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REVIEW

Potential Health-Related Benefits of Resistance Training[1]

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Public health guidelines primarily focus on the promotion of physical activity and steady-state aerobic exercise, which enhances cardiorespiratory fitness and has some impact on body composition. However, research demonstrates that resistance exercise training has profound effects on the musculoskeletal system, contributes to the maintenance of functional abilities, and prevents osteoporosis, sarcopenia, lower-back pain, and other disabilities. More recent seminal research demonstrates that resistance training may positively affect risk factors such as insulin resistance, resting metabolic rate, glucose metabolism, blood pressure, body fat, and gastrointestinal transit time, which are associated with diabetes, heart disease, and cancer. Research also indicates that virtually all the benefits of resistance training are likely to be obtained in two 15- to 20-min training sessions a week. Sensible resistance training involves precise controlled movements for each major muscle group and does not require the use of very heavy resistance. Along with brief prescriptive steady-state aerobic exercise, resistance training should be a central component of public health promotion programs.

Key Words: **resistance training; strength; musculoskeletal system; lower-back pain; bone mineral density; disease prevention; exercise guidelines.**

INTRODUCTION

Healthy People 2010 [*1*] spotlights physical activity and exercise promotion as one of its recommendations for disease prevention and health promotion because physical activity and exercise are protective against many diseases and disabilities. Resistance training, also known as strength training, involves the voluntary activation of specific skeletal muscles against some form of external resistance, which is provided by body mass, free weights (barbells and dumbbells), or a variety of exercise modalities (machines, springs, elastic bands, manual resistance, etc.). Resistance training has profound effects on the musculoskeletal system and can contribute to the maintenance of functional abilities, prevent osteoporosis, sarcopenia, and accompanying falls, fractures, and disabilities [*2–5*].

Research showing the beneficial effects of resistance training for the musculoskeletal system has led to recommendations that it be included in an overall fitness program for all adults [*2*] and it is especially recommended for older adults [*6*]. What has not been captured by these recent public health guidelines is the research demonstrating the potential benefits of resistance training as an intervention to reduce risk factors associated with cardiovascular disease, diabetes, and cancer [*4*]. These recent findings suggest that rather than being a secondary or peripheral component of fitness and other disease-prevention programs and, indeed, barely noted in public health physical activity and exercise goals, guidelines and recommendations [*1,7*], resistance training should be a central component.

Two other considerations lend further credence to this position. Resistance training is already seen as a preventive intervention for osteoporosis because of its favorable impact on bone mineral density [*5,8*]. However, a far greater burden on the economic and health care systems of developed countries is incurred from lower-back pain and disability [*9*]. Most lower-back interventions focus on passive symptom-reduction protocols, but there is little supportive evidence that such

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interventions reduce the risk of subsequent episodes and disability [*10*]. In contrast, resistance training can safely and effectively strengthen the lower back regardless of differential diagnosis and apparently reduces the incidence of disabling lower-back conditions [*10–12*].

Although resistance training is often depicted even within professional circles as complicated, time-consuming, and requiring the potentially dangerous practice of explosively lifting heavy weights [*13*], the converse is actually true [*14*]. In fact, resistance training is a safe, relatively simple activity, does not necessarily involve using very heavy weights, and takes minimal time. Based on an extensive review by Feigenbaum and Pollock [*15*], it appears that most of the benefits of resistance training can be accrued from two 15- to 20-min sessions a week. In fact, strengthening the lower back requires only 75–90 s a week [*10*].

The purposes of this article are to: (1) review recent research with resistance training that has demonstrated its beneficial impacts on multiple systems and risk factors and describe common mechanisms that appear associated with coronary heart disease, cancer, and diabetes; (2) further illuminate recent perspectives and training modalities for treating lower-back pain and injuries; (3) describe the principles of resistance exercise and effective training programs; and (4) offer guidelines both for an extensive research agenda for studying the health benefits of resistance training and for how resistance training should be described in public health policies, promoted within disease prevention and health programs, and offered in numerous settings.

HEALTH-RELATED OUTCOMES OF RESISTANCE TRAINING

Overview

Resistance training studies involving middle-age to older men and women show favorable changes for risk factors associated with osteoporosis [*16,17*], cardiovascular disease [*18–21*], cancer [*22*], diabetes [*23–27*], and report increases in strength of ~20 to ~60%, with no differences in percentage of changes by age or sex. Several caveats need to be introduced for interpretation of these outcomes. Most of these studies, with the exception of the ones focusing on bone mineral density where protocols have extended from four to 12 months [*12*], are short-term (3–4 months) training studies [*15*]. Thus, it is not yet clear if the initial effects that were reported would persist with continued training. For example, reviews indicate that increases in strength and muscle mass appear to asymptote at about 18 months of consistent training [*28*]. It is not known if other health-related outcomes are directly or indirectly influenced by the training stimulus and concomitant musculoskeletal changes, hormonal responses to exercise, physical activity and caloric expenditure, or some combination of factors. That is, as strength and muscle mass asymptote, other health-related responses may asymptote as well.

If intensity remains high, increases in strength and muscle mass may be maintained with one training session per week [*29–32*]. However, it is not clear if other health-related changes attributable to resistance training will be maintained with reduced training frequency. It is also apparent that while the training studies typically noted employ 10–15 exercises, only six or seven movements may be required to strengthen all the major muscle groups and increase muscle mass [*15*]. Whether 10–15 exercises are required to produce other favorable health-related outcomes is unknown.

There are also some inconsistencies in the outcomes of studies on resistance training. For example, some studies have demonstrated a favorable change in lipoprotein–lipid profiles with resistance training [*33,34*], while other studies using similar protocols have shown no changes [*35*]. Layne and Nelson [*12*] noted that resistance training has produced increases in bone mineral density attributable to the site-specific principles of mechanical loading associated with specific resistance exercise movements [*8*], but a few studies have not shown such increases. Lack of effects has been associated with shorter duration of the training study, lower intensity protocols or lower force protocols (see later), less supervised training, measurement techniques, and subjects' characteristics including initially higher than average bone mineral density [*12*]. Studies consistently show that resistance training can result in a marginal but significant reduction (~3 mm Hg, systolic and diastolic) of high-normal blood pressure to normal levels [*19,36*]. Studies focusing on hypertensive populations are needed. Some studies have reported significant increases in resting metabolic rate [*37–41*], while others have not [*42*]. Despite these remaining and important questions, the American Heart Association has recently recommended resistance training to prevent and help to treat heart disease [*43*].

There are other minimally researched areas. For example, with the exception of lower-back training, studies focusing on bone mineral density have sometimes used protocols with three sets per exercise movement [*8*]. There is very little data to suggest that multiple sets are required to increase strength and muscle mass [*44–45*] and a recent review [*12*] has shown that a greater volume of training is not required to produce significant increases in bone mineral density. At present, because it appears that the primary requisite stimulus for increasing bone mineral density is an overload to specific bones, the necessity of added volume is very unlikely.

Weight and Body Fat Loss

In order to create a caloric deficit, weight loss (reduction of body fat) and weight control have traditionally revolved around restricted caloric intake and increased caloric expenditure through low to moderate intensity physical activity and aerobic exercise. It can be argued that while such approaches result in weight loss in the short run, reviews indicate that there is no compelling evidence that this approach has been effective for continued reduction of body fat beyond 3 to 6 months or that the fat loss is maintained [*28*]. If the goal is a loss of body fat and a change in body composition, it can be argued from a metabolic perspective that this commonly used approach is not a very effective strategy. With continued and marked caloric deficits, reviews of weight loss protocols indicate that lean body mass may be compromised and the resting metabolic rate may be markedly decreased [*28*]. As an adaptive response to such a regimen, the "successful dieter" may then be left with less muscle mass and the need for fewer calories. Further weight loss or maintenance becomes extremely difficult, and body weight (body fat) is often subsequently regained. Given the loss of muscle mass, individuals who regain their initial weight loss may then exhibit a higher percentage of body fat than their prediet status [*28*]. Rather than merely a cosmetic problem, such additional gain of body fat appears to appreciably increase risk for a number of diseases [*46*].

Interestingly, even when the focus is primarily fat loss and improvement in typical risk factors for diabetes and heart disease, more recent data show that it is primarily higher intensity cardiovascular training or resistance training—not the more typically prescribed lower to moderate intensity exercise—that most impacts these risk factors [*47–50*]. The addition of resistance training to weight loss programs can help increase or maintain the resting metabolic rate [*4,37–41*] and add muscle mass [*40*] but it appears that this therapeutic effect of resistance training only occurs if there is no severe caloric restriction [*40*]. Fat-free mass is perhaps a major determinant of resting metabolic rate [*51*], although the mechanisms that may contribute to an increase in resting metabolic rate following resistance-training programs are unknown. Increased protein turnover and elevations in basal sympathetic nervous system activity are two speculated mechanisms [*52*].

The complexity of the mechanisms involved in increasing resting metabolic rate with resistance training is illustrated by a recent study by Lemmer and colleagues [*53*]. This 24-week resistance training study showed that while younger and older men and women had similar significant increases in strength, only the men significantly increased resting metabolic rate. The increase was apparently associated with the men's responsiveness to training, i.e., hypertrophy, and possibly greater sympathetic nervous system activity. Resistance training may not be effective for increasing resting metabolic rate in women. These and other findings previously noted suggest that resistance training may preserve lean body mass when used in conjunction with a marginally restricted caloric intake. Clearly, the efficacy of combinations of different weight management, nutrition, and resistance training protocols needs further study.

Central Obesity

Considerable recent data from multiple epidemiological studies have shown the association of body mass index and body fat with coronary heart disease, diabetes, and cancer [*46,54–58*]. What may be a key component of this obesity-related risk is increased central obesity (also known as intraabdominal fat or visceral adipose tissue) that appears to place a person at higher risk of colorectal cancers [*46,58*]. Central obesity seems to set the stage for a cascading series of events that can result in insulin resistance, glucose intolerance, abnormal lipoprotein–lipid profiles, and hypertension [*3,46*]. Thus, visceral obesity is now considered an important component of the insulin-resistant dyslipedemia syndrome [*46*]. Resistance training may reduce risk for these diseases through alteration of body composition and other mechanisms noted shortly. For example, Ross and colleagues [*50*] report a 40% reduction in visceral fat in middle-aged obese men following a regimen of caloric restriction and low-volume resistance training.

Other Risk Factors

In addition to increasing lean body mass and decreasing regional and total fat mass [*24,26*], it also has been shown that resistance training can markedly improve other risk factors and mechanisms associated with coronary artery disease, diabetes, and cancer. For example, resistance training has been shown to decrease heart rate, systolic blood pressure, and rate pressure product (without change in maximum oxygen consumption) on a standard treadmill protocol [*21*]. These data suggest that resistance training can make tasks of daily living less demanding and, hence, less risky. While not completely consistent, studies indicate that resistance training can increase HDL cholesterol [*4,33–35,59*].

Age-related decreases in muscle mass may be related to a reduction in glucose metabolism, which predisposes older people to the sequelae of insulin resistance, diabetes and heart disease, hyperinsulinemia, and increased cancer risk [*4*]. Several studies also show that resistance training can improve mechanisms involved in glucose metabolism, including glucose tolerance and insulin resistance [*23*]. Recent data from Schoen *et al.* [*60*] indicate persons with central obesity demonstrating high fasting glucose and high glucose and insulin 2 h following a 75-g oral glucose challenge have at least a twofold risk of colorectal cancer. For fasting insulin levels, a threshold effect was seen; that is, if a person had fasting insulin levels above the median in their sample, their risk of colon cancer rose to 1.6. Rubin et al. [*25*] showed that resistance training may also increase chromium absorption. Chromium appears to be another mechanism associated with glucose tolerance and insulin sensitivity.

In another study, Koffler and colleagues [*22*] showed that resistance training accelerated whole bowel transit time by 56% and thus could reduce the risk of colon cancer through that mechanism. However, there appears to be no prospective studies that have focused on long-term impacts of resistance training, which suggests that the area of resistance training and disease risk reduction is still in its infancy [*61,62*]. It also should be obvious, as noted, that none of these potentially highly favorable disease and disability reduction outcomes is likely to be evident unless resistance training is maintained.

LOWER-BACK PAIN, LOWER-BACK INJURY, AND MORBIDITY

Back Pain

Back pain is the most common workers' compensation claim in the United States. It accounts for about one-fourth of all claims and one-third of total compensation costs. Back pain, which results in about 40% of absences from work, is second to only the common cold as the most frequent cause for sick leave. In 1990, estimates of the cost of back pain in the United States ranged from $50 billion to $100 billion [*9*], and the workdays lost due to back pain could be estimated at $14 billion [*9*]. The magnitude of the back pain problem is so large that even a 1% reduction in overall prevalence could considerably reduce morbidity and save millions of dollars [*9*].

Mooney and colleagues [*63*] have demonstrated in a strip-mine operation that performing one set on a lower-back machine once a week increased strength from 54 to 104% in a treated group of workers, reduced the incidence of back injuries to one-half the industry mean and about one-sixth of the mean incidence rate for the prior 9 years at the coal mine. They reduced the mean workmen's compensation liability from $14,430 to $380 per month. Given the brevity and infrequency of training that is required, a similar lower-back machine could service hundreds of employees and pay for itself within weeks while remaining operational for years. A case can be clearly made that a lower-back machine and other resistance exercise machines should be available in all except the smallest worksites.

Carpenter and Nelson [*10*] reviewed the history of treating lower-back pain and found that for the past 40 years, treatment of lower-back pain has primarily consisted of passive modalities such as bed rest, massage, electrical stimulation, hot or cold packs, medications, and stretching. A common denominator among these passive treatments is that they do *not* promote healing through positive physiological adaptation. Instead, these procedures appear to provide symptomatic relief but offer no long-term efficacy. People with lower-back pain often experience a cycle of pain, disuse, more pain, and less use. They become deconditioned with little strength, endurance or flexibility in their lower back. Safe, effective lower-back exercise involves brief, infrequent training with progressive variable resistance through a full range of motion, isolation of the lower-back musculature, and pelvic stabilization [*10*].

The prescribed training dose is one set of lower-back exercise performed once or twice a week [*11*] and the same training protocol increases lumbar vertebrae bone mineral density and erector spinae muscle cross-section area. Multiple sets or more frequent training of the lower back does not result in greater increase in strength [*10*]. Most importantly, chronic lower-back pain patients showed an increase in lumbar extension strength, a reduction in pain, greater daily functioning, and less use of the health care system [*10*].

Bone Mineral Density

Bone mineral density (BMD) is the relative amount of bone mineral per measured area of bone (grams per square centimeter). Attaining a greater BMD throughout life may help prevent osteoporosis and fractures. BMD increases in response to the application of mechanical stress and decreases when the forces generated from the stress are removed [*64*]. It appears that the magnitude of the stress on a specific area of bone, rather than the number of times the stress is repeated, is the major determinant of BMD. Brief, high-intensity periods of loading that generate a diversity of strain patterns on the bones will provide the maximal osteogenic response [*65*]. Thus, resistance training rather than repetitive low-intensity activities such as walking is recommended.

For example, Nelson and colleagues [*8,12*] reported an increase in femoral neck (1%) and lumbar spine (1%) BMD in postmenopausal women after 1 year of resistance training, compared with a decrease (−2.5 and −1.8%, respectively) in a control group. Muscle mass, strength, and dynamic balance increased in the strength-trained women and decreased in the controls. The BMD response is specific to the region of bone stressed—similar to increases in muscle strength and mass when specific muscles are stimulated. Therefore, a training protocol consisting of one set of repetitions for a variety of resistance exercises, using free weights or machines, two or three times a week, should provide an adequate stimulus for increasing BMD in the anatomical regions that are stressed by each specific exercise and is the recommended protocol [*12*].

Kerr and colleagues [*66*] demonstrated that a relatively standard protocol of 8–10 repetitions, i.e., 8–10 RM, compared to 20–25 RM, generally considered light resistance, is required to increase site-specific bone mineral density. Kerr and colleagues [*66*] speculate that the mechanisms of osteogenesis (bone formation) occur as a result of muscles pulling on the bone, which is mediated through the muscular action at the site of the tendon attachment to the bone. The results suggest that the osteogenic response is related to the magnitude of the load—heavier weight and fewer repetitions. The researchers concluded that the magnitude of the load is more important than the number of loading cycles for increasing bone density. Increases in bone density in this study [*66*] were also site specific. That is, the increases were at the attachment sites (e.g., trochanter and intertrochanter) for the specific muscles involved in the exercises that were performed. Because many females may fear that using heavier weights (e.g., 6–10 RM) will produce large muscles, a very unlikely consequence of using any protocol (see later), they tend to use a lighter resistance and a greater number of repetitions (20–25 RM). Fewer repetitions with a heavier load may be more beneficial for increasing bone density. A wide variety of exercises, including weight-bearing exercise, should be employed in order to stimulate maximal increases in bone density throughout the body—another good reason to perform a variety of exercises, including some weight-bearing exercises, rather than multiple sets of the same exercise. It appears likely that the usual generally recommended protocol (6 to 10 repetitions using 4 s to raise the resistance and 4 s to lower the resistance; see later) will favorably impact bone mineral density and is similar to a protocol used in seminal work in this area [*8,12*].

Functional Ability

Resistance training has great potential to increase functional ability in an elderly population. Fiatarone and colleagues [*67*] reported the effects of 10 weeks of resistance exercise in 63 women and 37 men ranging from 82 to 98 years of age. Strength increased 113%, muscle area of the thigh increased 3%, walking speed increased 12%, and stair-climbing power increased 28%. Nutritional supplementation had no significant effect on any primary outcome measure. The authors concluded that the impaired mobility seen in very elderly people is strongly related to muscle weakness. They demonstrated that the muscles of the very elderly respond very well to resistance training and that the response is accompanied by improvements in functional mobility and overall activity [*65*]. Vanderhoek and colleagues [*68*] reported increases in strength that ranged from 41 to 96% (average 61%) for eight exercises following 32 weeks of resistance training in older women. They also showed significant improvement in balance tests, which were associated with the increase in dynamic strength. These responses to the resistance training may reduce the risk of falling in this population and thus increase or prolong their level of independence and improve quality of life [*67*].

PRINCIPLES OF RESISTANCE TRAINING

Misconceptions

Effective resistance training is a scientifically based intervention that revolves around specific principles that are largely verified by research. Specific protocols can be prescribed in precise dosages. Before describing the principles of resistance training and its application, it is important to understand why contemporary resistance training does not often follow scientifically based guidelines. Two misconceptions and points of confusion have resulted in most people performing resistance training in ways that are in direct opposition to scientific principles and research. The first misconception is failure to differentiate between a minimal exercise *stimulus* that is required to produce *adaptations* and the amount of exercise that can be *tolerated*. As will be detailed shortly, the required amount of exercise is minimal but precise. The amount of exercise that can be tolerated by a small percentage of people is substantial—a degree of toleration that appears to be largely genetically mediated [*69*]. It has been assumed that tolerance for a large volume of exercise is necessary because it is also assumed that a greater volume of exercise will produce superior adaptations and outcomes. We call this the *volume theory* [*70*] and despite the lack of scientific data to support this *volume* position [*15,44,45,68*], it permeates popular belief and has its proponents in professional circles [*13*].

A second related set of misconceptions and points of confusion involve the failure to understand that tolerance and *responsiveness* to resistance training such as increased muscle mass and strength is largely genetically mediated—as is the case with aerobic training [*69*]. Thus, it has been reported that in resistance training studies where the same training protocol is used for everyone, some men and women may increase strength as little as 5% while other men and women may increase strength more than 100% [*4*]. Large inter-individual differences for gains in fat free mass also are reported [*4*]. For example, Van Etten and colleagues [*71*] classified young untrained males according to body build, either slender or solid, and subjected them to similar resistance training protocols. The free-fat mass was 13.3 kg greater in the solid males and increased 1.6 kg after 12 weeks. The slender males did not significantly increase free-fat mass. It also has been shown that the size, structure, and strength of specific muscle groups are largely genetically mediated [*72–74*].

When high *tolerance* for resistance exercise is combined with a high *responsiveness* to resistance training and a genetic predisposition to strong and large muscles, then an individual can frequently perform a large volume of exercise and show remarkable gains in strength and muscle mass. However, this does not mean that a large volume of exercise is required or that anyone seeking improvement of the musculoskeletal system needs to perform a high volume of exercise.

Principles

The principles of effective resistance training are remarkably simple to understand and apply. They consist of the intensity, volume, and frequency of the exercise and require training protocols that are precise and time efficient. The most basic goal of resistance training is to apply a stimulus to each major muscle group for approximately 30–90 s and provide a marginal overload compared to a prior training session [*15*]. An overload can be a small increase in resistance used for the same duration, use of the same resistance but for a marginally longer duration, or both. Progressive overload is essential for increasing muscular strength and size. What appears to be required for stimulating increases in strength and muscle mass is just slightly surpassing a threshold established in prior training sessions. Passing a threshold apparently sets in motion complex physiological responses such as an increase in protein synthesis, which results in increased strength and muscle mass. Once the threshold has been passed, any additional volume of exercise appears unnecessary and, indeed, potentially counterproductive. That is, unnecessary exercise not only takes more time, but as an additional stressor, or disruption in homeostasis, it can undermine recovery from the training session through immunosuppressive effects [*75*]. Moreover, it is during the recovery time between training sessions that the requisite physiological adaptations occur, which provides the basis for subsequent overload in the next training session. Thus, *a minimum but very prescriptive dose of resistance training appears to be the ideal dose to produce a positive response*.

Resistance training typically comprises two types of muscle actions for each repetition. Lifting the resistance is the concentric muscle action and lowering the resistance is the eccentric muscle action. Muscle fibers are stimulated by moving a resistance through a series of consecutive repetitions (concentric and eccentric) for each specific exercise, and the time required to complete the repetitions is designated as the time under load. A series of repetitions is called a set. Research demonstrates that increases in strength and muscle mass can be obtained with the use of one set of a specific exercise for each muscle group twice a week in beginners or advanced trainees [*43,45*]. Yet, some individuals who display a large musculature and demonstrate a high level of strength may perform as many as 20 sets for each muscle group three or four times a week. Thus, their dose of resistance training for each muscle group is 30 to 40 times the amount that is required. Genetically gifted people who employ multiple sets per muscle group show superior levels of muscle mass and strength—not *because* of the volume of exercise, but perhaps *in spite* of the volume of exercise.

Data from studies using two sets for lower body movements and one set for upper body movements suggest there was no added benefit accrued from using two sets [*14,44*]. However, a conservative interpretation of the outcomes of these studies is that it still is unknown (though unlikely) if some specific outcomes such as alteration of glucose metabolism or decrease in gastrointestinal transit time require a greater training frequency and greater volume of training for any muscle group. The recommended frequency of training for each major muscle group is twice a week, with some evidence that once a week can also increase strength and muscle mass, although to a lesser degree than twice a week [*15*]. There is little evidence to support the added benefits of training three times a week compared to twice a week [*15*].

The most important conclusion that can be drawn from these studies is that a very similar resistance training protocol can result in multifactor risk reduction. For example, Kelley and Kelley [*36*] in their meta-analysis of randomized controlled studies of resistance training and resting blood pressure report no significant difference or relationship when changes in resting blood pressure were portioned or regressed according to training program characteristics such as frequency (2–5×/week), duration (6–30 weeks), resistance (30–90% 1 RM), time of sessions (20–60 min), number of exercises (6 to 14), or the number of sets per exercise movement (one to four).

Intensity and Exercise Performance

Research suggests that training should be done under conditions of moderate to high intensity. Intensity is defined as the percentage of the momentary degree of effort that is required. A person exercising at a high degree of intensity will likely terminate the set when it becomes difficult to complete another repetition in good form. If the execution of six repetitions is the immediate goal with a given resistance and six are completed, but a seventh repetition cannot be completed, then that person is training at a relatively high percentage of momentary ability – high intensity. Research has not specified the precise level of intensity that yields optimal outcomes, but exercising at the aforementioned level of intensity, or close to it, generally assures that an adequate intensity and stimulus for adaptation is achieved.

The absolute amount of resistance that is used in a training program for a given exercise primarily depends on the strength level of each person. A 20-year-old woman may use 50 kg of resistance for a specific exercise and fatigue the muscle on the sixth repetition while a 75-year-old man may use 25 kg and fatigue on the sixth repetition. Both are exercising at a relatively high intensity. If a rational progression and training plan are followed, both will produce increases in strength and muscle mass, as well as health-related benefits—all of which are dependent on their genetic potential.

Intensity of effort does not necessarily involve very high levels of force and it does not mean performing repetitions at a fast cadence. Moving quickly not only puts stress on the joints at the beginning and end of each exercise movement, but it essentially undermines effectively overloading and fatiguing the muscles throughout the range of motion. Quick movements mean that momentum is used to help move the resistance instead of relying as much as possible on the targeted muscle groups. Thus, more resistance may be used in an exercise when quick repetitions are executed, but it is not because the muscles are working harder; it is because momentum makes the exercise easier. The result is that an exercise may be less productive and potentially more dangerous because of the greater required forces (greater mass and acceleration). Very slow repetitions decrease momentum, create a higher intensity stimulus, potentially decrease the chance of injury, and may result in greater strength outcomes than moving more quickly [*76*]. As noted, repetitions taking about 8 s were also used in the seminal research demonstrating increases in bone mineral density [*8,12*]

Our recommendation is to take 4 s to perform the concentric phase of a repetition (lifting the resistance) and 4 s for the eccentric phase (lowering the resistance). At approximately 8 s per repetition, executing 8 to 10 repetitions requires about 64–80 s per set. At its simplest level, nothing more is required than selecting one effective exercise movement for each of the major muscle groups, performing one set of each exercise movement twice a week, and slowly progressing by increasing either resistance and/or repetitions as the exercise becomes easier [*77*]. For adequate recovery, training sessions should be separated by 2 or 3 days [*15,77*].

Specific exercises for each muscle group will vary depending upon equipment, personal preferences, and physical limitations. There is little evidence to suggest that one modality of resistance training such as resistance exercise machines results in better outcomes than other modalities such as free weights, as long as the guidelines for effective training are followed [*15*]. The exception is that to safely and effectively stimulate the muscles of the lower back, a lower-back machine is required [*10*].

RESEARCH AGENDA AND APPLICATIONS OF RESISTANCE TRAINING

This article presents encouraging findings showing the favorable impacts of resistance training on multiple risk factors associated with diseases and disabilities. Despite these positive findings, an ambitious and diverse set of research protocols must be tested to more definitively answer a number of key basic and applied questions [*78*]. It remains unknown, for example, if the same basic exercise protocol of one set of 8 to 10 exercises performed two to three times a week [*15*] will optimally impact the range of risk factors discussed in this article. Perhaps, some risk factors such as those associated with body composition may be more favorably impacted by somewhat different protocols and as discussed previously, metabolic and skeletal responses to resistance training are complex. Moreover, in some areas such as gastrointestinal transit time [*22*], there is only very preliminary research with positive outcomes.

Likewise, there is only preliminary research on more minimal doses of resistance training such as training only 1 day each week [*79*]. Such reduced training frequency appears to marginally (~25–30%) blunt strength and hypertrophy outcomes but it is unclear how such reduced frequency affects other risk factors. It is also unclear how a range of mechanisms and risk factors are affected by less intensive training as exemplified by curtailing a resistance training set well before muscular fatigue.

Critical questions remain about the degree of risk reduction afforded by resistance training. Except for hypertension, where evidence shows that resistance training can effectively reduce risk particularly for people with borderline hypertension [*36,43*], how much resistance training reduces risk through a number of mechanisms such as insulin resistance needs intensive study. Additionally, as suggested in a prior section, it is unclear if changes in risk factors are necessarily associated with some stimulus that parallels increases in strength and hypertrophy. This is an important consideration because increases in strength and hypertrophy plateau after several years of training [*28*]. If there are no appreciable changes in strength and muscle mass, would there be no stimulus for further changes in mechanisms associated with risk or, for that matter, would there be indications of regression?

Few studies have examined how resistance training can be productively combined with other health beneficial interventions such as weight management, cardiovascular training, and a general overall increase in physical activity. This is quite complex and not simply a matter of additive, much less synergistic, effects. For example, as noted above, resistance training apparently will not preserve lean body mass if caloric restriction is severe [*40*] and unless cardiovascular training is performed within specific parameters associated with central and peripheral adaptations, it appears to diminish increases in strength and hypertrophy from resistance training [*80*].

By emphasizing resistance training in this paper and suggesting that it be the central component in exercise programs, we are not suggesting that cardiovascular training be abandoned. Rather, in a prior article [*70*] we have described how epidemiological and experimental research points toward the effectiveness of very brief (∼10–12 min), twice weekly cardiovascular training protocols, which result in sufficient enhancement of the cardiorespiratory system. As suggested above, research is needed to more fully optimize concurrent resistance and cardiovascular training.

While a range of basic research areas needs to be investigated, there are also more applied research issues that need to be addressed. One major concern is maintaining exercise behaviors once people have initially adopted them either independently or through enrollment in a program. To date, there is no set of procedures that can reliably be used to promote long-term maintenance of exercise behaviors [*81*]. Preliminary data do suggest that a more personalized and intensive approach may be required that teaches people principles, protocols, and skills and then provides enactive ways to transpose behaviors to preferred settings such as the home [*82*].

Finally, just as prospective studies a generation ago began the long-term investigation of cardiorespiratory fitness and morbidity and mortality, such studies, now only in a seminal stage with musculoskeletal strength [*60,61*], need to be undertaken.

Even in the absence of answers to these and other questions, the preponderance of evidence shows that resistance training is a very time-efficient activity and has favorable impacts on multiple systems with few contraindications and that properly performed resistance training can be a very cost-effective preventive intervention. For example, quite remarkably, Hurley and Roth [*4*] have noted that a few months of properly performed resistance training after age 50 can regain two decades of strength loss and muscle mass. That is, resistance training can reverse the 12–14% loss in strength and the ∼6% loss of muscle mass per decade after age 50.

When scientific guidelines for resistance training are not followed, however, training is not likely to be very effective and can be potentially harmful. Therefore, facilities for effective resistance training should include well-educated and supervised instructors who can explain effective training principles, demonstrate proper exercise form, guide individuals through initial training sessions, provide specific goals for training sessions to meet intensity requirements, and monitor progress. From a public health perspective, as we have noted, with the exception of a lower-back machine, equipment need not be costly or require much space. A basic free-weight set up is highly durable, provides the tools to meet the requirements we have specified, and can service hundreds of people.

Healthy People 2010 [*1*] has designated the promotion of physical activity and exercise as one of its priorities. When properly performed, resistance training is a very cost-effective time-efficient intervention that has the potential to provide a myriad of disease-prevention and health-promotion benefits. To this point, few people have realized the multiple risk-reduction benefits of resistance training, its relative simplicity, and very high safety and time efficiency. Based on Bandura's [*83*] theoretical synthesis of dissemination principles and diffusion theory, active promotional campaigns now consistent with the goals of *Healthy People 2010* are likely to be more effective in enabling significant segments of the population to adopt resistance training if they: (1) provide accurate information about resistance training based on the burgeoning scientific research that clearly described the benefits and where such information is endorsed by leading health organizations [*43*]; (2) use modeling tactics that involve diverse sets of people depicting proper training techniques and prescriptions and where such modeling vividly shows the simplicity, time efficiency, and benefits of resistance training; (3) designate specific settings as meeting standards of practice for staffing and equipment so that people are most likely to safely produce positive outcomes in their training and hence serve as exemplars for other people, creating a "snowball effect"; and (4) provide some incentives to make such settings more readily available in diverse communities. Such carefully constructed public health policies, recommendations, and promotional campaigns that focus on resistance training should have enormous beneficial impacts on our nation's health [*1*].

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