The Role of Resistance Training in the Prevention and Treatment of Chronic Disease

Joseph T. Ciccolo, Lucas J. Carr, Katie L. Krupel and Jaime L. Longval
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THEMED
REVIEW

Joseph T. Ciccolo, PhD, Lucas J. Carr, PhD,
Katie L. Krupel, MS, and Jaime L. Longval, MS

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Abstract: *Recent research suggests that resistance training (RT) in adults has the potential to prevent, treat, and possibly even reverse the impact of several chronic diseases. A properly designed progressive program can have profound effects on the musculoskeletal system, resulting in enhanced physical and mental health. In this review, the authors summarize recent research detailing the numerous benefits gained from participating in an RT program in those with or at risk for chronic disease. This includes increases in muscle mass and strength; enhanced physical function; reduced risks for osteoporosis and cardiovascular and metabolic diseases; improved management of cancer, neuromuscular disorders, HIV, and chronic obstructive pulmonary disease; and reductions in negative mood states. Given these benefits, numerous national organizations, including the committee commissioned to create the National Physical Activity Guidelines for Americans, have endorsed the participation in RT as a necessary component of maintaining health. Fortunately, the most current estimates show that a growing number of individuals are participating in RT, but these national estimates still fall below the goal of 30% set by Healthy People 2010. Future research will therefore need to focus on increasing the adoption and adherence of RT, as it carries the potential to dramatically affect public health.*

Keywords: resistance training; chronic disease; prevention; public health

> Proper RT prescription is complex and involves numerous factors that do not allow for generalized prescriptions.

Resistance training (RT; ie, strength training; weight training) is a well-established form of exercise that results in improved physical and mental health.[1,2] When properly prescribed, RT increases muscle strength, speed, size, power, endurance, balance, and coordination, and it can reduce the risks for several chronic diseases and physical and mental impairments.[3,4] An enhanced musculoskeletal system can have profound effects on health, as evidenced by a recent study that found muscular strength to be inversely and independently associated with death from all causes in men, even after adjusting for cardiorespiratory fitness and other potential confounders.[5] These results are further supported by a wealth of other prospective studies that have shown this relationship for both men and women.[6-9] Such reports underline the importance of regularly participating in an RT program and provide a base from which numerous national health organizations (eg, American College of Sports Medicine [ACSM]; American Heart Association [AHA]) endorse the participation in an at least 2-day per week RT program.[1,10]

DOI: 10.1177/1559827609354034. From the Alpert Medical School of Brown University, Providence, Rhode Island (JTC, LJC) and Centers for Behavioral & Preventive Medicine, The Miriam Hospital, Providence, Rhode Island (JTC, LJC, KLK, JLL). Address correspondence to Josephe T. Ciccolo, PhD, Alpert Medical School of Brown University and The Miriam Hospital, Centers for Behavioral and Preventive Medicine, Coro Bldg, Suite 500, One Hoppin Street, Providence, RI 02903; e-mail: joseph_ciccolo@brown.edu.

Table 1.

Resistance Training Program Guidelines and Recommendations

Author/Year	Topic	Type	Major Findings/Conclusions
American College of Sports Medicine (ACSM), 2009[10]	Resistance training (RT) prescription guidelines	ACSM position stand	Progression in RT is dependent on the development of appropriate and specific training goals and should be an individualized process using appropriate equipment, program design, and exercise techniques needed for the safe and effective implementation of a program.
Bird et al, 2005[12]	RT program design	Review	The success of an RT program depends on manipulation of the acute program variables: (1) muscle action, (2) loading and volume, (3) exercise selection and order, (4) rest periods, (5) repetition velocity; and (6) frequency. These variables will determine the magnitude to which the neuromuscular, neuroendocrine, and musculoskeletal systems adapt to both acute and chronic RT.

In this review, we provide a general overview of the most up-to-date information on the role of RT in the prevention and treatment of several chronic illnesses. Using an electronic search (PubMed, PsycInfo, Web of Science), we collected articles on RT published in print or online through February 2009. We strictly limited our search to randomized controlled trials (RCTs) conducted with adults, and particular attention was given to recent systematic reviews and meta-analyses that have contributed uniquely to the literature. In addition, although there is ample evidence to support the benefits, efficacy, and/or use of aerobic exercise or a combined aerobic and RT program, we specifically chose not to include a focus on these studies. Instead, it was our aim to describe the unique and independent effects derived from the participation in an RT-only program. Finally, although many of the chronic diseases included are related and often occur comorbidly within the general population, we only provide individual reviews of each topic.

Resistance Training Program Variables and Guidelines

Proper RT prescription is complex and involves numerous factors that do not allow for generalized prescriptions. An effective RT program will take into account multiple moderating factors that include but are not limited to age, gender, race, health status, and previous RT experience.[10] Thus, it is critical to take a sophisticated approach to ensure that an appropriate and individually tailored program will effectively stimulate the physiological changes necessary to achieve the desired outcome.

The most basic RT program is a full-body, 2-d/wk, 1-set per muscle group, 8- to 12-repetition routine.[10] However, to achieve maximal results, a program needs to adhere to the key training principles and manipulate the acute program variables of RT.[11,12] Following the key training principles, an effective program will use *progressive overload* and gradually increase the amount of stress placed on the body. A program will also need to monitor *specificity*, or the physiological adaptation occurring in a targeted muscle or group of muscles. Lastly, a program is more likely to be successful if *variation* is employed repeatedly. Periodically altering the program in a systematic manner will produce optimal results. Adherence to these principles will allow for the successful manipulation of the acute program variables: (1) *muscle action* (concentric/eccentric action), (2) *loading* (weight used) *and volume* (the number of sets and repetitions), (3) *exercise selection and order*, (4) *rest period*, (5) *repetition velocity*, and (6) *frequency of training*.[11,12] Constructing a program using these guidelines will produce the neuromuscular and neuroendocrine responses needed to stimulate musculoskeletal system adaptation (see Table 1 for reviews). The end result will ultimately be a change in maximal muscular strength, endurance, size, function, and/or power.[11,12]

Importantly, RT has been shown to be relatively safe for all populations,[3,13] as it does not pose an increased risk over other types of exercise (ie, aerobic training). Safety, proper form, and an individualized prescription, however, are crucial components of a well-developed program. For specific guidelines on program construction and planning, we refer readers to Table 1.

Cardiovascular Disease

Using an RT program as a tool to prevent and treat cardiovascular disease (CVD) has now been well established and accepted.[3,13] Several recent high-quality evidenced-based systematic reviews and meta-analyses detailing the specific and isolated effects RT has on the prevention and treatment of CVD currently exist (see Table 2). We briefly describe 3 related areas (ie, arterial stiffness, hypertension, chronic heart failure) in which

Table 2.

Cardiovascular Disease

Author/Year	Topic	Type	Major Findings/Conclusions
Williams et al, 2007[3]	Cardiovascular disease risk reduction	Review	Resistance training (RT) has a significant beneficial effect on the cardiovascular system structure and function, and it can substantially modify cardiovascular disease risk. Guidelines for RT programming in apparently healthy and known cardiovascular disease populations are provided.
Braith and Stewart, 2006[4]	Cardiovascular disease risk reduction	Review	RT appears to mitigate the effect of numerous risk factors associated with the development of cardiovascular disease. RT-only programs appear to reduce some aspects of disease reduction, but there is little evidence to challenge existing guidelines that call for moderate-intensity RT to be performed in combination with aerobic exercise. More randomized controlled trials (RCTs) among diverse populations are needed.
Cornelissen and Fagard, 2005[17]	Hypertension	Meta-analysis	Moderate-intensity RT is not contraindicated and could become part of the nonpharmacological intervention strategy to prevent and combat high blood pressure. Additional studies are needed, particularly in the hypertensive population.
Braith and Beck, 2008[13]	Chronic heart failure (CHF)	Review	Provides a review of the safety and efficacy of RT for patients with CHF. Evidence-based recommendations for designing safe RT programs are also presented to help clinicians and rehabilitation professionals formulate exercise prescriptions for their patients. Where possible, the separate and independent effects of RT on patients with CHF are discussed. Presents evidence that improvement of skeletal muscle phenotype (muscle mass, fiber morphology, and histochemistry) should be a fundamental goal of rehabilitation in patients with CHF.

RT programs have begun to make an impact but still remain under debate and/or require further study.

Hypertension

Approximately 1 of every 3 Americans has hypertension.[14] Overall, aerobic exercise has been well supported as a method to prevent and treat hypertension,[15,16] but recent evidence suggests that RT may also be helpful. For instance, a 2005 meta-analysis on the effects of RT on resting blood pressure found moderate-intensity RT to be an effective nonpharmacological/lifestyle intervention for the prevention and treatment of hypertension.[17] Specifically, the authors found significant net decreases in both systolic and diastolic blood pressure (eg, 3 to 3.5 mm Hg, respectively) in both hypertensive and normotensive groups. In addition, training intensity did not seem to influence the beneficial changes (ie, reductions), but both systolic and diastolic blood pressure decreased significantly in the shorter trials (<15 weeks) in comparison to a nonsignificant decrease in the longer trials (>15 weeks). Caution needs to be taken when interpreting these results, however, as the authors point out the significant limitations, including a small number of studies and participants, as well as a high variability in the frequency, intensity, and duration of each RT program. Although this meta-analysis confirmed the findings from previous reviews, illustrating the safety and efficacy of RT for reducing blood pressure,[15,17,18] future studies will be needed to clearly define the optimal RT prescription for preventing and reducing hypertension.

Arterial Stiffness

Central arterial stiffness increases systolic blood pressure, pulse pressure, and cardiovascular risk, and it can independently predict future cardiovascular events and mortality.[19] Aerobic exercise and combined aerobic and resistance training have shown success in reducing arterial stiffness for both apparently healthy and diseased populations.[20,21] RT alone, on the other hand, when performed at high intensities, demonstrates unfavorable effects, increasing central arterial stiffness in both men and women.[22,23] As outlined by Braith and Beck,[13] high-intensity programs with increasing/high volume augment central arterial stiffness, whereas programs that use a moderate intensity/moderate volume do not. For example, using a 11-week, 4-session per week, high-intensity RT program, Cortez-Cooper et al[22] found reduced carotid arterial compliance, which is in contrast to both Casey et al[24] and Yoshizawa et al,[25] who recently found no detectable change in arterial compliance after 18 and 12 weeks, respectively, of moderate-intensity RT. As such, more research with longer trials investigating the differential effects of high- and moderate-intensity programs on arterial stiffness are needed; however, this should not currently deter health professionals from recommending moderate-intensity RT (ie, at a level recommended by ACSM, AHA), particularly given its numerous other beneficial effects.

Chronic Heart Failure

Approximately 5 million Americans have chronic heart failure (CHF), and about 287 000 people with CHF die each year.[26] Individuals with CHF experience multiple physiological changes, including reduced left ventricular function, fatigue, dyspnea, and reductions in skeletal muscle size and strength. The changes in skeletal muscle result from major alterations in muscle function and morphology that can be attributed to the reduced peripheral blood flow and cellular perfusion that occurs with CHF.[27] Recent research has shown muscular strength to predict survival in those with CHF,[28] which suggests RT may play a vital role for this population. Despite initial concerns over safety, RT is now known to be safe, with several studies showing significantly positive results (for a review, see Braith and Beck[13]). Currently, there is some debate over the optimal exercise prescription for CHF patients, and recent studies have sought to determine the differential impact of aerobic and RT programs. For example, Feiereisen et al[29] randomized 60 individuals with CHF to a 40-session RT-only, aerobic-only, combined aerobic and resistance program, or control group. All intervention participants exercised 3 times a week for 45 minutes. Results showed significant improvements over the control, without significant differences among the 3 training groups in peak oxygen consumption, peak workload, and thigh muscle volume. This study is representative of several others,[13] and as a result, it appears RT is as effective as aerobic-based programs on functional measures of health for CHF patients. Importantly, RT as an enhancement to an aerobic training program may continue to allow these patients to maintain the strength that is needed to function in daily life with better ease. Similar to other diseased (and healthy) populations, however, tailoring an exercise program to fit the specific needs of individuals will yield the most desirable results.[10]

Metabolic Diseases

The beneficial effects RT has on metabolism are widely accepted and established. Several epidemiological studies have shown RT to be inversely correlated to several metabolic disorders that ultimately result in an increased level of disability, disease, and mortality. Below we outline literature examining the use of RT as a tool for the prevention and treatment of several metabolic disorders (see Table 3 for a list of reviews).

Obesity

Obesity, defined as having a body mass index (BMI) of 30 or greater, is well known to increase the risk for numerous diseases, including cardiovascular disease, osteoarthritis, type 2 diabetes, and certain cancers.[30] Research has shown total physical activity >250 min/wk to be associated with significant weight loss.[31] RT independent of aerobic activity, however, has mixed support for reductions in body weight. The increases in muscle mass, found in both genders[32,33] and all ages,[34,35] are generally offset by the reduction in body fat, resulting in a net-zero change in body weight.[36] Instead, the unique and chief benefit RT can provide an overweight or obese individual is the maintenance of and increase in lean muscle mass.[37-40] Specifically, increases in lean muscle mass gained from RT can result in stable increases in basal metabolic rate (BMR),[37-40] a strong predictor of future weight gain.[41] As such, this change in body composition/caloric dynamics makes RT a valuable and effective weight *management* technique[37-41] and one that can potentially combat age-related increases in body fat, which are often attributed to muscle loss (ie, sarcopenia).[42] For example, using doubly labeled water, van Etten et al[43] found a 9.5% increase in the average daily metabolic rate in 12 men after 18 weeks of RT, and other studies provide support for the reported increases in BMR immediately following and after RT.[44,45] Thus, the evidence to date suggests that RT can be used as a tool to increase and maintain lean body mass with a concomitant decrease in body fat, which has implications for both the prevention and management of overweight and obesity.[46] Researchers remain to be challenged by finding ways in which to increase the adoption and maintenance of RT for this population.

Type 2 Diabetes

Diabetes currently contributes to 200 000 deaths annually and is the sixth-leading cause of death in the United States.[47] Type 2 diabetes, characterized by abnormal insulin secretion and insulin resistance, is the most common type of diabetes.[47] Although the mechanistic manifestation of type 2 diabetes has yet to be elucidated, physical inactivity and overweight/obesity are known risk factors for its development.[48] RT may help manage and potentially reduce the risk of type 2 diabetes (for reviews, see Tresierras and Balady[46] or Gordon et al[49]), as it is hypothesized that muscle growth augments muscle glucose storage and/or glycemic control,[50,51] whereas improved muscle function may alter insulin sensitivity via the expression of the GLUT-4 transporter.[52] These theories are supported by studies demonstrating correlations between increased muscle mass, improved muscle function, reduced insulin resistance, and reductions in glycosylated hemoglobin (HbA_{1c}), a measure of mean plasma glucose concentration.[50-53] Recently, Sigal et al[54] randomly assigned 251 type 2 diabetic men and women to a 3-session/wk, 22-week aerobic exercise–only, RT-only, combined aerobic and RT, or a control group. Compared to the control, adjusted absolute HbA_{1c} values significantly decreased in all exercise groups, and there was a significant decrease in the combined exercise group when compared to the aerobic-only or RT-only groups. Importantly, the combined group performed the full aerobic plus the full resistance training program, greatly increasing the total exercise time/week for these individuals. Thus, it remains clear that exercise is beneficial for type 2 diabetics; however, the specific

Table 3.

Metabolic Diseases

Author/Year	Topic	Type	Major Findings/Conclusions
Donnelly et al, 2009[31]	Obesity	American College of Sports Medicine (ACSM) position stand (exercise based)	Resistance training (RT) does not enhance weight loss but may increase fat-free mass and increase loss of fat mass and is associated with reductions in health risk. Existing evidence indicates that aerobic physical activity or RT without weight loss improves health risk.
Tresierras and Balady, 2009[46]	Diabetes/obesity	Review	RT appears to enhance insulin sensitivity and improve glucose tolerance in a wide range of study groups. Studies have shown that improved glucose uptake is likely a result of qualitative changes in resistance-trained muscle. There is also substantial evidence that regular RT can increase total fat-free mass, muscular strength, and resting metabolic rate and preferentially mobilize the visceral and subcutaneous adipose tissue in the abdominal region.
Gordon et al, 2009[49]	Diabetes	Systematic review	RT is effective in improving glycemic control and increasing insulin sensitivity. Higher intensity and longer intervention duration of RT appear most beneficial, but further investigation is required. RT has been shown to be equivalent to aerobic exercise in ameliorating diabetes and its associated complications; it may also be the exercise of choice for individuals with diabetes or prediabetes who find adherence to continuous moderate-intensity aerobic training too physically challenging.
Kelley and Kelley, 2009[58]	Hyperlipidemia	Meta-analysis	A total of 29 studies including 1329 men and women found a significant beneficial change in total cholesterol, the ratio of total cholesterol to high-density lipoprotein cholesterol, non-high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and triglycerides with RT.
Cheema and Singh, 2005[61]	Chronic kidney disease	Systematic review	Appropriately prescribed aerobic exercise/RT is safe and beneficial. Even though methodological shortcomings exist, there is sufficient evidence to support the use of aerobic exercise and RT, as no other medical treatment with the capacity to produce beneficial adaptations across a wide range of physiological, functional, psychological, and clinical domains is available.

mechanisms responsible for RT improving insulin sensitivity still remain uncertain.[49] Future studies will therefore need to further investigate issues of exercise time, intensity, frequency, and adherence, as the current research has fallen short in these areas,[49] preventing a better understanding of the role of RT for type 2 diabetics.

Hyperlipidemia

About 17% of Americans aged 20 years or older have hyperlipidemia, a major risk factor for cardiovascular disease characterized by abnormally high total cholesterol levels above 200 mg/dL.[55] Aerobic exercise has repeatedly been shown to positively affect the lipid profile of men and women (for a review, see Kelley and Kelley[56] and Kelley et al[57]), whereas RT programs have generally shown little or no effect. Numerous RCTs have reported conflicting findings or no effect. Results from a recent meta-analysis, however, indicate that RT can positively affect lipids despite unsupported previous reports. Specifically, Kelley and Kelley[58] analyzed RCTs, published between January 1, 1955, and July 12, 2007, using a ≥4-week RT program to impact lipids and lipoproteins in adult men and women ≥18 years of age. A total of 29 studies with 1329 men and women (676 exercise, 653 control) were included. Statistically significant improvements were found for total cholesterol, the ratio of total cholesterol to high-density lipoprotein cholesterol, non-high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and triglycerides; however, there were no

Table 4.

Cancer

Author/Year	Topic	Type	Major Findings/Conclusions
Galvão et al, 2007[68]	Prostate cancer	Review	Side effects accompanying androgen deprivation therapy (ADT; eg, sarcopenia, loss of bone mass, reduced muscle strength) can compromise physical function, particularly in older patients. Resistance training (RT) may be an effective and cost-efficient strategy to limit or even reverse some of these adverse effects during and following therapy. Guidelines for prescribing RT programs for this population are included.
Cheema et al, 2008[66]	Breast cancer	Systematic review	Reviewed studies suggest that women surgically treated for breast cancer can derive health-related and clinical benefits by performing RT after breast cancer surgery. Robustly designed randomized controlled trials (RCTs) prescribing targeted RT regimens throughout various phases of breast cancer treatment are warranted. RCTs with thorough, standardized reporting of interventions and adverse events are required to establish the efficacy of this intervention for the posttreatment management of breast cancer patients and survivors as a means to improve health status and quality of life.

effects on high-density lipoprotein cholesterol. It is important to note that less than half of the data analyzed included information on the intensity of training or the rest period between each set and exercise, and only 65% of the exercise groups had sufficient data on compliance to the RT protocol. Therefore, although exciting, these results should be interpreted with caution. Newer studies assessing the intensity, amount of work performed (ie, sets/repetitions), and adherence to an RT program are still warranted.

Chronic Kidney Disease/ End-Stage Renal Disease

It is estimated that 26 million American adults have chronic kidney disease (CKD).[59] Those who receive hemodialysis or have end-stage renal disease (ERSD) are known to experience muscle atrophy and weakness, which can result in significant physical (eg, metabolic) and mental (eg, depression) impairments, increasing the likelihood of disability and mortality.[60] A substantial amount of research currently exists to support the safe[60,61] use of exercise as an adjunctive treatment for this population, and recently, RT has gained attention given its potential to combat the negative changes in muscle function and size (for a review, see Cheema and Singh[61]). For example, in the Progressive Exercise for Anabolism in Kidney Disease (PEAK) trial,[62] 49 patients receiving dialysis were randomized to a 12-week RT program or to usual care. Participants engaged in 3 full-body supervised RT sessions per week, at an intensity eliciting a 15 to 17 range on the Borg perceived exertion scale. Significant and beneficial improvements in muscle strength, mid-thigh/mid-arm circumference, intramuscular triglycerides, and body weight were found in the RT group relative to the usual care condition. Importantly, the RT sessions were conducted during routine dialysis, suggesting that such an intervention could become part of standard care. Thus, experts within this field have now called for a widespread dissemination and promotion of exercise (ie, RT) as an adjunct therapy to dialysis,[60,61] as it carries the potential to dramatically improve health outcomes for this population.

Cancer

Cancer is the second-leading cause of death among American adults, with prostate and breast cancer being the most frequently diagnosed nondermatologic cancers for men and women, respectively.[63] There are numerous side effects to cancer treatment, which often include muscle wasting or atrophy, reduced physical functioning, unfavorable changes in body weight and composition, and depression and fatigue.[64] Recent reviews have shown that RT programs for both men and women carry the potential to combat many of the side effects of cancer[64-66] and therefore can be of significant benefit to patients in the short and long term[65] (see Table 4). Below we briefly outline RT research done with prostate and breast cancer patients.

Prostate Cancer

Androgen deprivation therapy (ADT) is increasingly used for the treatment of prostate cancer,[67] but it creates a catabolic environment resulting in numerous negative physical side effects, including reduced muscle mass and strength, reduced bone mass, and increased fat mass.[67] As such, RT interventions seem appropriate for those suffering with prostate cancer,[68] although only a few trials have been conducted. Recently, in the Prostate Cancer Radiotherapy and Exercise Versus Normal Treatment study, Segal et al[69] randomized 121 men with prostate cancer (scheduled to receive radiotherapy with or

Table 5.

Aging/Older Adults

Author/Year	Topic	Type	Major Findings/Conclusions
Latham et al, 2004[81]	Physical function/ activities of daily living (ADL)	Systematic review	Resistance training (RT) showed a positive influence on muscular strength, with a modest effect found for physical functional with no clear evidence for an effect on disability. Future studies warrant a multidimensional approach to measuring disability.
Borst, 2004[88]	Sarcopenia	Systematic review (exercise based)	Ten randomized controlled trials (RCTs) reviewed provide key evidence for RT continuing to be the most effective intervention for increasing muscle mass and strength in older adults.
Orr et al, 2008[92]	Balance performance	Systematic review	Only modest support exists for improvements in balance. Further examination of RT programs that focus on the key muscle groups included in balance performance is needed. Programs with a multidimensional approach may be most effective in improving balance performance.
Sherrington et al, 2008[93]	Balance/falls	Systematic review/ meta-analysis (exercise based)	Greatest relative effects were seen for programs that include exercises that challenge balance, use a higher dose of exercise, and do not include a walking program.

without ADT) into an RT group, aerobic group, or usual care control group for 24 weeks. Participants exercised at a moderate intensity 3 times per week for 45 minutes per session, and assessments were collected at baseline, 12 weeks, and 24 weeks. Both exercise groups experienced reduced fatigue at 12 weeks, but only the RT group maintained this at follow-up. In comparison to the usual care, the RT group also had significantly higher quality of life and aerobic fitness, greater upper and lower body strength, and lower body fat (ie, no increase). The aerobic training group had higher aerobic fitness when compared to baseline levels. Thus, results from this study as well as others[70,71] suggest that moderate-intensity RT can be used with great success in this population. More evidence with diverse samples and longer follow-up is still needed, however.

Breast Cancer

Several studies using a combined aerobic and resistance exercise program for breast cancer patients have been conducted, but we are aware of only 2 studies that have specifically focused on using an RT program. The first was the Weight Training for Breast Cancer Survivors study, which examined the safety and efficacy of a 6-month RT program among recent breast cancer survivors.[72] Results showed significant increases in muscle mass and significant decreases in body fat when comparing immediate to delayed treatment from baseline to 6 months. More recently, a multicenter trial in Canada randomly assigned 242 breast cancer patients to usual care, supervised RT, or supervised aerobic exercise for the duration of their chemotherapy.[73] No significant between-group differences were found, but RT was found to be significantly superior to usual care for improving self-esteem, muscular strength, lean body mass, and chemotherapy completion rate. Overall, the independent effect RT may have on women with breast cancer remains to be elucidated. However, it appears that women being treated for breast cancer can derive health-related and clinical benefits, including improved compliance with their chemotherapy, by engaging in RT. Future RCTs with targeted subpopulations (ie, different age ranges), as well as those varying the exercise prescription (ie, intensity, volume), are needed.

Aging/Older Adults

Older adults are at an increased risk for loss of lean muscle mass (ie, sarcopenia), reduced muscle quality, and reduced power as they age.[74,75] Maintaining and/or improving muscular strength and power throughout the life course is crucial to sustain an adequate level of physical functioning, allowing tasks to be performed with ease. Specifically, as physical function decreases, there is an increased risk of disability, institutionalization, and mortality.[76] The following section provides a summary of the current literature and recommendations for improving strength and physical function among older adults (see Table 5 for a list of reviews).

Physical Function

In 2002, 52% of older adults reported having some form of physical disability, with 37% reporting severe disability and 16% needing assistance because of this disability.[77] RT has been shown to positively influence multiple measures of functional performance among older adults of various ages and functional abilities.[78] Several reviews have provided a summary of key interventions designed to combat the effects of aging through the improvement of muscular strength, power, and function.[79-81] Seeking the optimal program, studies have examined varying intensities,[82] contraction velocities,[83] and frequencies[84] for RT interventions. For example, Vincent et al[82] compared low- to high-intensity RT in a randomized controlled trial of 62 male and female older adults aged 60 to 83 years. Participants trained 3 times a week for 24 weeks, at 50% or 80% of 1-repetition maximum (1RM). Both groups demonstrated a significant increase in muscle strength, endurance, and functional performance (ie, stair climb time) relative to the control. In a different study, Bottaro et al[83] compared high (8-10 repetition sets performed as fast a possible at 60% of 1RM) versus low (three 8-10 repetition sets with 2- to 3-second contractions at 60% of 1RM) velocity RT in 20 men 60 to 76 years old. Both groups exercised 2 d/wk for 10 weeks. There was a significantly greater improvement in measures of functional performance (ie, arm curling, chair-stand) for the high-velocity group, although both groups increased muscle strength. Last, Taaffe et al[84] examined frequency by randomly assigning 46 older adults (65-79 years) to a high-intensity (80% 1RM) RT program 1, 2, or 3 days per week for 24 weeks (or to a control group). There were no between-group differences among the 3 exercise groups, but all exercise groups improved muscle strength and chair-stand time relative to the control. Thus, when using an RT program to improve physical function in older adults, a multidimensional approach can be used, as programs of varying intensity, velocity, and frequency have shown success in this population. Larger studies including older adults of varying degrees of function that compare RT versus physical training (PT) and examine the mechanisms underlying these changes in physical function are warranted.

Sarcopenia

Sarcopenia is defined as the age-related loss in lean muscle tissue (5% average loss/y) and is associated with decreases in muscle strength and physical function in older adults.[85,86] This chronic loss in lean muscle tissue occurs in about 20% of the aging population, with an even higher prevalence rate found in those 80 years or older.[87] Several reviews have summarized the significant beneficial effects RT has on sarcopenia, which include increases in lean muscle mass and muscle cross-sectional area and reductions in total fat mass.[86,88] To date, there is very little doubt that RT is the optimal and most powerful intervention to reduce sarcopenia in older adults. The next step, however, is to determine how, on a molecular level, RT is providing a benefit. Specifically, recent research has shown RT to produce independent fiber-type and satellite cell (SC) changes. Verdijk et al[89] showed that after a progressive 12-week RT intervention, 13 elderly men (mean age 72 years) demonstrated significant increases in leg lean mass, quadriceps cross-sectional area, and strength. At baseline, mean fiber area and SC content were smaller in the type II versus type I muscle fibers; however, following training, type II muscle fiber area and type II muscle fiber SC content significantly increased, whereas no changes were observed in the type I muscle fibers. As such, these results begin to identify the potential mechanisms responsible for the RT-induced cellular adaptations observed in older adults. Much more research examining the mechanistic link between RT and change in muscular health is needed to replicate and further expand on these initial findings. As some lean muscle loss can occur even in healthy, active adults, a specific regimen of RT at least 2 days per week to target and combat this loss is recommended.

Balance and Falls

Each year in the United States, approximately one third of older adults fall, with this percentage increasing as individuals age.[90] Improving muscular strength and balance through RT in older adults at risk for disability has been shown to reduce fall risk,[91] but a recent systematic review examining the independent effect of RT indicated only modest support for increasing balance in older adults.[92] The authors suggest that increased muscle strength (ie, lower body strength) may partly reduce falls through restored balance, yet very few studies have tested this assumption by examining the relationship between the change in strength and the change in balance. In addition, the authors note that balance was not considered a primary outcome in any study, and therefore, none were designed to investigate the specific changes in balance that may occur with an RT program. Other research has shown much stronger support for a multimodal approach, specifically one that incorporates balance training with a significant dose of exercise. For example, a systematic review and meta-analysis[93] identified a 17% to 35% reduction in falls with a comprehensive exercise and balance intervention. Overall, the most effective interventions were those that focused on balance training and met at least twice weekly for at least 25 weeks. Conversely, interventions including a walking component were less effective, and interventions including moderate- to high-intensity RT had no effect. Thus, the current literature provides little support for RT interventions for increasing balance in older adults. Future interventions should place more focus on balance-specific exercises rather than on changing muscle strength through RT, as once a certain level of strength is reached, further strength may not provide an added benefit.[93]

Orthopedic Diseases/ Disability

Orthopedic diseases and disabilities such as osteoarthritis and osteoporosis afflict millions of Americans every year, resulting in substantial medical costs, absenteeism, and decreased quality of life. The following section presents recent data supporting the efficacy of RT as an effective and viable mode of prevention and treatment of osteoporosis and osteoarthritis (see Table 6 for reviews).

Table 6.

Orthopedic Diseases/Disability

Author/Year	Topic	Type	Major Findings/Conclusions
Martyn-St James and Carroll, 2008[98]	Bone mineral density (BMD)/ osteoporosis	Meta-analysis	High-intensity progressive resistance training (RT) was shown to be efficacious in increasing absolute BMD at the lumbar spine but not the femoral neck in premenopausal women.
Lange et al, 2008[103]	Osteoarthritis	Comprehensive systematic database	Self-reported measures of pain, physical function, and performance, along with muscle strength (mean 17.4%), maximal gait speed, chair-stand time, and balance improved significantly following RT in 56% to 100% of studies where they were measured.

Bone Mineral Density/ Osteoporosis

Osteoporosis, characterized by low bone mineral density (BMD), is a major public health concern as it predisposes both men and women to future fall-related fractures,[94] increasing the risk for morbidity and mortality.[95] Several reviews and meta-analyses on the effectiveness of RT on BMD and the treatment/prevention of osteoporosis have been conducted. Overall, research has consistently demonstrated a beneficial site-specific response of bone to high-intensity RT, although a systemic response (ie, bone turnover) is possible. Brief, high-impact,[96] and dynamic exercises that impose an unusual strain and loading pattern on the bones[97] have been recommended for the maintenance of peak bone mass, as prior research has shown greater benefits with higher intensity RT programs.[98] For example, Vincent and Braith[99] randomized 62 men and women aged 60 to 83 years into a control, low-intensity (50% 1RM), or high-intensity (80% 1RM) RT program for 24 weeks. Markers of bone turnover were measured along with BMD for total body, femoral neck, and lumbar spine. Participants in both the high- and low-intensity groups significantly increased 1RM for each exercise tested, but only those in the high-intensity group significantly increased bone turnover and BMD (femoral neck). As such, it is clear from past and current research that RT has beneficial effects on BMD; however, whether there is a site-specific or systemic response to RT has yet to be determined, and future studies are needed.

Osteoarthritis

Osteoarthritis is an age-associated progressive articular disease that typically affects large weight-bearing joints such as the knees and hips, resulting in severe pain and physical dysfunction. Symptoms of knee osteoarthritis (ie, pain, dysfunction) have been correlated with lower extremity muscle weakness,[100,101] implicating RT as an effective form of treatment. In an effort to examine the effects of RT intensity of training on symptoms of osteoarthritis, Jan et al[102] randomized 162 men and women with clinically diagnosed osteoarthritis to 8 weeks of high-resistance exercise (60% of 1RM; 3 sets/8 repetitions), low-resistance exercise (10% of 1RM; 10 sets/15 repetitions), or no treatment control. Both RT groups reported significant improvements in knee pain, physical function, and knee muscle torque, but there were no significant differences between treatment groups. The results of this study are in line with a recent evidence-based review of 18 RCTs testing the efficacy of RT as a treatment for osteoarthritis of the knee. Lange et al[103] found significant improvements in several symptoms of osteoarthritis, including pain, physical function, and muscle weakness. Future research, however, will need to examine the efficacy of RT on osteoarthritis of the hip and other joints. Higher quality studies are also needed, as many studies have suffered from poor methodological quality, limiting their generalizability.

Neuromuscular Disorders

Neuromuscular disorders cover a wide range of conditions, and more than 40 different types of neuromuscular diseases have been identified. There are many causes to these conditions, but all result in some form of muscular weakness or atrophy that can lead to muscle aches, pain, cramping, and/or twitching. Below we outline some of the most common conditions that have been studied with RT (see Table 7 for reviews).

Stroke

Stroke is the third leading cause of death in the United States, killing slightly fewer than 150 000 individuals each year.[104] For those who do survive, stroke remains a major cause of serious long-term disability. Motor deficits are typical and prevalent and manifest as changes in gait and balance, as well as reductions in muscle mass, strength, and function. RT is likely to be helpful, as demonstrated by a recent study involving 24 poststroke (6-48 months) patients who were randomized into a 10-week lower body–focused RT intervention twice weekly or to a no-treatment control.[105] Both groups were

Table 7.

Neuromuscular Disorders

Author/Year	Topic	Type	Major Findings/Conclusions
Pak and Patten, 2008[106]	Stroke	Evidence-based review	Sufficient evidence exists to support the use of resistance training (RT) for poststroke patients. Without increasing spasticity, RT can increase strength, gait speed, and functional ability, as well as potentially change quality of life. Greater efforts in both research and neurorehabilitation practice are needed to optimize further understanding of neural adaptations.
Busch et al, 2008[114]	Fibromyalgia	Review (exercise based)	RT remains underevaluated for people with fibromyalgia. There is limited evidence that RT improves a number of outcomes, including pain, global well-being, physical function, tender points, and depression.
Dalgas et al, 2008[121]	Multiple sclerosis (MS)	Review (exercise based)	Although RT appears to be beneficial for MS patients, a limited number of studies evaluating RT exist, and many are of low methodological quality. There is a need for future randomized controlled trial (RCT) studies that evaluate different resistance training protocols, particularly studies that systematically evaluate program parameters such as training frequency, mode, intensity, and volume are needed.
Falvo et al, 2008[129]	Parkinson disease	Review	More RCTs are needed. Thus far, RT has been shown to be effective in increasing muscle strength and function. Future clinical interventions should consider high-intensity RT with particular emphasis on musculoskeletal and neural adaptations. Guidelines for RT programming are included.

assessed before and after the intervention and at a 5-month follow-up. Muscle strength significantly increased only in the RT group, and improvements were maintained at follow-up. Both groups improved in gait performance, but only the RT group maintained a significant improvement in at least one functional measure (ie, Timed "Up & Go") at follow-up. Such results are representative of the field, but it is important to note that there is some debate as to the potential adverse effects (ie, increased spasticity) RT may produce for those who have muscle tone and strength deficits resulting from neural damage and hemiplegia. Concerns are generally unfounded,[106,107] as safe and effective increases in muscle strength and function have been repeatedly found in poststroke patients without any major impact on spasticity. As outlined by 3 recent reviews,[106-108] the current challenge for the future does not reside in determining the safety of RT for poststroke patients but rather in determining the optimal frequency, duration, and timing to begin RT, a valuable and effective therapeutic intervention.

Fibromyalgia

Fibromyalgia (FM) is a poorly understood disorder characterized by widespread chronic tender point pain, abnormal pain processing, muscle weakness, sleep disturbance, fatigue, and psychological distress.[109] Approximately 2% of American adults have been diagnosed with fibromyalgia, with the majority of the cases being women.[109] The optimal treatment and management have yet to be elucidated, but both pharmacological and behavioral methods have been somewhat successful.[110,111] In particular, aerobic exercise is considered helpful and has been recommended for the past 2 decades,[112] but more recent investigations using RT have shown promise as well. For example, Kingsley et al[113] randomized 29 women with fibromyalgia into a 12-week RT program or wait-list control. Participants trained 2 times per week, performing 11 exercises at a progressive intensity of 40% to 80% 1RM over the 12 weeks. The RT group significantly improved upper/lower body strength and physical function in comparison to the control, although there was no difference in tender point sensitivity. Other studies have shown similar results with reductions in pain, improvements in well-being, and fewer active tender points; however, these results are based on lower quality, pilot, or quasi-experimental studies.[114] Thus, more research with adequately powered, larger sample sizes and longer term follow-up are needed to determine the specific benefits that can be gained with an RT program. The optimal frequency, duration, and intensity that are least likely to exacerbate symptoms while promoting adherence to a regular program are also needed.

Multiple Sclerosis

Approximately 400 000 Americans have multiple sclerosis (MS),[115] a progressive chronic disease characterized by axonal degeneration and central nervous system lesions that result in physical function impairments, poor muscle control, and disability.[116] MS patients have an increased incidence of obesity,[117] osteoporosis,[118] depression,[119] and cardiovascular disease,[120] making RT an ideal intervention. Despite this, current research on the effects of RT in MS patients is limited (see Dalgas et al[121] for a review). Very few studies have used an RT program to address the more common symptoms such as abnormal gait, poor balance, and muscle weakness.[122] Recently, de Souza-Teixeira et al[123] enrolled 13 individuals with MS into a 16-week (8-week control, followed by 8-week intervention) RT study. Participants exercised twice per week at 40% to 70% 1RM, and significant changes were found in isometric strength, muscular endurance, maximal power, muscular hypertrophy, and functionality. As such, it appears that those with MS can benefit from a moderate-intensity RT program, but given the lack of substantial evidence to date, many more well-designed and controlled studies are needed. Future studies should also seek to determine how best an RT program be used to manage the daily symptoms faced by those with MS.

Parkinson Disease

Parkinson disease (PD), a chronic and progressive condition affecting approximately 1 million Americans,[124] is characterized by a loss of dopaminergic neurons from the pars compacta region of the substantia nigra. It is manifested by symptoms that include muscle weakness and rigidity, bradykinesia, tremor, and postural instability.[125] In addition, those with PD often experience mood disturbance and cognitive dysfunction, and they are at an increased risk for low BMD.[126] Although the specific mechanisms have not yet been identified, regular physical activity is associated with decreased mortality in PD patients,[127] in addition to providing a protective effect for PD risk in men.[128] RT has just begun to be studied, with only a few RCTs having been conducted over the past 10 years (see Falvo et al[129] for a review). Current results are promising, as safety for low to high intensities has been established, and significant changes in muscle strength and function have been found. For example, Dibble et al[130] recruited 19 individuals with PD into a 12-week (45-60 minutes, 3 sessions per week), eccentric-focused RT intervention or a standard-care group exercise program. Both groups participated in a traditional exercise rehabilitation program, but the RT group also performed high-force quadriceps contractions on an eccentric ergometer. Results showed that the RT group demonstrated a significantly greater difference in muscle volume (ie, hypertrophy), muscle force, and physical function as measured by a 6-minute walk test, and all of these measures were significantly greater than the control group. Hence, it appears that RT can provide a benefit to this population, as it carries the potential to reduce the severity of the neuromuscular symptoms experienced with PD. Larger, more comprehensive and well-controlled trials assessing the full range of symptoms and side effects (eg, mood disturbance, cognition, BMD) are needed.

Other Illnesses

Depression

In the United States, the lifetime prevalence of major depressive disorder (MDD) has been estimated at roughly 13% in adults.[131] Depression is associated with increased risk for cardiovascular disease,[132] and its combined workplace, direct medical, and suicide-related mortality costs in the United States have been estimated at $83.1 billion.[133] Previous research supports a beneficial effect of both aerobic exercise and RT on depressive symptoms in young and middle-aged adults. In a systematic review of controlled trials examining the dose-response effect of physical activity on depression and anxiety,[2] 3 studies that used RT as its primary intervention found significant improvements in reducing depressive symptoms. Although few RCTs have examined the efficacy of RT only on depression in clinically diagnosed populations, there is evidence that RT can induce improvements in depressive symptoms. For example, Singh et al[134] conducted an 8-week (3 sessions/wk) RCT in which participants aged 60 years and older with major or minor depression were randomized into a high-intensity (80% 1RM) or low-intensity (20% 1RM) RT group or no treatment control. Significant between-group differences on all depression measures were observed, with the high-intensity group having the greatest reduction in depression scores. Despite these results, there is still only modest evidence to support a beneficial impact on depression through regular RT. Future research on the mechanistic links between regular RT and depression is warranted, as previous research has shown promising results (see also Table 8).

HIV/AIDS

The Centers for Disease Control and Prevention (CDC) have recently estimated that 1.1 million Americans are currently living with human immunodeficiency virus (HIV).[135] A recent systematic review and meta-analysis on HIV-infected adults indicated that significant and clinical improvements in muscle strength, lean muscle mass, body weight, body composition, and health-related quality of life can be obtained with participation in an RT program.[136] Importantly, the results also showed that overall, there were no significant changes in CD4+ cell count or HIV viral load, suggesting that RT is safe for this population. These conclusions, however, need to be interpreted cautiously, as there have not been a large number of RCTs testing the effects of RT in the HIV-infected population. In addition, almost all of the interventions have been 16 weeks or less, and most have focused exclusively on middle-aged men. With a recent increase in survivor rates,[137] studies have begun to examine a newer population of HIV-infected individuals who are overweight or obese,[138] as well as women[139] and older adults.[139] For example, Souza et al[140] recently conducted a 12-month RT program with 14 HIV-infected men and women aged 62 to 71 years. Participants completed a full-body program twice a week, with assessments taken at baseline and 12 months. Results indicated significant increases in muscle strength, physical fitness (as measured by a walking test), and CD4+

Table 8.

Other Illnesses

Author/Year	Topic	Type	Major Findings/Conclusions
Dunn et al, 2001[2]	Depression/anxiety	Systematic review (exercise based)	Quasi-experimental and randomized controlled trials demonstrate that resistance training (RT) can successfully reduce symptoms of depression.
O'Brien et al, 2004[141]	HIV/AIDS	Systematic review	RT with or without aerobic exercise is associated with improvements in body weight and body composition (arm and thigh girth); a trend toward improvements in cardiopulmonary fitness (submaximal heart rate and exercise time) was also observed.
O'Shea et al, 2004[144]	Chronic obstructive pulmonary disease (COPD)	Systematic review	RT can produce increases in upper and lower limb strength. RT protocols are feasible and have high levels of adherence, as few adverse events were reported. There were inconclusive findings for aerobic capacity, walking endurance, and psychological and respiratory function.

cell count, with no changes in body composition or HIV viral load. Fortunately, reports such as those above continue to add to the literature base, suggesting that all HIV-infected individuals can safely participate in and benefit from RT. Future studies will likely use RT as an intervention for other health-related outcomes that were previously not a significant concern for this population (eg, increasing bone mineral density), as continued research is needed to support the current recommendation of RT for this population.[136,141]

Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease (COPD) is defined as a preventable and treatable disease state producing significant systemic consequences characterized by progressive airflow limitation that is not fully reversible.[142] COPD is a major leading cause of death in the United States, as respiratory failure and comorbid illnesses such as lung cancer and heart disease are common.[143] Individuals with COPD suffer from an array of debilitating symptoms that include dyspnea, fatigue, alterations in muscle morphology, reduced muscle strength and size, reductions in functional ability, and poor quality of life.[144] As such, exercise, specifically aerobic exercise, has been widely used as a therapeutic treatment for inpatient/outpatient pulmonary rehabilitation programs. Investigations into the use of RT-only programs, however, have shown great promise for this population. Specifically, RT places less demand on the respiratory system, creating a lower sensation of dyspnea while still achieving an at least similar beneficial outcome.[145] For example, Skumlien et al[146] compared 12 weeks (2 sessions/wk) of resistance or endurance training in 40 COPD patients (after the completion of 4 weeks of inpatient pulmonary rehabilitation). Results indicated a significant increase in muscular strength for the RT group and a significant increase in walking capacity for both groups. Thus, evidence from this study, as well as others, suggests that RT is equally as beneficial as aerobic training and can be used safely for those with COPD. Future studies will need to investigate the long-term outcomes associated with RT and factors that predict adherence to an RT program.

Conclusion

It is clear that there are specific health-related benefits to be gained from participating in a resistance training program. In this review, we outlined the most current evidence for the role of resistance training in the prevention and treatment of several chronic diseases. Overall, larger, more diverse trials will need to be conducted, but current results are promising, as beneficial changes in physiological and psychological factors for both apparently healthy and known disease populations have been shown. The next steps will require discovering ways in which individuals at risk, as well as those currently enduring chronic illness or physical dysfunction, will adopt and adhere to a resistance training program. Unfortunately, most of the research conducted thus far has used supervised, facility-based programs with expensive equipment. Future progress likely will be made when effective programs can be disseminated more easily. Additional research, therefore, will need to determine the optimal way to promote adherence to resistance training, as it offers great potential for a wide section of the population. AJLM

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