderate volume (defined by the product of sets × repetitions) (i.e., 24 repetitions) increased muscular power more than low (i.e., <24 repetitions) and high volume of resistance training (i.e., >24 repetitions) (580). The number of repetitions is strongly determined by percentage of 1RM, and for this reason, lower repetitions may induce greater strength gains due to the higher training intensity used. Yet, repetitions to failure are not necessary and do not promote additional physiological adaptations in older individuals (92,141). In general, 50–70% of the maximal number of repetitions possible performed in good form is sufficient to elicit neuromuscular improvements while avoiding poor form and injury.

In summary, 2–3 sets of 6–12 repetitions at 50–85% of 1RM per muscle group should be prescribed to promote greater maximal strength and muscle size gains. The number of repetitions is dependent on the intensity (i.e., load) used and should be adjusted accordingly, considering that repetitions to failure are not needed to optimize neuromuscular adaptations. One multijoint exercise should be prescribed for major muscle groups, although lower limbs may respond better to 2 exercises (i.e., leg press and knee extension) (141).

Frequency. Training frequency represents the number of resistance training sessions performed per week, per muscle group. In a meta-analysis by Steib et al. (573), in which 2 randomized controlled trials were included in training frequency analyses, training 2 times weekly produced higher SMD than training one time weekly (SMD between groups = 1.55) (160), and training 3 times weekly achieved higher SMD on maximal strength than training one time weekly (SMD between groups = 2.57) (589). A meta-analysis by Borde et al. (66) showed that 2–3 sessions per week produced greater effects on muscle strength measures (SMD between intervention and control groups of 2.13 and 1.49 for 2 and 3 times per week, respectively). In addition, 2–3 sessions per week also resulted in increases in muscle size (66). Of note, 8 of 9 randomized controlled trials included in the meta-analysis examined the effects of resistance training on muscle mass using a training frequency of 3 times per week.

In summary, a training frequency of 2–3 times per week, per muscle group, provides the optimal stimulus to maximize increases in strength and skeletal muscle size in older adults.

Speed of Movement and Power. Resistance training performed at maximal velocity during the concentric phase (i.e., explosive resistance training where muscles exert maximum force in short intervals of time) may promote greater functional improvements than resistance training performed at slower velocities in older adults (71,488). This may reflect the ability to perform ADL, which may be more dependent of the capacity to apply force quickly than the capacity to exert maximal strength (105,245,291,500).

Some studies have shown greater functional enhancements comparing explosive resistance training and traditional resistance training in older adults (44,71,416,488). In a meta-analysis by Steib et al. (573), explosive resistance training was more effective than traditional resistance training in improving performance of the chair rise (SMD = 1.74), and somewhat effective for stair-climbing ability (SMD = 1.27), whereas no differences between resistance training modes were observed in walking speed, timed up and go (TUG) test, and maximal strength. As expected, explosive resistance training induced greater increases in maximal power than traditional resistance training (SMD = 1.66).

More recently, Straight et al. (580) performed a meta-analysis including 12 RCTs assessing lower-body muscular power (only 1 of 12 RCTs included individuals less than 60 years of age). These authors showed that explosive resistance training was more effective than traditional resistance training for increasing lower-body muscular power. Interestingly, no effects of training intensity were observed in lower-body muscular power. One interesting characteristic of explosive resistance training prescription in older adults is that maximal strength and power, as well as muscle size and functional performance enhancements, are achieved at low to moderate intensities (i.e., 40–60% of 1RM) (88,488).

Individual studies have also shown that performing explosive resistance training at low, moderate, and high intensities induce similar neuromuscular and functional adaptations in older adults (150,501). This can be explained because performing muscular actions at high velocities includes the recruitment of high threshold motor units composed of type II muscle fibers (4). In addition, because force is the product of mass displaced and acceleration, even at a moderate intensities, performing repetitions at a faster velocity increases the net force considerably. Moreover, given that speed of movement is inversely associated with relative intensity, it may be considered a direct indicator of training intensity (524).

Several RCTs and meta-analyses have provided evidence that resistance training programs using high velocity of movement during the concentric phase with moderate intensities (i.e., 40–60% of 1RM) induce increases in maximal strength, muscular power output, muscle mass, and functional capacity in older adults (44,71,88,416,488,573); however, there is a lack of data comparing different numbers of sets and different training frequencies of this specific type of resistance training.

Recent evidence suggests that both one and 3 sets of power training performed over 12 weeks improves dynamic and isometric strength, contractile impulse, and functional performance in older women (487). Moreover, to optimize the power output during the sets and avoid muscle fatigue, repetitions should not be performed until concentric failure (230). Muscle fatigue may pose safety risks and is not necessary for strength and power adaptive responses (230). Exercises designed and prescribed for power development should be implemented with special attention and proper form and technique to reduce risk of injury. Before progressing in load, speed, or intensity, proper form should be achieved. In addition, exercises for power development should avoid deceleration (holding on the bar/load) to maximize neuromuscular stimuli. Ballistic movements in open chain exercises such as knee extension and chest press should be avoided in knee OA and rotator cuff diseases, respectively. In addition, the leg press exercise should be avoided in lumbar spine disk degeneration and OA conditions, as well as in hip OA.

Because there is a discordance between the magnitude of neuromuscular adaptations induced by explosive resistance training at moderate intensities, and high-intensity traditional resistance training, both types of training are recommended and should be combined throughout a periodized resistance training program.

In summary, resistance training should include power exercises performed at high velocities in concentric movements with moderate intensities (i.e., 40–60% of 1RM) to benefit functional improvements.

Maximizing Adaptations in Strength and Cardiorespiratory Endurance. Resistance and endurance training have specific cardiovascular and neuromuscular adaptations that are different in nature. The primary adaptations to resistance training include muscle cell hypertrophy, increase in the maximal motor unit recruitment, enhanced maximal motor unit firing rate, elevated spinal motorneuronal excitability, and increased efferent motor drive (339). These neuromuscular adaptations result in enhanced strength and power (4). By contrast, endurance training induces central and peripheral adaptations that enhance $\dot{V}O_2$max and the ability of skeletal muscles to generate energy through oxidative metabolism. These adaptations include enhanced mitochondrial biogenesis, myoglobin content, capillary density, substrate stores, and oxidative enzyme activities, as well as enhanced maximal cardiac output (94).

With both aerobic exercise (72) and strength training (275,601), there is considerable variation among individuals in responses to training. Both responders and nonresponders to training are apparent, even when accounting for factors such as age, sex, and ethnicity (72,275,601). Thus, genetic differences are partially attributable for the interindividual variation in both adaptations with exercise training and age-related changes (210,624). In fact, heredity studies show that up to 76% of muscle mass (5) and 65% of muscle strength (103,495) have been attributed to genetics. Multiple genes as opposed to specific polymorphisms seem to contribute to the declines in muscle strength, size, and function with age (210). Yet, some evidence suggests that the relative contribution of genetics to strength declines with aging, as environmental factors (103) and chronic diseases (194) play a larger role.

A combination of strength, power, and endurance training (i.e., "concurrent training") in older adults seems to be the most effective strategy to counteract declines in muscle mass, strength, cardiorespiratory fitness, neuromuscular function, and functional capacity (89). Concurrent training also increases overall physical activity for the prevention and control cardiometabolic diseases.

However, the concomitant promotion of neuromuscular and cardiorespiratory adaptations might be challenging because an excessive volume and intensity, especially in the endurance training prescription, may compromise the neuromuscular adaptations induced by resistance training (i.e., interference effect) (95,203,267,345,434). Thus, to optimize the concurrent training prescription, it seems relevant to identify the most effective combination of training variables (i.e., intensity, volume, weekly frequency, and exercise order) to promote both neuromuscular and cardiovascular adaptations in the older adults. The volume and frequency of training plays a critical role in concurrent training-induced adaptations in older adults. One study suggested a minimum weekly frequency of concurrent training (1 session per week of strength and 1 session per week of cycle endurance training) may promote marked increases in strength, muscle size, and endurance performance in previously untrained older adult subjects (293). If time constraints prevent a person from meeting frequency recommendations, a minimal frequency of 1 time per week may be used to prevent muscle atrophy.

Studies investigating training programs with greater weekly volumes report that concurrent training induces similar strength adaptations using 2 sessions per week of each training type (i.e., strength and endurance) on separate (i.e., 4 total training days: 2 resistance training + 2 endurance training) days when compared with strength training alone (551). However, 3 times per week of concurrent training with resistance and endurance training performed on same day can result in an "interference effect" in this population (95). Greater strength increases have been observed with strength training when compared with concurrent training when performed 3 times per week (95). Despite the potential interference effect, the strength gains observed were comparable with those observed in studies where strength and concurrent training groups increased strength similarly (293,551,650). In addition, intrasession exercise sequence may also influence the magnitude of strength adaptations in older adults (554). Performing strength training before endurance exercise may optimize the neuromuscular adaptations in this population; however, it should be noted that both exercise orders promoted similar muscle hypertrophy and endurance increases (91). It has also been shown that concurrent training both 2 and 3 times per week induce similar neuromuscular and cardiovascular changes in previously well-trained older adults (180).

In summary, concurrent training protocols should be performed 2–3 times per week. Lower concurrent training frequency (1 session per week of strength and 1 session per week of endurance training such as cycling) may also promote marked neuromuscular and cardiovascular changes in untrained older adults. In the case of both strength and endurance training being performed on the same day, strength changes may be optimized with strength training performed before endurance exercise during intrasession exercise sequences.

Functional Movement. Progressive resistance training is recommended to prevent or reduce late-life disability for older adults (42,533). Some studies have highlighted that once muscle strength has reached a certain threshold, additional strength improvements may not provide additional benefits to ADL performance (69,144,323,324,359,378,380,410,559). Therefore, the incorporation of functional training exercises to a multicomponent training program is beneficial for added improvement of ADL performance (162,168,394). Functional training focuses on multijoint, complex, and dynamic movements and incorporates variations to advance one's functional capacity to execute a certain task of daily living (557). Functional training improves ADL performance through training with movement specificity, whereby performed exercises require similar movement patterns to those of ADL and everyday movements. Some trials show that functional training programs have positive effects on ADL performance and can be sustained even 6 months after the conclusion of training (125,151,220).

The age-related decline in physical function can be only partly be explained by the loss of muscle mass or muscle strength. Other essential motor control aspects also strongly influence an older

Table 1
Resistance training general recommendations for healthy older adults.†

Program variable	Recommendation†	Details
Sets	1–3 sets per exercise per muscle group	1 set for beginners and older adults with frailty progressing to multiple sets (2–3) per exercise.
Repetitions	8–12 or 10–15	Perform 6–12 reps with variation for muscular strength for healthy older adults. Perform 10–15 repetitions at a lower relative resistance for beginners.
Intensity	70–85% of 1RM	Begin at a resistance that is tolerated and progress to 70–85% of 1RM using periodization. Lighter loads are recommended for beginners, or individuals with frailty, or special considerations such as cardiovascular disease and osteoporosis. Exercises should be performed in a repetition-range intensity zone that avoids going to failure to reduce joint stress.
Exercise selection	8–10 different exercises	Include major muscle groups targeted through multijoint movements (e.g., chest press, shoulder press, triceps extension, biceps curl, pull-down, row, lower-back extension, abdominal crunch/curl-up, quadriceps extension or leg press, leg curls, and calf raise).
Modality	Free-weight or machine-based exercises	Beginners, frail older adults, or those with functional limitations benefit from machine-based resistance training (selectorized weight or pneumatic resistance equipment), training with resistance bands, and isometric training. High functioning older adults gain added benefit from free-weight resistance training (e.g., barbells, dumbbells, kettlebells, and medicine balls).
Frequency	2–3 days per week, per muscle group	Perform on 2–3 nonconsecutive days per week, per muscle group, may allow favorable adaptation, improvement, or maintenance.
Power/explosive training	40–60% of 1RM	Include power/explosive exercises where high-velocity movements are performed during the concentric phase at moderate intensities (i.e., 40–60% of 1RM) to promote muscular power, strength, size, and functional tasks.
Functional movements	Exercises to mimic tasks of daily living	Healthy, high functioning older adults benefit from the inclusion of multijoint, complex, and dynamic movements, with base of support or body position variations.

*RM = repetition maximum.
†General guidelines are provided. Resistance training programs should include variation in intensity and program variables. Strength exercises should be performed before endurance training during concurrent training sessions to optimize strength gains.

adult's functional performance of ADL, including the deterioration in dynamic balance and movement coordination (534). Through progressive complex and coordinated movements, functional training can incorporate multiple motor control aspects to better simulate ADL performance (378). Previous studies applied functional training through dynamic balance-based resistance training exercises, such as weighted box step-ups (374) to improve lower-body functional strength, by adding weight to everyday functional movements such as chair stands (559), or by practicing functional movements at different speeds (349). A combination of balance and coordination activities, such as practicing an ADL task in a posture that challenges balance has also been used (125). In addition, exercises can be modified to a limited range of motion, as needed, while still improving range of motion, strength, and function (571). The efficacy of these various methods has not been compared, and such comparison is difficult due to the varied design and assessment methods used in relevant functional training studies. However, it has been recommended that comprehensive exercise programs that include dynamic resistance training for muscle strength, power, and endurance improvement, combined with dynamic balance and functional movement tasks, can improve physical capacity and prevent functional decline in older adults (315). Like progressive resistance training, functional training exercises, intensity, and range of motion should be individualized to a person's ability.

In summary, dynamic balance and functional training in combination with dynamic resistance training can improve physical capacity and prevent functional decline in older adults.

Resistance Training Programs for Older Adults Should Follow the Principles of Individualization, Periodization, and Progression. Program design of resistance training for older adults should make use of the same principles that have been well established for younger populations (17,341), yet individualization may be even more important for the older adult. When working with any older individual, needs assessments and individualized modifications of the resistance training workouts and programs should be made. Workouts and training programs should ideally be monitored and designed to match the unique physical, psychological, and medical challenges of the individual and address any comorbidities, orthopedic issues, mobility, and/or toleration of the training modality (e.g., endurance, strength, and power or functional training), to sequentially meet their changing health/fitness goals over time. Furthermore, supervision of the workouts in a resistance training program may be important to facilitate optimal improvements in muscle, strength, and balance (354).

Acute program variables are important to consider with respect to the design of the individual workouts and then progression over a training period. Such designs should be based on recovery and possible need for modification in the resistance training program. Selection of exercises determines the musculature that may benefit from enhanced for strength, power, and local muscular endurance. Decisions on whole-body programs versus highly specific single muscle groups or a few dedicated exercises for a muscle group (e.g., knee extensors) must be made. Many research studies are designed to examine the effects of training for a specific muscle group and thus may incorporate only 1–3 exercises for that muscle group. However, the practical application for this where individuals are training the whole body remains uncertain. In addition, the type or modality (e.g., free weights, machines, isoinertial, or type of repetition actions) will affect various features of the neuromuscular system. The order of exercises will be important for programs due to the progression of fatigue through a workout. Typically, large muscle groups are trained in the early part of a program. The order of exercises also is critical for circuit-type protocols, where different exercises are performed in sequence with short rest intervals, due to fatigue development with different sequences of exercises.

The training load used in older adult studies is often 30–90% of 1RM and is typically dependent on the progression and periodization schemes used, as well as the length of intervention (66,465). Repetition maximum and RM zone training has been used in various studies, but joint stress and soreness should be monitored when training at high intensities. Isoinertial resistance exercise using spinning flywheel(s) have of potential benefits in certain aging populations ready for higher resistance exercise stress (596). The number of sets contributes to total work volume and has ranged from 1 to 4 sets for an exercise and is relative to progression approaches and possible periodization concepts (17). The amount of time taken for rest periods between sets and exercises has ranged from 1.5 to 3.0 minutes in various studies in older adult populations but again is based on toleration of the protocol with a need for symptom-free progression (no dizziness and no nausea, etc.).

General formats for progression in resistance training programs have been published with regards to healthy older adults (17). The basic concern for progression in older adults is tolerance of the workload and optimal recovery. Many early studies have used constant loading and associated volume changes related to the inherent strength gains (201,358,425,483). Other studies have used different loading and volume cycles progressively leading up to heavier resistance loads (12,238,504). A few studies have used nonlinear periodization with different resistances on different days to provide variations (342,441). However, while many options are reported in the literature, only one study has made a direct comparison of different approaches. In a landmark study of aging and resistance training, Conlon et al. (132) made the first direct comparison of nonperiodized, block periodized, and daily undulating periodized training in groups of men (72 years of age) and women (70 years of age). For each health and fitness biomarkers, including systolic blood pressure, blood biomarkers, body composition, maximal strength, functional capacity, and balance confidence, significant improvements were observed with both periodized training protocols. However, no differences were demonstrated between the training groups after 22 weeks using a specific resistance training program (132), unlike younger populations, where periodized programs appear superior to nonperiodized programs for enhancing muscular strength (172). Yet, some evidence suggests that varying resistance may enhance improvements in physical functioning in older adults compared with constant resistance (279).

Thus, multiple approaches to resistance training appear possible, with much more research needed on this topic. Future studies should also address the individual response patterns and effects of program variation over longer periods of training to for adherence. Ultimately, each program needs to progress in a manner related to individual toleration and be specific to targeted goals for the individual.

Part 2: Positive Physiological Adaptations to Resistance Exercise Training in Older Adults

A Properly Designed Resistance Training Program Can Counteract the Age-Related Changes in Contractile Function, Atrophy, and Morphology of Aging Human Skeletal Muscle. Many studies (66,278,468) have examined the effect of resistance training on measures of total body lean mass, cross-sectional area (CSA) of specific appendicular muscles (i.e., quadriceps), and individual muscle fibers through biopsies. A meta-analysis by Peterson et al. (468) demonstrated that older adults (men and women aged 65.5 + 6.5 years) who perform full-body resistance training for an average of 20.5 weeks, experienced a 1.1 kg increase in lean body mass. The authors (468) also noted that training volume and the age of participation influenced the effectiveness of the resistance training on improving lean body mass, with higher training volume associated with greater increases in lean body mass.

Resistance training has been shown to increase skeletal muscle CSA, even in the oldest old (85 years of age and older) (183,352). Previous studies have reported increases of 4–33% in anatomical CSA (50,245,251,290,310,342,427,496,510,516); however, these changes are often smaller than the increases commonly reported for the improvements in muscular strength after resistance training in younger adults (generally 18–35 years of age) (66,140). Research on the effectiveness of resistance training on muscle size in older adults may also be influenced by sex (men > women (288)), the muscles examined (magnitude of increases differ among the 4 muscles of the quadriceps (245)), muscle length (greatest increase near the midregion of the muscle (245,496,510)), and measure of muscle size (e.g., anatomical versus physiological CSA) (496). Training-induced increases in single muscle fiber size have also been reported (201,241,243,352). Previous evidence suggests that fiber hypertrophy may be influenced by sex (29,277) and blunted in advancing age (337,399,472,492). Similarly, single fiber contractile function (i.e., peak force, power, and shortening velocity) is improved after resistance training in older adults (492,609); however, these adaptations seem to also be influenced by sex (608) and advancing age (561).

In summary, resistance training can counteract the age-related changes in contractile function, hypertrophy, and morphology of aging human skeletal muscle.

A Properly Designed and Implemented Training Program Can Enhance the Muscular Strength, Power, and Neuromuscular Functioning of Older Adults: Muscular Strength. Dynapenia has been used to describe the age-related loss of muscle strength (395). Previous studies have indicated that healthy older adults experience a 0.8–3.6% decrease in strength per year, which may be more pronounced in very old adults (199,225,373). Resistance training has been shown to be an effective mode of physical activity to mitigate the age-related loss in muscular strength. For example, upper- and lower-body strength can be significantly improved after resistance training (66,465) with increases ranging from 9 to 174% (7,28,40,53,63,71,81,101,102,115,143,154,177,178,183,232,236,254,257,258,264,271,272,279,281,284) (286,290,291,308–310,342,366,387,416,428,454,477, 482,483,491,497,502,503,516,540,579,581,594,606,630,641). Notably, resistance training elicits improvements in muscular strength even in the very old (>85 years of age) (183,184,351). Several studies have suggested that older adults experience similar percent strength gains when compared with younger adults (241,243,271,441); however, others have reported greater improvements in younger adults (365,389). Several recent meta-analyses and reviews have reported that strength adaptations are influenced by training duration (66) and training intensity (66,465,552,573). However, others have suggested differences between higher and lower intensities are minimized when matched for total training volume (140,493). Taken together, older adults may experience strength gains in response to resistance training that are dependent on duration, intensity, and volume.

Muscular Power. Skeletal muscle power can be defined as the product of the force or torque of a muscular contraction and its velocity. Previous investigations have suggested that skeletal muscle power declines at a greater rate (68,292,412,414,558) and is more closely linked to functional limitations (43,45) when compared with muscular strength in older adults. Resistance training has demonstrated marked improvements in skeletal muscle power ranging from 14 to 97% (150,186,262,263,274,383,398,489,499,528,559). Recent meta-analyses have indicated that high-velocity resistance training may be more effective at improving muscle power when compared with traditional low-velocity resistance training (573,580). Furthermore, lower training volumes have been reported to be associated with greater improvements in muscle power (580).

Rate of Force Development. The rate of force/torque development (RFD/RTD) is a measure of explosive or rapid strength that is commonly derived from the early rise in force/torque during an isometric maximal voluntary contraction (MVC). Age-related reductions in MVC strength (i.e., peak force) are well documented (51,161,216,272,292,602,603). However, RFD/RTD has been reported to decrease at a greater magnitude than maximal strength (161,216,292,330,602,603) and has been suggested to be more important to function (451,452) and falls risk (54,453) in older adults. Upper- and lower-body rapid strength has been shown to significantly increase after resistance training in older adults (34,107,241,243,245,272,583,619).

Muscle Activation. Voluntary muscle activation of agonist muscles and the coactivation of antagonist muscles have been reported to decrease (60,296,426,429,619,659) and increase (292,331,390), respectively, in older adults as a function of aging. However, as noted in previous reviews (280,329), these findings are not universal. Chronic resistance training has been shown to increase agonist muscle activation (428,496,497,529,619), whereas others have reported no changes (181,251,333). It is possible that increases in activation are most noticeable among subjects with lower initial levels of activation (529). Furthermore, a strong positive relationship has been reported between the change in voluntary activation and the change in isometric strength ($r = 0.92$) and specific force ($r = 0.86$) after resistance training in the oldest old (251). Findings regarding the training-induced changes in coactivation are also mixed with previous studies reporting decreases (241,243), no change (427,428,496), and an increase (147) in older adults. It has been suggested that decreases in antagonist coactivation after resistance training may occur in older adults who demonstrate elevated antagonist coactivation (4).

Muscle Architecture. Previous research has reported mixed findings regarding the age-related changes in muscle architecture. For example, previous studies have reported that aging results in decreases in fascicle length and pennation angle (436), decreases in pennation angle only (216,429,604), decreases in fascicle length only (575), and no change in muscle architecture (314). Nonetheless, chronic resistance training has been shown to increase fascicle length (496) and pennation angle (427,496,584). However, Suetta et al. (585) demonstrated that older adults may have an attenuated resistance training-induced change in muscle architecture when compared with younger adults after a period of immobilization.

Chronic Inflammation. Chronic inflammation often accompanies aging (193,443) and is believed to contribute mechanistically to the loss of skeletal muscle mass and function (460). Circulating inflammatory markers (cytokines and acute phase reactants) are typically 2–4 fold higher in older adults (443). Yet, an inverse and independent dose-response relationship between inflammation (as measured by plasma C-reactive protein concentration) and level of physical activity has been reported (443). Long-term resistance training seems to ameliorate inflammation (98). Specifically, as described in a recent meta-analysis, exercise volumes with a higher number of exercises (>8), higher weekly frequency (3 times/week), and longer durations (≥12 weeks) showed reductions in inflammation (as measured by circulating C-reactive protein and TNF-α) (525). Interestingly, evidence suggests that this relationship may be mediated by muscle mass (525).

Lifelong Resistance Training. Most resistance training studies include training periods that may last 6–52 weeks (66), and yet, the aging masters athlete has been used as a model to investigate the effects of resistance training on muscle function and morphology, implemented over the individual's lifetime. Previous studies have reported master athletes competing in weightlifting have greater strength, power, RFD, muscle volume, and mean type II fiber CSA when compared with untrained age-matched controls (3,459,620). Furthermore, a recent study indicated that master athletes demonstrated greater voluntary activation when compared with sedentary and recreationally active older adults and had similar values to younger adults (620). These findings suggest that resistance training may be an important mode of physical activity to counteract the age-related changes in neuromuscular function (620). These studies also reported that chronically resistance-trained athletes demonstrated similar age-related reductions in strength and power when compared with untrained controls (459); however, 85-year-old weightlifters demonstrated similar power to the 65-year-old controls, suggesting an approximately 20-year advantage with chronic resistance training (459). Moreover, older strength trained adults (~68 years of age) have been shown to have muscle features (maximal isometric torques, speed of movements, CSAs, specific tensions, and a content of myosin and tropomyosin isoforms) similar to those of adults 40 years younger (332). Lastly, Kennis et al. (321) demonstrated that previously sedentary older adults, who performed chronic resistance training for 1 year, still possessed greater strength values after 7 years of detraining when compared with an age-matched control group, despite a similar rate of decline in strength over the 7-year follow-up.

In summary, despite age-related declines, older adults engaged in long-term resistance training, preserve muscle strength, power, mass, and function.

Adaptations to Resistance Training in Older Adults Are Mediated by Neuromuscular, Neuroendocrine, and Hormonal Adaptations to Training: Neuromuscular. The primary adaptations to resistance exercise in older adults are observed in the improved neuromuscular domain directly related to the application of load on the muscle. Classic research by Moritani and deVries in 1980 revealed that neural changes may be the primary mediating mechanism for strength gains in older individuals in the early phase of training (425). Muscle strength and hypertrophy increases with resistance training occur at different times (483), indicating 2 distinct mechanisms at work in the adaptive time course. The increases in muscle size resulting from improved neural function are seen as the hallmarks of the adaptive change.

The neuromuscular system experiences distinct aging effects (280). The effects of age have been speculated to impact motor unit function, whether from apoptotic loss with age or nonuse (439). Loss of motor units, even in healthy active individuals, is a primary factor underlying the age-associated reductions in strength (163–166). Investigators have estimated that there is a 47% reduction in the number of motor units in older individuals (60–81 years of age) (165,166). However, older adults tend to recruit large motor units during muscle activation, while smaller motor units are generally recruited in younger individuals during muscle contraction (439). Yet, despite the loss of motor units, older adults are still able to fully activate their muscles during resistance training (84,473). Therefore, muscle weakness that occurs with aging is not believed to be caused by a failure in relative muscle activation.

Resistance training mitigates the rate and magnitude of age-related declines in the neuromuscular system (4,197,199,547). Resistance training in older adults has been shown to produce various neurological changes including increased central nervous system activation, increased amplitude of maximal electromyogram (EMG) activity resulting in a greater magnitude of neuromuscular activity, improvements in the RFD, increases in maximum motor neuron firing frequency, improved fine motor control, improvements in agonist muscle activation and antagonist muscle coactivation, greater force steadiness, and reductions in spinal inhibitory influences, as reviewed by Aagaard et al. (4). Increases in maximum integrated EMGs of the trained muscles are primarily seen during the first 8 weeks of training, indicating altered neural activity for improved performance (238–240,248). With long-term (year-long) moderate- to high-intensity resistance training (3 sets of 8 repetitions at 75% of 1RM, 3 times a week), strength increases rapidly over 3 months, then plateaus with increases ranging from 30% (hip extensors) to 97% (hip flexors) in older adults (average age 68 years of age) (483).

Hypertrophy. Resistance training has been shown in several reviews to be a viable means to collectively improve strength, structure, and function in older men and women (4,58,89,94,96,106,132,208,259,282,388,391,437,474,498, 527,580,615,648). More specifically, resistance training can increase muscle size and effect adaptations in the structural characteristics of muscle and tendons by increasing stiffness and functional (498). Dramatic increases in strength and muscle size occur using circuit training from 50 to 75% of 1RM (611) to 75–90% of 1RM (658) in older men (60 years of age).

Some studies have shown similar gains in older men and women (238,240,607), while others have shown greater muscle size responses to resistance training in older men than women (287,307). Regardless, while CSA changes may be larger in men than women, muscle volume seems to show no sex differences in adaptations to 6 months of training (516). In addition, although 10 weeks of nonlinear, periodized, whole-body resistance training is effective at increasing muscle strength and size in older men, the adaptations are not as profound as those seen in younger men (342). This is likely due to differences in neural and/or hormonal influences.

At the fiber level, hypertrophy with light load and high repetition resistance training has been observed in older men of about 65 years of age (358). Muscle fiber size of both types I and II have been shown to increase in cross-sectional size (33 and 27% respectively), with accompanying computerized tomographic scans also demonstrating a general increase in quadriceps muscle size (201). After 30 weeks of resistance training, the CSA of both type I (58%) and type II (67%) muscle fibers increases (483). Interestingly, skeletal muscle from untrained men and women appear to show some differences in structural aspects of the type I and type II fibers (202). However, chronic resistance training may well diminish the between-sex differences, seen in hypertrophy across fiber types.

In summary, resistance training can improve the neuromuscular structures and functions that are known to deteriorate with age. While the aging process in the neuromuscular system cannot be stopped, it is obvious from work over the past 50 years that it can be attenuated in magnitude and rate of decline across the various neuromuscular systems.

Endocrine Adaptations. Acute hormonal responses to resistance exercise mediate adaptations to resistance training (346). A combination of the acute hormonal response to an exercise bout and the mechanical stimuli of muscle contraction, which impacts cytoplasmic steroid receptors, stimulates muscle growth and remodeling resulting in increases in muscle strength and hypertrophy (346). As resistance exercise stress plays a role on the secretory capabilities as well as changing basal concentrations of the hormones (338), blood sampling of hormones at rest or after resistance exercise has provided insights into the role resistance exercise and training play in adaptations (631). With age, cells and tissues making up various known endocrine glands, as with almost all cells in the human body, change not only their structural make up but also their secretory capabilities (159,382). As evidenced by different literature reviews, resistance exercise has differential impact on various hormone and molecular signaling pathways even with aging (4,531,566,631). Because of the anabolic nature of resistance training, it has been long thought that resistance exercise will enhance structure and function of these glands and play a role in the mitigation of the aging processes (513,517). The interface of hormonal signaling with aging and sarcopenia became apparent through the 1980s and 1990s (549).

The clinical literature has shown that older men demonstrate lower testosterone concentrations in the blood, often called "andropause," yet the progression and individual variation has been controversial (59,175,319,463). However, when hypogonadal function has been properly diagnosed with the constellation of symptoms beyond low testosterone, a multitude of adverse effects in men's physiological function are present (36,104). A 2010 review article noted that resting blood levels of testosterone in men decline at a rate of 1–3% per year after age 40 (631). In women, despite inherently lower values, aging sees a decline in total testosterone with a leveling off or slight increases after menopause (175). With resistance training, resting concentrations of testosterone do not seem to change in older men and women, but effects depend on the type of exercise challenge and/or length of training

(10,12,67,137,201,244,246,289,299,342,504,636). However, in response to an acute bout of resistance exercise, older men produce a significant increase in circulating testosterone (10,246), especially with exercise protocols involving large muscle mass such as squats (342). It remains unclear whether androgen receptor mRNA expression increases in response to resistance training in older men with studies reporting conflicting results (10,12,276). Yet, intramuscular androgen receptor content has been shown to influence skeletal muscle hypertrophy after resistance training in younger men (430). Although resistance exercise can upregulate androgen protein content (by Western Blot analysis) after resistance exercise, the timing of measurement, protocol used, and nutritional status impact upregulation (347,631). Moreover, testosterone also has many nongenomic interfaces with tissues, most notably skeletal muscle (347).

The hypopituitary-adrenal axis is involved in older individual's stress and resilience and culpability for age-related pathologies (205,212). Cortisol, a catabolic hormone, is estimated to increase by 20% from 50 to 89 years of age for both men and women (360). With resistance training, resting cortisol concentrations remain unaltered in older adults (89,244,291). The responses of resting cortisol concentrations to resistance training in older men and women are mixed, with some individuals showing transient decreases or no changes (67,95,244,246,291,342,440). The pattern of the acute cortisol response to resistance exercise is similar in older and younger adults, but the magnitude may be diminished in older adults (67,342,636). However, such findings are dependent on the type of exercise test used, the training program, and/or the length of the training program.

Growth hormone (GH) includes a superfamily of aggregates, splice variants and binding proteins (340,447,520). The bioactive form of GH exists at higher concentrations in the blood than the immunoreactive form (343). In younger women, resistance training elicits increases in the concentrations of bioactive GH in the blood (340,344,447). Bioactive GH has been shown to be significantly lower in older (61 years of age) women than in young (23 years of age) women after acute resistance exercise (228). Moreover, over half of older men and women (60–90 years of age) show extremely low or have no detectable concentrations for bioactive GH in their blood (343), suggesting that in some older men and women, pituitary synthesis and secretory functions are dramatically diminished with age.

In regard to immunoreactive GH, which is found in much lower concentrations than bioactive GH, resting values do not seem to be affected by resistance training (108,137,244,249,342,611,614). As the acute response of immunoreactive GH is related to the type of exercise and changes in blood pH (229,507), the response to acute resistance exercise in older men and women is variable. However, acute exercise typically leads to little or no change in immunoreactive GH (219,299,348,611,622,636).

Insulin-like growth factor also represents a superfamily of peptides, binding proteins and splice variants (213,446). Insulin-like growth factor–I (IGF-I) has been documented as an important biomarker with regard to repair and metabolism of tissues with significant health and fitness implications (401,446,448). Age-related changes in IGF-I may influence a host of different anabolic mechanisms related to tissue growth (565) and neuromuscular function (450). Thus, IGF-I has been used as a biomarker for aging and has been shown to be associated with the immuno-endocrine mechanisms that are related to frailty and functional declines in older individuals (65). A recent genome wide meta-analysis demonstrated that circulating IGF-I and IGFBP-3 (binding protein 3) may have a crucial role in mechanisms mediating longevity (598), and older individuals may see an age-related reduction (250).

Changes in circulating IGF-I or its binding protein with resistance exercise or training is highly variable and not seen in all studies of older men and women (614,658). In response to resistance exercise, no changes in resting or acute exercise-induced increases in IGF-I have been observed (484). Similarly, basal levels and acute responses to resistance training in mechano growth factor (MGF), extracellular signal-regulated kinase (Erk1/2), AKT8 virus oncogene cellular homolog (Akt), and ribosomal protein S6 kinase (p70S6K) protein levels or insulin-like growth factor-I isoform Ea (IGF-IEa), and MGF mRNA expression do not differ between younger and older men (11). However, resting concentrations of IGF-I have been shown to increase as a result of periodized (342) and heavy (80% of 1RM) (108) resistance exercise training in older adults. But progressive resistance training with resistance bands did not stimulate increases (269).

In summary, the endocrine system plays a vital role in signaling various hormones in response to resistance exercise. Yet, the changes in circulating concentration of basal/resting and acute exercise responses to and with resistance exercise and training are variable in older men and women. Because of the multiple interactions with tissue receptor targets and multiple cellular components that are affected by the circulating secretions from endocrine glands, difficulty exists in the interpretation of the changes in circulating values that are observed. Hormonal concentrations or changes with exercise stress have been related to changes in strength, muscle size, and muscle anabolism, but how these signals are mediated at the cellular level remains to be further elucidated. There is little doubt that the endocrine system is activated with both resistance exercise and training, but further work is needed to demonstrate local mechanisms that are operational and mediate the anabolic and/or catabolic effects in older individuals.

Part 3: Functional Benefits of Resistance Exercise Training for Older Adults

A Properly Designed Resistance Training Program Can Improve Mobility, Physical Functioning, Performance in Activities of Daily Living, and Preserve the Independence of Older Adults. Age-associated decreases in health and physical functioning can hinder older adults' ability to perform the ADLs required for independent living (9,283). As physical functioning is related to muscular strength and power (37,184,190), interventions to maintain and build strength and power in older adults are requisite for maintenance of physical functioning. Research has demonstrated that physical activity and exercise are related to delayed disability, preserved quality of life, restored independent functioning (76), and prolonged independent living in older adults (567), where higher levels of exercise were most effective at improving functional ADL (353). The cumulative incidence of disability with ADL is lower for older adults who exercise (resistance and/or aerobic) (37.1%) than nonexercisers (52.5%) (461). Moreover, resistance training added to aerobic training results in greater improvement in functional tasks (562).

In regards to the type and quantity of exercise, multimodal (e.g., resistance, aerobic, functional, and balance) exercise appears to have a broad effect on improving muscle strength, balance, and physical functioning (379), while resistance exercise has resulted in the most consistent gains in functional tasks

(455,605) and increases health-related quality of life (152). A review by Bray et al. (76) reported that components of aerobic, resistance, flexibility, and balance training should be incorporated into the exercise prescription to prevent the onset of frailty; resistance and balance activities should be emphasized (76). In particular, resistance training can specifically attenuate age-related changes in functional mobility, including improvements in gait speed, static and dynamic balance, and fall risk reduction (455). As such, resistance training alone and in combination with functional training (2 times per week for 10 weeks) has been shown to improve the ability to perform ADL by 21 and 26%, respectively (394).

Although the exercise prescription for performance of ADL should follow a needs assessment and individualization, research has shown that older adults should exercise 2–3 times a week, using large muscle groups, for 30–60 minutes, with 2-minute rest between sets (76,353,455). Greater functional fitness benefits may be achieved by participating 3 times a week than less frequently than 3 times per week (435). Sessions that last 30 minutes or more have been associated with fewer difficulties with ADL (353). Resistance training intensity should be based on a percentage of estimated 1RM. Program onset should occur at 55% of 1RM (muscle endurance) and progress to higher intensities of 80% of 1RM (strength) as tolerated by the individual to maximize functional gains (76,455). For mobility, physical functioning, performance of activities of everyday living, and independence, older adults should be encouraged to participate in progressive resistance training activities, and should begin resistance training at an individualized level appropriate with abilities, and progress toward the recommended daily amounts of activity (455).

In summary, resistance training can improve mobility, physical functioning, performance of ADL, and preserve independence of older adults.

A Properly Designed Resistance Training Program Can Increase an Older Adult's Resistance to Injuries and Catastrophic Events Such as Falls. Falls are a common danger in the older adult population in the United States where 30% of older adults experience at least one fall annually, and 50% of adults older than 80 years experience a fall each year (24). While falls can be catastrophic for older adults, resulting in fracture and serious injury, they are also a major cause of chronic pain and disability (111). Both physical disability and frailty can increase older adults' susceptibility to severe catastrophic events (99,200,433,490). Yet, older adults without a fall history report more time in aerobic and strength training sessions compared to those with a fall history (15). In addition, the significant protective association between strength training and fall incidents is further strengthened after adjusting for covariates (15).

Several studies have reported that multicomponent exercise interventions may reduce the incidence of falls and consequently prevent disability, morbidity, and death (33,93,96,195,255,385). A meta-analysis of 44 trials with 9,603 subjects revealed that physical exercise reduced the rate of falling by 17% (546). Similarly, a more recent meta-analysis of almost 20,000 community-dwelling older adults demonstrated that exercise reduced the rate of falls in by 21% (545). The greatest relative effects of exercise on fall rates were seen in programs that included higher exercise volume and balance exercises (546). Several studies have demonstrated the importance of resistance exercise in an exercise regimen to reduce vulnerability to falls (564) and falls resulting in injury (316). In addition, exercise interventions in community-dwelling older people reduce fear of falling (320). Progressive resistance training programs including both free-weight– and machine-based exercises for the whole body, including closed-chain standing exercises, such as squats and split squats, are effective at improving static balance (221).

In addition, programs that challenge balance with exercises that included standing with feet close together and/or on one leg, minimal support by hands, and controlled movements of the center of mass, but not walking, demonstrated the greatest effects in fall prevention (546). Thus, exercise progression for older adults at risk for falls may begin with resistance and balance training before aerobic exercise, particularly for those with osteoporosis.

In summary, evidence supports the efficacy of resistance training as an effective means to reduce the incidence and consequences of falls in older adults.

A Properly Designed Resistance Training Program Can Help Improve the Psychosocial Well-Being of Older Adults. Psychological or mental health disorders affect about 20% of older adults (635). Among the most prevalent psychological and mood disorders in older adults are dementia, depression, and Alzheimer's disease, affecting 14% (479), 10% (572), and 10% (479) of older adults, respectively. Such conditions seem to be interrelated as depression has been shown to be associated with impaired functioning, increased medical morbidity and mortality, and dementia (572). Sedentary lifestyles are associated with increased risk of depression (108,599). In addition, with aging, loss of one's physical fitness is believed to contribute to depression (64,592).

Properly designed resistance training programs bring a variety of psychological health benefits for older adults. Resistance exercise programs have been effective in lowering self- and therapist-rated levels of depression in older adults residing in long-term care facilities (592) or the community (317,556). Resistance training has been shown to offer similar antidepressant efficacy as standard pharmacotherapy treatments for older adults with depression (556). In addition, resistance training may mitigate behavioral problems (such as social disturbance, communication difficulty, self-care, and confusion) associated with advanced stages of dementia (119).

Benefits of resistance exercise for improving depressive symptoms are most apparent in older adults with moderate to severe clinical levels of depression. For example, Chen et al. (119) noted that a resistance training program administered for older adults with dementia residing in nursing homes reduced depression over a 15-month period, while the condition of nonexercising control subjects' deteriorated. On the other hand, studies evaluating mood changes after resistance training in healthy and highly motivated adults showed positive mood benefits (408,617).

Resistance training programs have been shown to have other psychological and behavioral benefits in older adults, such as improved overall mood (108,119,660), positive changes on confusion and anger (408), reduced trait anxiety (108,616,617), improved quality of sleep (108,556), reduced tension (408,616,617), improved vigor (408,616,617,660), spatial awareness and visual and physical reaction times [192], and self-efficacy (556,616).

Studies focusing on the psychological effects of resistance training in older adults have generally used machine-based training modalities (108,408,556,616,617,660), while a few studies used elastic bands (119,592) targeting the major muscle groups. Intervention programs ranged from short-term 8–12 weeks (556,592,616,617,660) to 6–15 months (108,119,317,408). One study documented the greatest increase in quality of life and decrease in depressive symptoms to occur during the first 3 months of the resistance training program and remain through the end of the 9-month intervention (317). These authors theorized that the large initial gains in physical function contribute to better psychological functioning, but both physical and psychological gains may plateau after some months (317). At the same time, evidence also indicates that psychological improvements return to baseline if older adults terminate their involvement in resistance training programs (317).

Most studies provided supervised sessions 3 times per week (108,119,408,556,592,616,617,660). One study aimed at comparing the psychological benefits of resistance training conducted at 1, 2, or 3 sessions per week (317). The authors concluded that 2 and 3 sessions per week elicited greater improvements in environmental quality of life than 1 session per week. Psychological quality of life and sense of coherence improved in response to both 1 and 2 sessions per week, while depressive symptoms decreased only in response to 2–3 sessions per week (317). These authors suggested that 2 sessions per week may be the most beneficial and theorized that for previously sedentary older adults, 3 high-intensity resistance training sessions per week might be too much for their psychological functioning (317).

Resistance training intensity varied among the relevant studies. For example, 2 studies used sets of 8–10 repetitions at 80% of 1RM (108,408), while another study applied 10 repetitions at 80% of 5RM (660). A few studies aimed at observing the relationship between training intensity and psychological benefits (408,556,616,617). Tsutsumi et al. (616) compared high-intensity training (8–10 repetitions at 75–85% of 1RM) with low-intensity training (14–16 repetitions at 55–65% of 1RM) and found that both protocols similarly reduced tension and trait anxiety, and improved self-efficacy of the older adult subjects. These authors concluded that psychological changes do not necessarily correlate with the intensity of the training program (616). A similar high- versus moderate-intensity protocol was adopted by Tsutsumi et al. (617) and resulted in no differences between the experimental groups in mood and trait anxiety changes. The authors noted, however, that for the previously untrained older women, the moderate-intensity program was less demanding and thus may have provided a "more enjoyable experience" (617). Singh et al. (556) also compared high-intensity (3 sets of 8 repetitions at 80% of 1RM) and low-intensity (3 sets of 8 repetitions at 20% of 1RM) protocols. These authors found a dose-response effect, whereas the high-intensity program led to reduced depression and anxiety, improved confidence for physical capability, overall well-being, and quality of life (317,556,616).

Training intensity is associated with the positive benefits of resistance exercise, where greater reductions in depression symptoms result from higher intensity training and greater strength gains (556). Strength gains as a result of resistance training have been shown to be directly associated with reductions in depressive symptoms (556). In addition, reductions in depressive symptoms are associated with higher intensity training (556). Furthermore, higher intensity training has been associated with greater positive improvements in vitality, quality of life, and change in sleep quality (556). The authors concluded that high-intensity resistance training is a feasible and safe treatment method for depressed older adults with a greater treatment efficacy than low-intensity training and general practitioner care (556). In regards to training frequency, resistance training twice a week is beneficial for psychological functioning (environmental quality of life and sense of coherence) (317).

In summary, resistance training performed 2–3 times per week at moderate to high intensities provides a variety of positive mood and psychosocial benefits for older adults.

Part 4: Considerations for Frailty, Sarcopenia, or Other Chronic Conditions

Resistance Training Programs Can Be Adapted for Older Adults With Frailty, Mobility Limitations, Cognitive Impairment, or Other Chronic Conditions: Frailty. Frailty is an age-associated syndrome characterized by decreases in the biological functional reserve and resistance to stressors due to changes in several physiological systems, which increases vulnerability to poor outcomes (disability, fall death, and hospitalization) from minor stressors (509) (100,508,509). Frailty encompasses changes that are associated with aging, lifestyle, chronic diseases, and the interactions among them (55,639). The prevalence of frailty in people older than 65 years of age is high (ranging from 7.0 to 16.3%) and increases with age (30,196,211), and frailty is the main risk factor for disability in aging (654). One of the main pathophysiological issues underlying the frailty syndrome is the loss of muscle strength and mass with increasing age. Muscle atrophy is exacerbated by decreased physical activity, causing a decline in overall function that leads to frailty (424,600). Physical inactivity is also a key factor contributing to the onset of muscle mass and function decline, which in turn seems to be a vital aspect related to frailty (509).

Poor health, disability, and dependency do not have to be inevitable consequences of aging. Indeed, older adults who practice healthy lifestyles, avoid sedentariness, participate in physical exercise (e.g., walking, strength training, or self-adjusted physical activity), use clinical preventive services and continue to engage with family and friends are more likely to remain healthy, live independently, and incur fewer health-related costs (656). Resistance exercise training is one of the most important components in improving the functional capacity of frail older adults (96,121,153,381). Studies have found that resistance training tailored to this population can help restore physical function in frail older adults (88,184,255,384,536). Resistance training programs that are performed 3 times a week, with 3 sets of 8–12 repetitions and an intensity starting at 20–30% of 1RM and progressing to 80% of 1RM, result in positive effects on habitual gait velocities, stair-climbing abilities, overall levels of physical activity, and gains in muscle strength and power (88,96,184,261,384,536). Resistance training seems well tolerated in frail older adult populations as injuries, or adverse side effects were not reported or monitored in several studies that investigated the effects of strength training in frail older adults (184,261,359,536,586).

To optimize functional capacity, resistance training programs should include familiarization to training in which the subjects' body mass is used for resistance and in which usual daily activities are simulated (such as the "sit-to-stand" exercise) (88). Furthermore, with periodized programming, resistance exercises that are performed with a high-speed of motion can be incorporated to promote greater improvements in the functional task performance of older adults (88,488). Twelve weeks of multicomponent exercise training including explosive resistance training has been shown to improve muscle power output (96–116%), strength (24–144%), muscle CSA, and muscle fat infiltration (4–8%), as well as functional outcomes and dual task performance (7–58%)

in frail institutionalized nonagenarians (88). However, poor form and execution of exercise and severe OA are contraindications for high-speed resistance training. Proper familiarization and progression should be adhered for explosive resistance training. Strength training interventions performed 3 times a week, with 3 sets of 8–12 repetitions and an intensity starting at 20–30% and progressing to 80% of 1RM, seem well tolerated by older adults with frailty, resulting in marked muscle strength gains (94,261,586).

Although resistance training interventions have been shown to promote marked enhancements in neuromuscular function, multicomponent exercise programs that include resistance training seem to result in greater overall improvements presumably because this type of intervention stimulates several components of physical health, such as strength, cardiorespiratory fitness, and balance (62,88,96,195,255). In addition, exercise programs (including resistance training) also lead to enhanced functional parameters, such as gait and balance, and reduced the risk of falls (33,88,96,125,255,385). Positive effects on functional capacity are more often observed when more than one physical-conditioning component (i.e., strength, endurance, or balance) comprises the exercise intervention (96,385,627), compared with only one type of exercise (536,595). Several studies also have reported that multicomponent exercise interventions may also reduce the incidence of falls and consequently prevent disability, morbidity, and early mortality (33,88,96,195,255,385).

In summary, a multicomponent exercise intervention program that consists of resistance training, gait retraining, and balance training seems to be the best strategy for improving gait, balance, and strength, as well as reducing the rate of falls in older adults and consequently maintaining their functional capacity during aging. Studies in which resistance training was performed either alone or as part of multicomponent exercise programs revealed greater strength gains in older adults with physical frailty or severe functional declines. Table 2 provides a summary of the main results and training characteristics of some studies that applied systematic resistance training programs alone or were included in multicomponent exercise programs in frail older adults.

Table 2

Resistance training guidelines for older adults with frailty.†

Variable	Recommendation
Resistance training	Perform 2–3 times per week, with 3 sets of 8–12 repetitions at an intensity that starts at 20–30% of 1RM and progresses to 80% of 1RM.
Power	Include power exercises performed at high speed of motion and low to moderate intensity (i.e., 30–60% of 1RM) to induce marked improvements in the functional task performance.
Functional training	Include exercises in which daily activities are simulated, such as the sit-to-stand exercise, to optimize the functional capacity.
Endurance training	Complements resistance training adaptations. Begin once strength and balance are improved. May include walking with changes in pace, incline and direction, treadmill walking, step-ups, stair climbing, and stationary cycling. Start at 5–10 min and progress to 15–30 min. The Rate of Perceived Exertion scale is an alternative method for prescribing exercise intensity, and an intensity of 12–14 on the Borg scale seems to be well tolerated.
Balance training	Include several exercise stimuli, such as line walking, tandem foot standing, standing on one leg, heel-toe walking, stepping practice, and weight transfers from one leg to the other.
Progression	Include gradual increases in the volume, intensity, and complexity of the exercises.

*RM = repetition maximum.

†Exercises should be performed with proper form and technique. Form and technique should be established before exercise progression and maintained during progression.

Mobility Limitations. Approximately 53 million Americans live with a disability (198). Mobility limitations stemming from physical disabilities can arise from many different etiologies including congenital (e.g., cerebral palsy and muscular dystrophy), acquired (e.g., spinal cord injury and lower-limb amputation), or as a gradual function of aging-related frailty. Regardless of etiology, persons with physical disabilities often experience many secondary negative health outcomes such as poorer quality of life (431) and increased chronic morbidity risk (327), as well as premature mortality (191). Moreover, having a physical disability may increase the risk of developing a health condition that is directly linked to the impairments (e.g., pain, joint contractures, muscle spasticity, hypertonia/hypotonia, and dyskinesia) or occurs as an indirect consequence of the impairment itself (e.g., increases in sedentary behaviors and obesity-related conditions such as diabetes and atherosclerotic cardiovascular disease [CVD]). Physical inactivity, a major driver of these health outcomes (149,464), is more prevalent in adults with physical disabilities, as only about a fourth of adults with disabilities are meeting current national recommendations for physical activity and are also significantly more sedentary than adults with no disabilities (70,133,402). Therefore, recommendations for physical activity intervention studies have been made for adults with disabilities such as using theoretical framework for behavior change, coaching, feedback, and role models (114,351). Indeed, there are several important considerations that determine the choice of intervention, along with the pathophysiology, including all the various aspects of the World Health Organization's International Classification of Functioning, Disability and Health (ICF) (646) and the psychosocial environment of the patient.

Twenty-four percent (24%) of adults aged 65 years and older use mobility aids (e.g., canes, walkers, or wheelchairs), with use increasing with advancing age (215). Mobility aids may compensate for decrements in balance, strength, coordination, sensation, reaction, and increased risk for falls. Falling presents a prevalent event in aging as 35–40% of community-dwelling adults age 65 years and older fall each year (113). As fall prevention efforts have increased, so has the use of mobility aids, which have increased by 26, 57, and 65% for canes, walkers, and wheelchairs, respectively, among all ages (357). Considering the high prevalence of mobility impairment with aging, traditional resistance exercises performed while standing unaided may not be realistic for older adults with compromised balance and mobility. As such, exercises can be adapted to be performed primarily in the seated position for chair-based exercise (23). Chair-based resistance exercise programs can be performed by older adults with limited mobility in both residential care home and community settings and have shown improvements in functional mobility (TUG, sit-to-stand tests, gait speed, strength, and physical activity) (23). Programs may progress to standing as strength, balance, and function improve. Programs have ranged in duration from 6 weeks to 6 months, with frequency ranging from daily to 3 times a week, and time ranging from 20 to 60 minutes per session (23).

Most published studies pertaining to resistance exercise in older adults have incorporated unilateral, single-joint testing and training. These are vital for highlighting strength asymmetries for single muscle groups, as well as for identifying strength ratio discrepancies between agonist/antagonist muscles (e.g., quadriceps and hamstrings). This is particularly important for adults with congenital conditions such as cerebral palsy or after a stroke, as there are often profound asymmetries between limbs or osteoporosis. Importantly, as people with cerebral palsy age, a wide range of nonpsychosocial and noncommunicable conditions arise, including decreased bone mineral density, increased visceral adiposity, muscle atrophy and sarcopenia, impaired glucose tolerance and insulin resistance, decreased physical activity participation, and exaggerated sedentary behaviors (31,356,423,471,512,544,550,569,645). These factors place individuals with cerebral palsy and other pediatric-onset disabilities at an accelerated risk for age-related secondary chronic conditions such as osteoporosis, diabetes, and primary CVD (466,612). Many of these health conditions facing individuals with cerebral palsy are non–population-specific and, thus, represent a model of premature aging and frailty.

As it relates to gross functional capacity, single-joint strengthening protocols are inherently limited. Yet, triceps exercises and hip abduction may benefit functional improvements in older adults at risk for falls. Rather, for patients that can tolerate bilateral closed kinetic chain exercises, these represent a far superior indication of intermuscular coordinated strength capacity. Testing and training should therefore reflect all major muscles groups in the upper and lower extremities with a priority for multijoint movements (e.g., leg press, chair stands, chest press, and lat pull-downs or seated row). For individuals with significant mobility impairments, standing exercises may not be practical or even possible due to fragility, pain, spasticity, and gait/orthopedic abnormalities. In such instances, strength exercises may be performed in a seated position, and complimentary aerobic exercise may be possible using a seated recumbent cycle ergometer and/or stepper, or an upper-body ergometer. Moreover, all exercise testing should be performed with caution, and be completed for the purpose of designing individualized physical activity and exercise prescriptions.

Mild Cognitive Impairment and Dementia. Mild cognitive impairment is seen as a transitional state between normal cognitive aging and early dementia (393,588). Recent studies have shown that older adults with mild cognitive impairment have a higher prevalence of gait impairments than cognitively normal older adults (420). Dementia is a syndrome that represents a major public health problem because it impacts the capacity for active daily living and impairs social and occupational functions (265).

Cognitive impairment has been closely related to frailty syndrome because both diseases share some pathophysiological mechanisms and short-term and mid-term consequences (e.g., hospitalization, incidence of falls, disability, institutionalization, and death) (105,211). In addition, with the progression of dementia, older adults with cognitive disorders generally become frail and institutionalized patients (265,555). Moreover, muscular and central nervous systems share common pathogenic pathways in the evolution of disability, probably underlying the negative association between muscle strength and cognitive impairment (420). Furthermore, one of the major negative consequences of dementia is the severe decline in physical activity, which can be attributed to several causes, including the use of physical restraints to prevent falls (56). Physical restraints, which are commonly used in older adults who require long-term nursing care (663), are associated with adverse social, psychological, and physical outcomes, such as loss of autonomy, exacerbated sarcopenia, loss of strength, impaired ability to stand and walk, and overall decreased functional status and quality of life (56,663).

Physical exercise is an effective intervention to counteract the physical consequences of mild cognitive impairment and dementia (185,265,375,478). In a meta-analysis by Heyn et al. (2004) including 30 trials of subjects with dementia and mild cognitive impairment (mean age = 80 years of age, range 66–91 years of age), it was shown that exercise training (several interventions including resistance training) improved fitness, physical function, and cognitive function. In addition, it has been shown in another meta-analysis that the strength and endurance improvements induced by exercise training in patients with cognitive impairment are similar to those achieved in cognitively intact older adults (266).

Although studies are sparse that compare the effectiveness of different exercise training protocols on cognitive and functional status of older adults with cognitive disorders, resistance training interventions have shown several benefits to these individuals (93,185,265,375,478). Such benefits include reductions in morbidity (375), improvements in strength, balance and gait ability (93), and global cognitive function (185), with maintenance of executive and global benefit (185). Cognitive benefits after resistance training have been observed in different RCTs (185,376,403,623) and meta-analyses (265,266). In addition, combined resistance and aerobic training interventions demonstrated greater benefits on cognitive function than those that only included aerobic training (129). Randomized clinical trials examining the effects of resistance training on cognitive function have demonstrated significant improvements on executive tasks of attention (376), memory (588), verbal fluency (588), and global cognitive function (185,588,593). Yet, physical activity interventions including resistance exercise have shown inconsistent benefits in preventing cognitive decline (313), and more studies are needed using resistance training in particular (313).

Even without consistent cognitive benefits in patient with mild cognitive impairment or dementia, resistance exercise alone or included in a multicomponent exercise intervention has been shown to promote several improvements in neuromuscular function and functional performance (256,393,478), even in subjects with severe decline in functional status (93). In a study by Hauer et al. (256), 3 months of progressive resistance training achieving intensities of 70–80% of 1RM combined with functional training twice weekly resulted in significant increases in maximal strength and functional performance in older adults with dementia. In addition, it has been recently shown that 4 weeks of high-speed resistance training combined with walking, cognitive exercise, and balance training improved gait ability, balance, and muscle strength (15–30%) and reduced the incidence of falls in frail polypathological patients with dementia after long-term physical restraint during nursing care (93). In this study, intensity of resistance training started at 30% or 1RM and progressed to 50% of 1RM. In another study, Mavros et al. (403) have shown in older adults (aged >55 years of age) with mild cognitive impairment that progressive resistance training (80% of 1RM, 2–3 days per week for 6 months) increases muscle strength and $\dot{V}O_2$peak. Interestingly, their study showed that higher strength scores were significantly associated with improvements in cognitive function.

Taken together, resistance training may improve cognitive, neuromuscular function and functional capacity losses associated with mild cognitive impairment and dementia (185,265,403,478). Resistance training programs can be adapted (with simplification and visual instructions) for older adults with mild cognitive impairment and dementia. Resistance training recommendations for individual with mild cognitive impairment and dementia are dependent on functional state, and in early phases of these pathologies, more conventional guidelines and programs with well-established resistance training components can be applied. In this way, progressive volume and intensities are recommended. Based on the studies mentioned above, intensities achieving 70–80% of 1RM are well tolerated with very few muscular skeletal adverse events for older adults with mild cognitive impairment and dementia, not different from older adults with intact cognitive function (265,403). However, lower intensities, ranging from 30 to 50% of 1RM, performed at faster velocities (i.e., explosive resistance training) may be an alternative to improve functional capacity and neuromuscular function in general (93). As the conditions progress with moderate to severe functional decline, significant modifications (including simpler exercises and instruction, greater supervision, and repetitive and visual instruction) are necessary often with physical therapist, physician, and/or occupational guidance.

Additional recommendations to improve the success during resistance exercise prescription for individuals with dementia include consideration of emotional aspects, such as reassurance, respect, empathy, and communication challenges (328). The simple structure of the instructions, haptic support, and use of mirror techniques rather than complex oral instructions may support the progress of training and create a familiar, empathetic training atmosphere to individuals with dementia (93). Finally, the exercise professional should be prepared to handle any outburst of anger or aggression with the understanding that these are consequences of a disease process and not a personal attack.

Diabetes. Diabetes affects approximately 1 of 4 older adults ≥65 years of age in the United States (112). Worldwide, there are more than 425 million people with diabetes, and the associated economic burden has reached nearly $550 billion in the United States alone (8). Age-related declines in physical function and morphological health further contribute to exaggerated risk at the individual level, and yet, increases in the incidence of diagnosed diabetes combined with declining mortality or increased life expectancy have led to an increased lifetime risk and more years spent with diabetes, and CVD, at the population level (235). The contribution of muscle atrophy and weakness on progression of secondary cardiometabolic diseases with aging and/or disease (e.g., frailty and mobility disability) is equally significant, and recent efforts to identify cut points or thresholds for weakness among older adults (14,409,568) should allow clinicians to screen individuals with the greatest risk.

Resistance training, itself, even in the absence of aerobic exercise has been shown to decrease risk of type 2 diabetes and CVD (237,548,591). Moreover, Senechal et al. (535) demonstrated that low strength is independently associated with increased odds of the metabolic syndrome in middle-aged and older men and were able to identify cut points for low normalized strength that best-predicted increased risk. Moreover, 2 recent studies from the Baltimore Longitudinal Study of Aging have demonstrated that greater adiposity (421) and chronic hyperglycemia (312) (i.e., 2 hallmark features of diabetes) are associated with persistently lower muscle quality and strength, respectively.

After controlling for age, people with diabetes are less physically active and have more functional impairment than those without diabetes (234). Fortunately, resistance training may reverse some of the negative functional and neuromuscular effect associated type 2 diabetes in older adults (273,364). Resistance training might benefit older adults living with type 2 diabetes through muscle hypertrophy, enhanced muscle quality, increased strength, power, mobility, function, improved body composition, and improved glycemic control (73,109,171,273). Resistance training has been shown to improve diabetes disease process measures including blood pressure, hemoglobin A1c (HbA1c), fasting glucose, insulin, and cholesterol (low-density lipoprotein and total) in older adults (273). In addition, resistance training can reduce HbA1c levels, increase muscle glycogen stores, and reduce the dose of prescribed diabetes medication (109) to a clinically similar extent as aerobic training (657).

Beneficial resistance training programs for older adults with diabetes have included progressive whole-body moderate- to high-intensity (60–80% 1RM) resistance training, 3 times per week for 16 weeks to 6 months (83,109,171). As diabetes is often associated with other risk factors and complications, resistance training programs for older adults with diabetes should be individualized and follow medical screening, testing, physician guidance, and clearance. In particular, individuals with diabetes may be vulnerable to episodes of hypoglycemia (glucose <70 $mg \cdot dl^{-1}$) during resistance exercise. Thus, glucose level should be monitored before and after the exercise session to reduce the fear of exercise-induced hypoglycemia (128). In addition, older adults with diabetes are also more prone to CVD, nerve disease, kidney disease, eye disease, and orthopedic limitations (128). Thus, special considerations for supervision, intensity, exercise selection, modality, positioning, foot examination and protection, and visual limitations are necessary as outlined in the American Diabetes Association Position Stand (128).

Obesity. Approximately 39% of older adults in the United States are obese (189); however, there is wide variability across races/ethnicities (non-Hispanic white: 39%; non-Hispanic black: 48%; Asian: 8%; and Hispanic: 39%). Yet, obesity is a heterogeneous condition that must be considered in the broader biological and public health contexts in which it is contained. Excessive visceral adiposity for a given body mass index may be an indicator of dysfunctional adipose tissue, triggering increased ectopic fat deposition (156–158). Ongoing research has demonstrated that obesity has pathophysiologic consequences on both bone and skeletal muscle health and function (77,224,231,626). Infiltration of lipids into nonadipose depots (e.g., muscle and liver) appears as a feature of certain disease processes (e.g., type 2 diabetes) (206) as well as with prolonged sedentary behavior (396) and is often characterized with gross morphological data from adults with computed tomography (22,224,661), or localized intramuscular adipose tissue, intramyocellular lipid, and/or bone marrow adipose tissue with magnetic resonance technologies (77,515). Previous research has revealed a robust link between intermuscular adipose tissue and elevated levels of proinflammatory, adipocyte-derived hormones and cytokines (46,662), which may also lead to skeletal muscle insulin resistance and impaired muscle and bone quality (126,633). Thus, in conjunction with pronounced changes in the hormonal/metabolic milieu, excessive visceral and muscular adiposity could yield a general, inhospitable physiologic environment contributing to musculoskeletal fragility. It is well known that sedentary older adults are at significantly increased risk for muscle weakness and sarcopenic obesity (336,522), which are believed to be the primary drivers of musculoskeletal fragility (131,445,458,618), cardiometabolic abnormalities (371,532), and early all-cause mortality (27,521,655). Findings have also indicated that localized adipose tissue within and surrounding the muscle is related to reduced muscle quality (i.e., strength per unit of muscle mass) in obesity and aging (155,222,226), as well as incident mobility disability (632). Excessive adiposity in older adulthood would thus create a double negative effect of not only increased mass, but also a simultaneous decreased ability for an individual to lift that mass due to diminished quality of muscle. Thus, treating obesity among older adults requires a comprehensive approach to simultaneously reduce excess adiposity, but also to directly stimulate muscular hypertrophy and lean body mass preservation.

Strength training has received little attention from the clinical and public health communities regarding its role in obesity prevention or treatment because it is generally believed to be ineffective for weight loss. However, a long-standing literature base has demonstrated the utility of resistance exercise in stimulating positive cardiorespiratory, endocrine, metabolic, neuromuscular, and morphological adaptations, independent of weight loss. With regard to exercise prescription, current minimum recommendations for older adults with obesity call for resistance training to supplement general physical activity and cardiorespiratory exercise and to be performed on 2 or 3 nonconsecutive days per week, using a single set of 5–10 exercises for the whole body, and at a moderate level of intensity that allows 10–15 repetitions. As is generally accepted for novice trainees, prescription of resistance training for older adults with obesity should include a familiarization period in which very low dosage training (i.e., minimal sets and intensity) takes place 1–2 times per week. After the familiarization phase, obese adults with obesity would benefit from gradual increases in dosage to accommodate improvements in strength and muscle hypertrophy. Although the established minimum guidelines provide a basis for increasing muscular fitness for untrained individuals, there is now ample evidence to confirm the viability of progressive resistance exercise for improving strength and muscle mass among all older adults. Additional suggestions on progression in resistance exercise include (a) gradual increases in intensity from very light (40% of 1RM) to light (50% of 1RM), moderate (60% of 1RM), and vigorous intensity (≥70% of 1RM); (b) gradual increases in the number of sets from 2 sets to as many as 4 sets per muscle group; (c) gradual decrease in the number of repetitions performed to coincide with progressively heavier loading, from 10 to 15 repetitions per set to approximately 8–12 repetitions per set; and (d) progression in mode from primarily machine-based resistance exercise to machine plus free-weight strength training (or seated exercises when knee or hip OA makes standing a challenge).

Sarcopenic obesity, a condition where both sarcopenia and obesity are present affects ~4–15% of the population (depending on criteria) (303,574). The combined presence of sarcopenia and obesity presents an unique consideration where the goals are to simultaneously improve body composition by reducing fat mass while increasing muscle mass and improving physical functioning (613). Low muscle mass in combination with high fat mass seems to amplify the risk for adverse health outcomes (613). Yet, studies evaluating the impact of exercise training in individuals with sarcopenic obesity have shown effectiveness in improving body composition, strength, and function (118,204). While protocols combining aerobic and resistance training have been shown to improve body composition in individuals with sarcopenic obesity, resistance training was particularly beneficial in benefitting strength performance (118). Resistance exercises may be modified with resistance bands or to a seated position for older adults with sarcopenic obesity in rehabilitation settings (369) and residents in long-term care facilities (120).

Cardiovascular Disease and Hypertension. Atherosclerotic CVD is the leading cause of death in the United States, accounting for 35% of adult deaths (432). Cardiovascular disease, including hypertension, CHD, heart failure, and stroke, affects 70–75% of adults 60–79 years of age and 79–86% adults aged 80 years or older (652). Hypertension, in particular, is highly prevalent among older adults affecting approximately 60–70% of the population (176). Exercise training is effective both for the treatment and prevention of hypertension development and complications (422).

Multiple studies have shown an independent and inverse relationship between cardiometabolic risk and low muscle strength (25,127,462,467,469). Moreover, a loss of muscle mass and quality has been identified as a key factor contributing to an increased CVD risk in older adults (582). Similarly, age-related loss of muscle mass and strength is a frequently overlooked nontraditional CVD risk factor for which resistance exercise ameliorates (576). As such, resistance exercise has been associated with a 23% risk reduction for CHD and improvement in endothelial function (576,591). In addition, resistance training combined with endurance training in older coronary heart patients results in enhanced strength and function (270,282). Moreover, resistance training can reduce major CVD risk factors (including dyslipidemia and type 2 diabetes) (582) and blood pressure responses to stress (214). In 2 meta-analyses, resistance exercise significantly reduced systolic and diastolic blood pressure by approximately 3 mm Hg (136,318). Significant reductions of approximately 6 mm Hg in systolic and approximately 7 mm Hg in diastolic blood pressure after resistance exercise training in older adults with prehypertension, and never-treated hypertension have been reported (260). Similarly, high-volume resistance exercise can promote a reduction of mean 24-hour and awake systolic blood pressure in older adults (530). A reduction in diastolic blood pressure by 5 mm Hg reduces the risk of stroke by an estimated 34% and ischemic heart disease by 21% (362). Because of the known benefits, resistance training is considered a nonpharmacological treatment to lower blood pressure (82).

Despite the benefits, resistance training had been associated with safety concerns in older adults due to the acute elevations in blood pressure while performing resistance exercise. While uncontrolled hypertension is a contraindication to resistance exercise, when hypertension is under control and managed by a physician, resistance exercise may be an effective intervention for improving blood pressure. Regardless, resistance exercise in older adults with controlled hypertension requires close monitoring and good clinical judgment. The magnitude of blood pressure elevations during exercise are determined by the intensity (% maximal effort) (372) and muscle mass (418) involved. Older adults with CVD who have obtained medical clearance to perform resistance exercise should begin at a lower resistance, progress slowly, and maintain lower to moderate intensity in load. Resistance exercise–induced elevations in blood pressure are dampened in low- to moderate-intensity resistance exercise performed with correct breathing technique (i.e., avoidance of the Valsalva maneuver) and training (405). In addition, some evidence suggests that resistance exercise, in comparison with aerobic exercise, results in a more favorable balance in myocardial oxygen supply and demand due to lower heart rate and higher myocardial (diastolic) perfusion pressure (179). For those using antihypertensive medications, an extended cool down is recommended to avoid potential hypotensive episodes after abrupt cessation of activity (505). Moreover, special precautions are needed as antihypertensive medications may impair the ability to regulate body temperature during exercise in hot and/or humid environments and provoke hypoglycemia (505).

Although risks to exercise exist for unstable disease, exercise training may also have a positive effect on the course of heart failure by preventing skeletal muscle atrophy and cardiac cachexia (20). Improvements in exercise capacity have been demonstrated without adverse effects or serious complications in those with clinical stability (476). Thus, it has been recommended that when benefits of exercise outweigh the risks, exercise training begin as early as possible to reduce the detrimental effect of bed rest (20). As exercise in critically hemodynamically unstable individuals may increase risk (188,475), the identification of clinical stability is an essential step before exercise (578). Clinical stability includes stable symptoms, absence of symptoms during rest, absence of postural hypotension, absence of congestion, stable fluid balance, stable renal function, and normal electrolyte values (578). Resistance training may be particularly beneficial in attenuating skeletal muscle atrophy in individuals with heart failure (75). Programs and progression should adhere to physician restrictions, consider risks or contraindications, and begin at well-tolerated intensities. Resistance training may include small muscle groups, short bouts, small loads, limited repetitions, and cautious progression (475). Individuals with heart failure can be expected to have an exaggerated ventilator response and decreased adaptive response to exercise (122).

Chronic Kidney Disease. Chronic kidney disease (CKD) affects approximately 39–46% of the older adult population (134,577) compared with approximately 14% of the general population (444). Chronic kidney disease follows a progressive decline in kidney function due to damage (135) often associated with hypertension and diabetes. Similarly, the aging kidney is characterized by reduced glomerular filtration rate, impaired regulation of fluid and electrolyte balance (48), impaired ability to excrete salt resulting in increased vasoconstriction and vascular resistance (597), and a tendency toward dehydration and hyperosmolality (302). With CKD-related muscle wasting, strength loss and impaired physical functioning is common and progressive (116,485). Muscle loss in individuals with CKD is attributed to a variety of factors including protein-energy malnutrition (417,485), protein degradation and loss (370), anabolic hormone resistance a chronic inflammation associated with increased levels of proinflammatory cytokines (370), and impaired insulin/IGF-I intracellular signaling from factors such as inflammation, metabolic acidosis, and hormones that stimulate protein degradation resulting in muscle wasting (481).

Resistance exercise provides a variety of benefits to individuals with CKD including increased serum albumin, increase muscle strength, increased physical functionality, increased IGF-I, increased glomerular filtration rate (419), reduced inflammation (300), improved muscle function (294), increased skeletal muscle hypertrophy and increased muscular strength, and improved quality of life (117). In addition, resistance exercise may attenuate muscle wasting and benefit quality of life during dialysis treatment and after kidney transplant (57,97). The benefits of resistance exercise seem to outweigh the risks for older adults with CKD (294). With physician clearance and control of the condition, resistance exercise should be performed to help older adults with CKD manage the condition and improve overall health. In addition to medical management of the condition, other special considerations include ensuring adequate hydration and after any restrictive guidelines for coexisting conditions such as diabetes or hypertension.

Osteoporosis. Osteoporosis is a prevalent disease of the bone affecting about 1 in 12 adults aged 60–69 years, with prevalence increasing to 1 in 4 adults aged 80 years and older (651). In addition to increasing risk of bone fractures, most commonly the hips and spine (523), osteoporosis is a painful and debilitating condition that contributes to impaired health-related quality of life (322). Research has shown that resistance exercise training is beneficial for older adults with osteoporosis and increases bone mineral content (335), prevents fall-related fractures (335), and significantly improves physical function, pain, vitality (368), and health-related quality of life through enhancing self-efficacy of physical abilities and modifying the experience of back pain (377).

Resistance exercise programs should be tailored to tolerance and ability for older adults with osteoporosis, especially in the presence of pain. Older adults with osteoporosis should begin at a lower intensity and progress at individualized rates toward performing 2–3 sets of 8–12 repetitions for each major muscle group (218). Special care should be taken during exercise to mitigate the risk of falls and fractures. Balance and standing exercises should be included but should have proper measures (spotting or handles) in place to prevent falling. Special attention should focus on practicing proper form and technique and moving safely especially when performing twisting or bending during transitions (218). In addition, exercises for standing posture (spinal extension), to counter hyperkyphotic posture may aid in balance improvements. It has been recommended that exercise programs be accompanied by sufficient calcium and vitamin D intake and address issues of comorbidity and safety (i.e., avoiding loaded spinal flexion and modifying impact) as described in more detail by the American College of Sports Medicine and Exercise and Sports Science Australia (1,47).

Arthritis. Arthritis affects approximately one quarter of adults in the United States (457), and 56% of older men and 69% of older women 65 years of age and older (295). Osteoarthritis of the knee (305) and hip (306) are the most prevalent forms of arthritis. Muscle weakness is considered a modifiable primary risk factor for the knee pain, disability, and progression of joint damage in persons with OA (560). As such, individuals with even advanced OA, rheumatoid arthritis, and malalignment can experience substantial gains in strength after resistance training without concomitant increases in pain or adverse effects (297,326,386).

For older adults with arthritis, the goal of resistance training programs includes controlling joint pain while improving range of motion, muscle strength, and function. Thus, a common barrier to training for individuals with arthritis is the fear of exacerbating joint pain. However, the opposite has been reported, where those with arthritis experience benefits from resistance training without worsening pain or symptoms (19). Training programs should begin with individualized exercise selections that address the individual impairments and progress to exercise guidelines. Although restrictions by joint pain and range of motion can impact ability to perform resistance exercise in older adults with arthritis, studies have shown that strength training that is progressive, performed at moderate intensity (50–70% of 1RM), 2–3 times per week, has greater effects on strength and function than lighter training in older adults with arthritis (297,326,386). Resistance training, 2–3 times per week at a moderate intensity for 6–8 repetitions and 2–3 sets per exercise, in a progressive overload manner, is also recommended by the American Geriatrics Society for older adults with arthritis (19). Yet, with arthritis, physical performance, pain, and range of motion can vary day to day, and training schedules should be accommodating. In addition, while moderate to higher intensities have shown benefits, individualized responses such as joint pain during the exercise or lasting 1–2 hours after, joint swelling, fatigue, or weakness may indicate excessive exercise volume or intensity and inform individual level of toleration.

Risk Stratification for Chronic Conditions. Although, most studies have examined healthy older men and women, the ability to use resistance training interventions is just starting to become clearer for various pathologies (e.g., arthritis, cancer, heart disease, and orthopedic). Multimorbidity (i.e., the presence of >1 chronic condition) is increasingly burdensome through the third phase of the epidemiologic transition, which is characterized by a compression of mortality rates combined with an expansion of the older-adult population. For the purposes of exercise testing and prescription, and in accordance with the NSCA and ACSM, preliminary risk stratification for older adults with multiple diagnosed chronic conditions should be conducted on the basis of general risk for cardiovascular incidents (2). Yet, for those who are currently exercising and are asymptomatic, preparticipation screening may not be necessary and may present an unnecessary barrier to beginning and maintaining exercise programs (506). Because of the frequently reported sedentary lifestyles and higher prevalence of sarcopenic obesity in older adults, many are at greater likelihood of being classified as either "moderate risk" (i.e., "asymptomatic men and women who have ≥2 atherosclerotic cardiovascular disease (ASCVD) risk factors") or even "high risk" (i.e., individuals who have known cardiovascular, pulmonary, or metabolic disease or one of more signs/symptoms of these diseases) (2). Identifying CVD risk factors is necessary for disease management, identifying individuals at greater risk for untoward events during exercise participation, and identifying those who may require additional medical screening. For individuals with some chronic conditions such as diabetes, the NSCA and ACSM recommend a clinical exercise stress test before engaging in exercise. However, considering the greater incidence of physical inactivity and profound weakness in older adulthood (170,409), an assessment of muscular fitness may be advisable for all patients.

In summary, resistance training programs can be adapted to benefit older adults with frailty, mobility limitations, cognitive impairment, or other chronic conditions. Table 3 provides a summary of exercise modifications for frailty, mobility limitations, and other chronic conditions.

Resistance Training Programs Can Be Adapted (With Portable Equipment and Seated Exercise Alternatives) to Accommodate Older Adults Residing in Assisted Living and Skilled Nursing Facilities. Assisted living facilities intend to promote independence for the resident older adults by creating a homelike environment for the integration of care (130). On the contrary, nursing homes or skilled nursing facilities accommodate older adults with serious health concerns, including frailty, various chronic and comorbid conditions, as well as functional disabilities (285). While in these institutions, the goal is that older adult residents remain functional and independent for as long as possible to achieve their highest potential quality of life; however, many individuals become dependent on care for their daily activities after their admission to a facility (621). In turn, these older adults' participation in physical activity decreases dramatically, resulting in an accelerated loss of muscle mass and further decreased functional ability (621). Sarcopenia is more prevalent among older adults residing in skilled nursing facilities than their community-dwelling counterparts (252). Therefore, regular participation in resistance training–based physical activity programs is vital for the maintenance of functional ability for these older adults. Nevertheless, data indicate that nursing home residing older adults spend more than 97% of their daily time in seated or reclining positions and nearly two-thirds of their time with passive activities (e.g., sleep, TV watching, reading, and fidgeting) and only approximately 3% of their time daily with movement activities (285). For most assisted living and skilled nursing facilities, exercise programs are offered to residents as optional recreational activities, failing to view resistance training as an effective strategy to maintain or increase muscular strength and functional capacity (621).

Table 3
Summary of exercise modifications.*

Condition	Modification
Frailty	Start at a lower resistance, progress more slowly, limit end point to volitional fatigue (start at 8–12 reps at 20–30% of 1RM and progress to 80% of 1RM).
Mobility limitations	Consider exercises in seated position.
Mild cognitive impairment	Select simple exercises. May require extrainstruction and demonstration.
Diabetes	Monitor blood glucose before and after training. Consider special considerations of associated cardiovascular disease, nerve disease, kidney disease, eye disease, and orthopedic limitations.
Osteoporosis	Begin at a lower intensity. Train balance, but exert extra care to prevent falls. Focus on form and technique and use caution with bending and twisting. Include postural exercises (spinal extension).
Joint pain or limited range of motion (arthritis)	Double-pinned machines may restrict ROM for joint pain, discomfort, and/or limited ROM. To allow for training through the pain-free part of the ROM and attain a training effect.
Poor vision, equilibrium and balance (falling), low-back pain, and dropping weights	Consider weight machines (as opposed to free weights).

*RM = repetition maximum.

Data from resistance training interventions among older adults residing in assisted living and skilled nursing facility suggest that resistance training has positive effects on muscle mass (88,167), muscle strength (35,79,80,88,167,182,183,187,252,301,363, 411,415,514,537,587,625), muscle endurance (187,537), and various outcomes of functional capacity including gait speed (182,301,514,587), mobility (35,38,79,80,88,301,363), dynamic balance (38,363,514), and stair-climbing power (79,182,537). In addition, an individualized, multicomponent exercise intervention including low-intensity resistance training exercises (30–60% of 1RM) performed during a short period (mean, 5 days) has also been shown to provide significant benefit over usual care to help reverse the functional decline associated with acute hospitalization in older adults (400). Therefore, resistance training is an effective activity for fall prevention and maintenance of independence (621).

A number of studies have demonstrated that dramatic strength improvements can be achieved through resistance training interventions implemented in nursing homes and similar institutions. Some studies with 8-week resistance training interventions reported as high as 23.7% (79) and 62% upper-body (350) or 108% (350) and 174% (183) lower-body strength increases, although these interventions targeted very elderly (79), mobility impaired (350), or very frail (183) older adults. Another 8-week intervention study reported 32.8% isometric and 41.2% isokinetic concentric strength improvement in composite strength of 8 muscle groups (415). Other studies with 10-week resistance training interventions reported 57.3% (537), 74% (587), and 95% (184) strength improvements, along with significant improvements in gait speed (184,587), stair-climbing power (184,537), sit-to-stand power (537,587), and muscular endurance (537). A study with a 12-week intervention for the oldest old population reported impressive 144% lower-body and 68% upper-body 1RM strength, 23.6% lower-body isometric strength, and 116% maximal power improvements (88). However, other studies with longer interventions reported more modest strength improvements, of 20–30% after 12–15-week programs (35,537,625). It seems that the intensity of the applied resistance training programs and the initial functional capacity of the older adult subjects are 2 primary influencing factors of the magnitude of strength increases. Among those with more significant frailty, the greater the magnitude of strength changes can be achieved, even in a relatively short period (i.e., 8–10 weeks).

The mode of resistance training varied between the study protocols. A number of studies have used training interventions with only resistance training machines, such as the leg extension (183,184,537), hip extension (183,184,587), or leg press machine (587) as their primary mode for resistance training intervention. One study used only the leg extension machine for isometric strength training (187), while other studies used a variety of seated exercises through isotonic (88,350), isokinetic (415), isometric (411) methods, or by using air-pneumatic machines (252). Other studies applied rubber bands (35,38,167,363,625), ankle weights (38,79,80), soft weights (38,167,363), and dumbbells (35,79,80,625). A number of studies limited their exercise choices to seated exercises only (38,183,184,187,411,537,587,625), while only a few studies applied standing exercises or full-body functional exercises to include squats, step-ups, and lunges (79,363,514). These studies using full-body functional exercises all reported significant improvements in subjects' functional capacity including mobility (363), gait or stair-climbing speed (79,514), dynamic balance (363,514), and chair to stand power (79,514). A recent pilot study aimed to directly compare the effectiveness of machine and free-weight full-body resistance training in nursing home residents and concluded that both methods were similarly effective in improving muscular strength and mobility (301).

The intensity of the applied resistance training programs was not reported in a number of studies (35,79,80,167,363). Studies that reported resistance training intensities varied in their protocols, including using 80% of 1RM resistance (183,184,537,587), 8–12 RM resistance (350,514), 50% of 1RM resistance (88,625), 75% of 8RM resistance (301), maximal isometric contractions (187), or 12–14 on the Borg scale (252,301). Most nursing home–based resistance training interventions used 3 exercise sessions weekly (38,79,80,167,183,184,187,363,415,537,587, 625), but some studies used only 2 sessions per week (35,88,252,301,411).

In summary, these resistance training interventions have demonstrated that strength and functional capacity of older adults may be significantly improved even in assisted living and skilled nursing facility settings. Known benefits should motivate assisted living and skilled nursing facilities to acquire proper training equipment. In the interim, equipment limitations of these facilities may be overcome by using inexpensive, portable items (e.g., rubber bands, soft weights, ankle weights, and medicine balls). Training adaptations can be elicited even for older adults with functional or mobility limitations by using a resistance training program with seated exercises only, although using full-body functional exercises will likely lead to greater impact on the general functional capacity of older adults. No relevant studies have reported incidents of cardiovascular adverse events or any serious injuries for the subjects, which suggest that resistance training is safe even for the frail, functionally impaired, and very elderly nursing home residing populations. Strength improvements reported by the relevant studies demonstrate that older adults in assisted living and skilled nursing facility settings have the capacity for muscular and neuromuscular adaptations in response to various resistance training program designs.

The evidence collected and reported in this Position Statement demonstrates the substantial health benefits of resistance exercise for older adults. There is strong evidence to support the benefits of resistance exercise for countering many age-related processes of sarcopenia, muscle weakness, mobility loss, chronic disease, disability, and even premature mortality. In addition, this Position Statement provides specific evidence-based practice recommendations to aid in the implementation of resistance exercise programs for healthy older adults and those with special considerations. While there are instances where low-intensity, low-volume programs are appropriate (i.e., beginning programs for individuals with frailty or CVDs), the greatest benefits are possible with progression to moderate to higher intensity programs. While general recommendations are provided with consideration of special circumstances, in good practice, all resistance exercise programs should be commensurate with the specific individual needs and capabilities of each older adult.

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