Strength training for health in adults: Terminology, principles, benefits, and risks

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INTRODUCTION

Physical inactivity is a major health problem worldwide, and predisposes to a wide variety of chronic degenerative diseases, including cardio-cerebrovascular disease, metabolic disease, musculoskeletal disorders, and frailty. Physical exercise has well-documented beneficial effects on numerous health outcomes, including cardiovascular disease and all-cause mortality [1]. Strength training has attracted increasing attention in the biomedical literature as a powerful and beneficial form of exercise [2-4].

To properly prescribe and monitor strength training for their patients, clinicians need to understand the forms of strength training and their implementation, benefits and risks, contraindications, and necessary modifications for special populations.

This topic will discuss some of the general principles of strength training for adults, provide an overview of its many health benefits, and describe potential risks. Guidelines for implementing strength training programs in adults, some common misconceptions about strength training, strength training in the pediatric population, and the benefits of exercise generally are all reviewed separately. (See "The benefits and risks of aerobic exercise" and "Exercise and fitness in the prevention of atherosclerotic cardiovascular disease" and "Obesity in adults: Role of physical activity and exercise".)

WHY IS STRENGTH IMPORTANT?

Muscular strength is defined as the ability to produce force against a resistance. Strength may be displayed dynamically, as in Olympic weightlifting or running, or statically, as in activities like gymnastics and yoga [5]. Dynamic and static force production can be applied discretely or repeatedly depending on the task. Weightlifting demands discrete, dynamic force production whereas running requires repeated, dynamic force production; however, force production is equally important to both activities [5]. Accordingly, the ability to generate muscular force has positive implications for virtually every other fitness attribute, including power, balance, agility, speed, endurance, and flexibility [6].

Power is the first derivative of strength with respect to time; it is the ability to produce force quickly. Endurance is the ability to produce force repeatedly over sustained intervals, usually in repetitive motor patterns (eg, running, bicycling, swimming). Full mobility requires not only joint integrity but also the ability to produce force over a full range of motion. Balance is the ability to maintain a stable position against the pull of gravity with minimal postural sway [7], and depends on both intact proprioception and the ability to produce muscular force. Muscular strength and muscle tissue also protect against injury [8,9], frailty [10-12], falls [13], and loss of independence. Fatigue, which is any reduction in force-generating capacity, reduces performance in all of these domains [14]. Therefore, the ability to produce muscular force (ie, strength) is a fundamental physical fitness attribute that influences all others.

STRENGTH TRAINING: DEFINITION AND KEY PRINCIPLES

Strength training is a rational, explicit program of carefully chosen exercises performed over an extended period and designed to increase the subject's ability to produce muscular force in useful movement patterns. This goal cannot be realized by sporadic, unplanned, random bouts of exercise, but rather requires the careful and progressive manipulation of training variables over time [6,15-18].

The Stress-Recovery-Adaptation model provides a useful conceptual framework for the development of physical training programs [15,19]. In this model, a training stress is imposed, the trainee recovers from and adapts to the stress, and subsequently demonstrates this adaptation as an increase in performance. Thus, the Stress-Recovery-Adaptation cycle corresponds to a training period, and the proper exploitation of this phenomenon forms the foundation of any rational strength training program.

Physicians, patients, and fitness professionals must understand the pivotal role of recovery in this paradigm. Elements of proper recovery include both training variables and lifestyle variables, and promote not only productive strength acquisition but also general health. These recovery variables include:

- Proper nutrition
- Adequate sleep
- Active rest (light, unstructured physical activity on non-training days), and
- Stress management [15-17].

Strength training relies on the principle of progressive overload—a steady increase in the applied training stress—which produces a corresponding increase in physiologic and performance adaptation. At the most basic or novice level of training, progressive overload can be achieved by simply increasing the load while holding other factors (eg, number of sets for a given exercise, number of repetitions in a given set) constant. (See "Practical guidelines for implementing a strength training program for adults".)

However, as the trainee gets stronger, this "linear" progression becomes less productive, and more complex programming strategies are needed, incorporating more sophisticated manipulation of volume (sets and repetitions), intensity (loading), training frequency, exercise selection, recovery, etc. These intermediate and advanced approaches are beyond the scope of this topic but are treated in detail in other resources [15-17,20].

In summary, strength training is most efficiently, productively, and safely implemented by using a systematic, programmed approach; relying on the appropriate imposition of training stress, progressive overload, adequate and carefully managed recovery; and demonstration and exploitation of adaptation to training stress.

WHAT ARE THE BENEFITS OF STRENGTH TRAINING?

General benefits — Strength training, as a form of physical exercise, confers the general benefits (and risks) of any form of regular, vigorous physical activity. These are explored at length separately and a detailed examination is outside the scope of the present discussion. (See "The benefits and risks of aerobic exercise".)

To summarize, all forms of regular exercise confer manifold beneficial effects at multiple strata of biological organization, with improvements in health at the cellular, metabolic, cardiovascular, neurologic, and functional levels. At the cellular level, regular exercise promotes optimal energy utilization and improved resistance to oxidative stress [21-26]. All forms of vigorous exercise promote improved glucose disposal during the exercise bout itself because muscle glucose uptake during exercise is insulin-independent [27,28]. Regular exercise increases insulin sensitivity [29-31] and is therefore an important treatment in the management and prevention of metabolic syndrome and type 2 diabetes [32-35]. (See "Prevention of type 2 diabetes mellitus", section on 'Exercise'.)

Resistance training improves body composition, leading to increases in lean body mass and decreases in fat, including visceral fat, an important risk factor for the development of metabolic syndrome, diabetes, and chronic systemic inflammation [36]. Exercise, including strength training, has well-established benefits to the cardiovascular system [37], including cardiac remodeling [38], improvements in blood pressure [39], and moderation of cardiac risk factors [40,41]. Finally, resistance training may confer functional benefits, with improvements in psychosocial health, depression, and sleep [42-45], although the data on functional outcomes are decidedly mixed and hampered by wide variations in experimental approach, methodologic quality, and outcome assessment [46]. (See "Obesity in adults: Role of physical activity and exercise" and "Exercise in the treatment and prevention of hypertension".)

Specific benefits — Strength training confers progressive improvements in several important fitness and health parameters not observed for other forms of exercise. Strength training obviously improves strength, the ability to produce muscular force [47]. It also improves power, the ability to express force quickly, which is closely tied to the fitness attributes of speed and agility. Strength training promotes muscle protein accretion and gains in muscle mass. When combined with appropriate nutrition, it is probably the single most powerful medicine against sarcopenia [48], endemic in older adult populations and a contributing factor to frailty and metabolic syndromes. The data on strength training and bone mineral density maintenance and improvement suggests a similar beneficial effect from strength training [49-52]. (See "Frailty", section on 'Exercise' and "Overview of the management of osteoporosis in postmenopausal women", section on 'Exercise'.)

Strength training, unlike most forms of endurance training [52], promotes significant increases in anaerobic capacity [53]. Strength training does not appear to produce significant improvements in maximum rate of oxygen consumption (VO_2max) and other biomarkers of improved mitochondrial metabolism [54-57], although there are contrary reports [58]. Some reports indicate improvement in aerobic metabolism in older subjects [59-61], but these data are hampered by small sample sizes and methodologic issues. However, multiple studies have demonstrated improvements in endurance performance and work capacity, especially in untrained individuals [61-64]. The available evidence suggests a broad range of individual variation in the adaptive response to a given standardized training intervention, and the type and magnitude of benefit can vary significantly based on the specific features of program design [65,66].

We recommend the addition of a conditioning component to any strength training program. For very frail patients who cannot perform sustained aerobic activity, we find it prudent to complete a strength-focused novice phase of training in order to develop the minimal strength necessary for subsequent conditioning exercise. The available data indicate that strength training combined with cardiovascular conditioning (either classical aerobic conditioning or interval training) confers greater health benefits than either modality alone [40,67,68]. (See "Practical guidelines for implementing a strength training program for adults" and "Exercise for adults: Terminology, patient assessment, and medical clearance".)

Mortality benefit — A large and growing evidence base shows a strong correlation between physical strength and a reduction in all-cause mortality across the lifespan [69]. Example studies include the following:

- A prospective study of over 1.1 million Swedish male adolescents over 24 years found that greater muscular strength (assessed by handgrip and knee extension) was associated with a 25 to 30 percent reduction in premature mortality due to any cause or due to cardiovascular disease, independent of body mass index or blood pressure [70].
- A prospective study of 555 adults aged 85 found that individuals in the lowest tertile of handgrip strength at the study's outset had a 35 percent increased risk of all-cause mortality at follow-up (average 9.5 years); those in the lowest tertile at age 89 had a 104 percent increased risk of mortality at follow-up, and those showing the greatest strength decline over four years had a 72 percent increased risk of mortality [71].
- A prospective study involving 4449 older adults found that low muscle strength was independently associated with elevated risk of all-cause mortality, regardless of muscle mass, metabolic syndrome, sedentary time, or leisure-time physical activity [72].

WHAT MEDICAL CONDITIONS IMPROVE WITH STRENGTH TRAINING?

An exhaustive review of the impact of strength training is beyond the scope of this topic. Below, we highlight those areas with the largest public health impact and greatest amount of supporting data.

Endocrine-metabolic — Muscle is increasingly recognized as an important endocrine and metabolic tissue [73-76]. Strength training, which increases the mass, function, and health of muscle tissue, has profound effects on metabolic health and body composition.

Obesity — The authors routinely prescribe strength training for obese individuals who have no contraindication to this form of exercise. We typically prescribe concomitant caloric restriction to produce weight loss, and advise patients to participate in interval conditioning or aerobic exercise for optimal improvements in health [16,40,67,68]. According to a meta-analysis of relevant studies, resistance training without dietary restriction appears to be less effective for weight loss in obese patients [77]. However, dietary restriction combined with exercise appears to produce up to approximately 20 percent greater weight loss initially, with better maintenance of weight loss at one year, than dietary restriction alone. (See "Practical guidelines for implementing a strength training program for adults" and "Obesity in adults: Dietary therapy" and "Exercise for adults: Terminology, patient assessment, and medical clearance".)

Obese patients tend to be more resistant to muscle-specific anabolic stimuli (exercise and dietary protein) than nonobese controls, generating a lower muscle protein synthetic response to these stimuli [78-80]. This is thought to be due to the metabolic effects of chronic systemic inflammation, intramyocellular lipid accumulation, and alterations in gene expression. However, obese individuals can increase lean body mass without gaining bodyweight and, in some cases, even while losing weight. The addition of skeletal muscle tissue may also increase resting metabolic rate. This may explain in part how resistance training prevents further weight gain in obese individuals, and regaining of weight in successful dieters [81-85].

In addition to preserving or even increasing muscle mass while in a hypocaloric state, resistance training may be at least as effective as diet and/or aerobic training at reducing abdominal obesity through reductions in visceral and subcutaneous adipose tissues [86-88].

An elevated waist circumference of ≥40 inches (102 cm) for men and ≥35 inches (88 cm) for women is indicative of increased cardiometabolic risk. Resistance training produces a modest decrease in waist circumference even in the absence of weight loss, although the effect appears to be more pronounced when weight loss occurs [40,89]. In addition, regular participation in resistance training appears to prevent or attenuate the waist circumference increase seen with aging [90]. (See "Obesity in adults: Prevalence, screening, and evaluation", section on 'Waist circumference'.)

Decreased body fat percentage — Body fat percentage is the ratio of fat mass (FM) to total body mass, expressed as a percentage. If the total mass of body fat is decreased or fat-free mass is increased, the body fat percentage decreases. Strength training is an effective means for decreasing body fat percentage by increasing skeletal muscle mass (a component of fat-free mass), decreasing FM, or both [78,85,91,92].

Metabolic syndrome — Metabolic syndrome, a constellation of findings arising from a complex pathophysiology driven primarily by insulin resistance, has become a major health problem. The specific criteria used to define metabolic syndrome vary among major health organizations, but include elevated serum glucose, dyslipidemia, hypertension, and increased waist circumference. (See "The metabolic syndrome (insulin resistance syndrome or syndrome X)".)

Resistance training not only addresses the clinical features of metabolic syndrome but also attacks the underlying state of insulin resistance, and the authors believe it is an essential part of any exercise prescription for its treatment or prevention. Meta-analyses of resistance training's effect on insulin resistance in those with diagnosed metabolic syndrome show improvement in both insulin sensitivity and diagnostic criteria [4,93,94]. As an example, one small randomized trial reported decreases in HbA1C, fasting insulin, fasting blood sugar, and HOMA-IR (homeostasis model assessment of insulin resistance) values after 16 weeks of strength training compared with controls managed with standard care alone [95]. A meta-analysis of 13 randomized controlled trials on the effect of resistance training on those with metabolic syndrome found an average 0.48 percent reduction in HbA1c (95% CI -0.76, -0.21), a 2.33 kg reduction in FM (95% CI -4.71, 0.04), and 6.19 mmHg reduction in systolic blood pressure (95% CI 1.00, 11.38) [96].

Diabetes — The most recent exercise recommendations of the American Diabetes Association include both aerobic and resistance training and are in agreement with the guidelines for nondiabetic adults put forth by the American College of Sports Medicine (ACSM) and the United States Centers for Disease Control (CDC) [97-99]. We concur and recommend strength training as an essential part of the exercise prescription for patients with diabetes [16]. (See "Effects of exercise in adults with diabetes mellitus".)

Strength training increases serum glucose uptake and oxidation, both during and following exercise, in populations with and without diabetes, including obese nondiabetics [100,101]. However, in patients with a history of impaired fasting glucose, type 1 or type 2 diabetes, or a history of hyper- or hypoglycemia, we agree with the recommendations put forth by the ACSM, which state that a pre-exercise blood glucose greater than 250 mg/dL [13.9 mmol/L] or the presence of ketosis should be considered a contraindication to vigorous exercise. Such patients should be referred to their physician. Glucose management for diabetics during exercise is reviewed in detail separately. (See "Effects of exercise in adults with diabetes mellitus", section on 'Managing blood glucose during exercise'.)

In the authors' suggested approach to strength training, exercise movements are generally performed at an intensity (expressed as percentage of 1-repetition maximum [1RM]) of >70 percent for three to eight repetitions. In addition, the majority of exercises entail the movement of multiple joints involving multiple large muscle groups to produce the forces necessary to perform the movement under load. (See "Practical guidelines for implementing a strength training program for adults".)

This combination of volume (total repetitions), intensity, and muscle mass recruitment produces a large increase in metabolic activity. This includes both substrate-level phosphorylation by adenosine triphosphate (ATP) and the creatine cycle, and robust glycogenolysis in the active muscle tissue. This intense metabolic demand increases the uptake of glucose from the circulation and its rapid conversion to energy [102]. Although patients with diabetes or metabolic syndrome have varying deficits in serum glucose uptake into cells due to insulin resistance, their rate of glucose uptake and oxidation during strength training is similar to lean controls, due to the insulin-independence of glucose transport during exercise [103,104]. Strength training stimulates translocation of the glucose transporter GLUT4 to the sarcolemma of working skeletal muscle in an insulin-independent fashion, improving glucose uptake for subsequent energy production or storage as glycogen, even in the setting of insulin resistance [93,101,103-108].

Resistance training increases the basal rate at which glucose is stored in muscle by increasing skeletal muscle mass [109]. Muscle is a vast repository of stored glycogen, with approximately five times the glycogen content of liver tissue. In addition, glycogen content is higher in the skeletal muscle of trained versus untrained subjects, as muscle glycogen stores are replenished within 24 hours post training through increased glucose uptake [108,110]. Meta-analyses and reviews of the effect of resistance training on fasting blood glucose levels and resting metabolic rate show corresponding improvements in these parameters [4,98,106,111-115].

Resistance training improves hemoglobin A1C (HbA1C) concentrations in patients with evidence of insulin resistance, including type 2 diabetes, according to a systematic review of 23 trials involving 954 patients [114]. Strength training appears to be more effective than aerobic exercise for this purpose. As an example, in a randomized trial, 20 untrained subjects with type 2 diabetes were assigned to either treadmill or resistance training, each group training three times per week for 10 weeks [116]. Pre-intervention HbA1C measurements were 8.7 percent for the treadmill group and 8.9 percent for the resistance training group. After 10 weeks, none of the patients in the treadmill group attained an HbA1C level of 7 percent or less, while 40 percent of those in the resistance exercise group reached target HbA1C levels [116].

Resistance training may also reduce the risk of developing diabetes. A review of the Health Professionals Follow-up Study, in which 32,002 men were observed over a period of 18 years, found that subjects engaging in resistance training greater than 150 minutes/week showed a 34 percent reduction in the risk for developing type 2 diabetes, after adjustment for aerobic activities and body mass index [115,117].

Cardiovascular

Coronary artery disease and myocardial infarction — Resistance training is beneficial in patients with stable coronary artery disease (CAD). While it is typically studied in combination with aerobic training, resistance training independently increases muscle strength and endurance performance, and the combination of resistance and aerobic training outperforms aerobic-only training for outcomes including muscle strength, work capacity, maximal oxygen consumption (VO_2 max), fat mass (FM), and fat-free mass [118,119]. The data do not show an increased rate of adverse effects (dysrhythmia, worsening of ejection fraction, hypertension, or angina) resulting from resistance training, even in those undergoing cardiac rehabilitation following acute myocardial infarction [120]. Preliminary evidence in animal models suggests that prior routine resistance training may reduce the extent of ischemia-reperfusion injury in the setting of acute myocardial ischemia or infarction [121].

Cardiovascular disease risk factors — Resistance training appears to have a beneficial impact on several risk factors for cardiovascular disease. These include lowering blood pressure (BP), reducing fasting serum glucose concentrations, improving insulin sensitivity and dyslipidemia, decreasing waist circumference, and improving body composition [40,77,86-90,122]. (See 'Hypertension' below and 'Diabetes' above and 'Obesity' above.)

Resistance training has a beneficial impact on dyslipidemia in the setting of type 2 diabetes. In one controlled trial over three months in which 56 obese type 2 diabetics were randomized to high-intensity resistance training (60 to 80 percent 1RM) versus no exercise, the resistance training group showed dramatic reductions in circulating ApoB concentration (from 135.92±30.97 mg/dL to 85.9±26.46 mg/dL) versus no change in the control group, with significant improvement in the ApoB/ApoA1 ratio as a consequence [123]. Similar results have been reported in nondiabetic individuals with obesity [122].

Hypertension — The conventional wisdom that progressive or heavy strength training increases resting BP has long since been debunked. On balance, the available data indicate that strength training exerts beneficial effects in hypertensive patients, including decreases in systolic and diastolic blood pressures (SBP and DBP, respectively) [124]. In addition, in our clinical experience, subjects with hypertension who initiate a strength training program typically effect changes in their diet and lifestyle, further contributing to improvements in resting BP.

A review of 33 randomized controlled trials (n = 1012) lasting at least four weeks showed reductions in SBP of 3.9 mmHg (CI -6.4 to -1.2) and in DBP of 3.9 mmHg (CI -5.6 to -2.2) among 28 normotensive or pre-hypertensive study groups [125,126]. However, only four of the included trials examined hypertensive individuals, and among these hypertensive study groups, the respective reductions of 4.1 and 1.5 mmHg for SBP and DBP did not reach statistical significance. A subsequent meta-analysis of five randomized trials (n = 201) analyzing the effect of resistance training performed for at least eight weeks on BP changes exclusively in “pre-hypertensive” or hypertensive individuals reported significant reductions in SBP and DBP of 8.2 mmHg (CI -10.9 to -5.5) and 4.1 mmHg (CI -6.3 to -1.9), respectively [127].

Some researchers believe the antihypertensive mechanism of resistance training is distinct from that of aerobic training; specifically, there is data suggesting that resistance training produces a greater increase in peripheral vasodilatory capacity, increasing microvascular flow and capacitance [128].

Antihypertensive medication interactions — Antihypertensive medications exert diverse and wide-ranging physiological effects beyond lowering BP. Their effects in the context of strength training and potential impact on training outcomes require due consideration by the clinician. A complete exposition of this issue is beyond the scope of the present article. Here we focus attention on two commonly-prescribed classes of antihypertensive agents, angiotensin-converting enzyme (ACE) inhibitors and beta blockers.

ACE inhibitors may enhance the hypertrophic response to strength training in older patients by modulating factors contributing to anabolic resistance. ACE inhibitors have been proposed as a therapeutic agent for sarcopenia, as they increase blood flow to skeletal muscle, promote more robust muscle protein synthesis, increase IGF-1 levels in response to activity, increase mitochondrial density in muscle, and decrease inflammatory processes associated with anabolic resistance [129,130].

The few trials examining the clinical effect of ACE inhibitors on training outcomes show mixed results. In an observational study of 2431 subjects age 70 to 79, those with hypertension who were being treated with an ACE inhibitor had significantly larger lower extremity muscle mass compared with those who used other medications [131]. However, the Berlin Aging Study-II (BASE-II) Trial reported that community-dwelling older adults on ACE inhibitors had higher amounts of lean body mass relative to height but lower amounts of lean body mass relative to body mass. Additionally, ACE inhibitors did not produce a significant difference in timed "Up and Go" performance tests [132].

In contrast to ACE inhibitors, beta blockers tend to blunt the muscle protein synthesis response and increase protein oxidation, with the net effect of decreasing lean body mass [133-136]. Additional data from chronic beta blocker users indicate decreases in daily energy expenditure, decreased postprandial fat oxidation, and increased FM compared with controls [135,136]. Beta blockers may also blunt compensatory tachycardia during exercise [137]. Beta blockers are not considered first-line therapy for hypertension, and we suggest that alternative antihypertensive agents be considered for patients engaged in strength training if second- or third-line medications are warranted.

Heart failure — Patients with chronic heart failure have significant physical disability compared with age- and activity-matched controls due to deficits in both aerobic capacity and muscular strength [138,139]. Myocardial dysfunction induces neurohormonal, metabolic, and circulatory changes that result in an imbalance between anabolic and catabolic processes at the level of skeletal muscle, producing a progressive skeletal myopathy and ultimately, a wasting syndrome. This myopathy contributes to the exercise intolerance observed in chronic heart failure.

There is growing evidence for the benefits of resistance training in both chronic systolic heart failure and chronic diastolic heart failure. These data indicate beneficial metabolic and functional adaptations in skeletal muscle, including improvements in skeletal muscle metabolism, increased muscle mass and strength, increased exercise tolerance, and increased maximal oxygen consumption (VO_2max, indicative of improved aerobic capacity and endurance) [140-142]. These adaptations have been reported with resistance exercise alone and in combination with aerobic exercise. However, evidence is limited in part by the highly variable interventions among studies, making conclusions about effect sizes unclear.

Despite widespread concern among physicians about harmful effects from the acute increase in afterload caused by resistance training, available evidence suggests that strength training does not cause adverse effects, such as reduction in ejection fraction, hypertension, dysrhythmia, or other cardiac dysfunction, and training in this population appears to be safe and beneficial. The role of strength training in patients with heart failure is reviewed in greater detail separately. (See "Cardiac rehabilitation in patients with heart failure", section on 'Resistance training'.)

Peripheral vascular disease — Patients with peripheral vascular disease have impaired muscle strength and walking ability, resulting in progressive functional impairment and poorer quality of life. Leg strength is linearly correlated with lower extremity ankle-brachial index and with functional performance in patients with peripheral arterial disease [143]. In patients with symptoms ranging from mild to severe claudication, resistance training using loads approaching 90 percent of 1RM induces vasodilation and reactive hyperemia as well as clinical improvements in maximal strength, maximal oxygen consumption (VO_2max), walking performance, stair-climbing ability, and quality of life, without evidence of adverse effects such as worsening pain [144-147]. (See "Management of claudication due to peripheral artery disease", section on 'Exercise therapy'.)

Musculoskeletal — The most obvious impact of strength training is on the musculoskeletal system. On balance, the data indicate that strength training has powerful effects against the loss of bone and muscle with concomitant beneficial effects on frailty, function, and metabolic health.

Sarcopenia — The progressive loss of muscle mass in aging adults is a physical, functional, and metabolic catastrophe. Sarcopenia predisposes to osteopenia, weakness, loss of function, and frailty. In addition, muscle tissue is increasingly recognized as both an endocrine organ and a major contributor to whole-body insulin sensitivity. Sarcopenia is therefore associated with insulin resistance, type 2 diabetes, and the metabolic syndrome, with the attendant increased risks of cardiovascular disease and stroke.

The sarcopenia of aging appears to be dominated by atrophy of large, high-powered, type II muscle fibers [148], which are precisely the fibers addressed by strength training. The results of multiple observational studies suggest that aging adults can slow, arrest, or reverse degenerative sarcopenia with resistance training [148-150].

Osteoarthritis — Osteoarthritis is one of the most common disabling conditions encountered in clinical practice, most often affecting the knees, hips, and hands of middle-aged and older individuals. Patients with knee osteoarthritis commonly show deficits in quadriceps muscle strength, which correlates strongly with both functional ability and pain. Chronic osteoarthritis pain has been associated with depression, poor psychological outlook, and decreased self-efficacy, all of which then perpetuate inactivity and further disability [151].

The available evidence shows that progressive resistance training induces clinically significant improvements in muscle strength, functional ability, and pain scores, even in patients with advanced disease. Earlier intervention to attenuate the progressive loss of muscle strength associated with osteoarthritis may retard progression of disease. In addition, progressive resistance training improves patient self-efficacy, in part through pain reduction [151-155].

Due to the heterogeneity of interventions studied, evidence on the optimal prescription for resistance training in this population is mixed. As an example, positive results have been shown with isokinetic, concentric-only, and combined eccentric-concentric resistance programs. Some data suggest greater improvement with eccentric-concentric training, which tends to incorporate large multijoint movement patterns. Concerns over the feasibility of high-intensity resistance training in patients with symptomatic osteoarthritis have been challenged by studies showing the safety of intensities above 80 percent 1RM without exacerbation of pain symptoms. Higher-intensity training programs also tend to show greater effect sizes in improvements in strength, functional status, and decreases in pain [152-155].

Resistance training appears to be safe and may be beneficial in patients after joint arthroplasty, starting as early as the immediate postoperative period. Patients undergoing hip arthroplasty are typically of advanced age, and often fail to regain their prior functional status due to the effects of perioperative immobilization and hospitalization. A small randomized trial comparing progressive resistance training (using 65 to 80 percent of the 1-repetition maximum), percutaneous neuromuscular electrical stimulation, and conventional physiotherapy showed that of the three interventions only progressive strength training resulted in decreased hospital length of stay, prevented postoperative muscular atrophy, and increased muscular strength when assessed at 12 weeks postoperatively [156].

Osteopenia and osteoporosis — The recommendation for weight-bearing exercise is well-accepted in the management of osteopenia and osteoporosis [157]. Mechanical loads that induce high-strain rates or frequencies induce adaptive bone remodeling in a dose-dependent fashion [158]. Bone remodeling cycles require several months to complete, and radiographic changes in bone mineral density changes can take even longer to manifest on dual energy x-ray absorptiometry (DXA) [159]. However, most research has involved small sample sizes, short durations (eg, 12 weeks or less), or low- to-moderate load training leading to modest results, with a mean treatment effect of 0.3 percent for bone density at the hip or spine [160].

Better designed trials report greater benefit. The 2017 Lifting Intervention For Training Muscle and Osteoporosis Rehabilitation (LIFTMOR) trial studied an eight-month, high-intensity (80 to 85 percent 1RM) progressive resistance training program among 101 postmenopausal women with low or very low bone mass, 28 percent of whom had suffered an osteoporotic fracture within the prior 10 years [161]. Compared with the control group, which performed a traditional home-based low-intensity program, the intervention group showed superior outcomes of bone mass, femoral neck geometry, and all measures of physical function. The lumbar spine and femoral neck bone density changes were 2.9 and 0.3 percent, respectively, versus -1.2 and -2.0 percent for the control group. No fractures occurred in the trial, although the trial was not powered or designed to specifically measure safety outcomes.

Back pain — Back pain is one of the most common complaints in the primary care setting. The large majority of back pain in this setting is nonspecific. Acute back pain (<4 weeks duration) has a good prognosis, with 70 to 90 percent resolving spontaneously within seven weeks. In general, exercise has **not** been shown to improve short-term outcomes in acute back pain compared with other conservative treatments. However, current guidelines suggest avoiding bedrest and staying as active as possible, including the maintenance of any existing exercise routine, if tolerated. For subacute (4 to 12 weeks) and chronic low back pain (LBP), the evidence in favor of exercise is stronger. (See "Treatment of acute low back pain" and "Exercise-based therapy for low back pain".)

While many of the studies focused on core strengthening exercises for the management of chronic LBP have generated mixed or negative results, there is favorable evidence for resistance training. In a study of 45 adults with chronic LBP, patients managed with a 16-week whole-body, progressive resistance training program using a variety of free weight and machine-based exercises demonstrated improvements in strength, pain reduction, and quality-of-life measures not seen in patients managed with aerobic training [162]. Two similar studies by the same research group involving different populations with chronic LBP have reported similar results [163,164].

Of note, evidence suggests that baseline psychosocial variables are stronger predictors of long-term pain and disability than structural findings on magnetic resonance imaging, which have only weak associations with long-term outcomes [165-167]. As an example, negative beliefs about back pain, fear-avoidance beliefs, kinesophobia (fear of movement), catastrophizing, and anxiety are associated with higher pain intensity, greater disability, and worse long-term outcomes. Clinicians' language and management approach have an important and underappreciated impact on these patient beliefs. The results of a survey study of 130 patients suggest that up to 89 percent of patients with persistent or recurrent LBP learn their negative beliefs from health care professionals [167].

While it is important for clinicians to perform a careful assessment of acute or chronic back pain for high-risk features (eg, history of cancer or osteoporosis, signs of infection, neurologic deficits), it is also important to avoid inducing or exacerbating negative beliefs and fear in the patient. These may result in increased pain intensity, duration, or disability stemming from a reluctance to be active, engage in exercise, or participate in rehabilitation activities. One of the primary mechanisms by which resistance exercise benefits patients with chronic back pain is by modulating these psychological factors. In one randomized trial of 49 obese adults with chronic LBP, patients participating in a total-body resistance training program experienced greater reductions in perceived disability, pain catastrophizing, and pain severity than those following a specific lumbar extensor exercise program [168].

Gastroenterology

Cirrhosis — Cirrhosis is characterized by a number of complex metabolic alterations that affect muscle growth and contribute to atrophy. Sarcopenia is among the most frequent complications of cirrhosis and is most severe in patents with alcohol-related and cholestatic diseases [169]. Sarcopenia is compounded by malnutrition and dietary protein restriction as well as by certain medications. These include glucocorticoids or, in the post-transplant population, other immunosuppressants (eg, sirolimus) that directly inhibit the mTOR signaling pathway (a primary driver of muscle protein synthesis). Sarcopenia and the associated loss of function is a major contributor to diminished quality of life in these patients.

Studies of resistance training in the setting of cirrhosis are limited, and theoretical concern exists about increases in portal pressures from exercise, which may pose risks in patients with complications from portal hypertension. A 2018 systematic review on physical exercise in patients with cirrhosis identified six randomized trials ranging in length from 8 to 14 weeks, only one of which studied resistance training alone and two of which studied combined aerobic and resistance training [170]. Based on this limited and generally low-quality evidence, this review was unable to show clear benefit or harm. However, several small studies not considered in the review have shown significant improvements in muscle mass, strength, functional capacity, quality of life, and fatigue, and reductions in the hepatic venous pressure gradient without apparent adverse events [171]. Further study is needed to determine the appropriate role of strength training for patients with this complex and common condition.

Pulmonary — Limited data exist concerning the impact of resistance training on pulmonary function and disease. We restrict the present discussion to chronic obstructive pulmonary disease (COPD), the best-studied condition in the context of strength training. (See "Pulmonary rehabilitation", section on 'Exercise training'.)

COPD has a number of known extrapulmonary effects, including weight loss, progressive skeletal muscle dysfunction, and atrophy. Historically, these were thought to result from patient inactivity due to dyspnea with exertion. However, it is now recognized as a multifactorial process also involving systemic corticosteroid exposure, chronic hypoxemia, systemic inflammation, and oxidative stress [172-174]. These factors result in various structural, metabolic, and functional changes that directly impair muscle function, while also inducing an imbalance between anabolic and catabolic processes that results in progressive muscle wasting. These findings have led some authors to suggest that the muscle dysfunction observed in COPD results not only from disuse but also from an intrinsic myopathy. In fact, some evidence suggests that maximal voluntary contraction force of the quadriceps is a more powerful predictor of mortality in patients with COPD than age or forced expiratory volume in one second (FEV1) [175].

Muscle dysfunction influences patient symptoms, functional capacity, quality of life, health care utilization, and overall mortality in patients with COPD. Conversely, resistance training in patients with COPD reduces markers of systemic inflammation, increases muscle strength and hypertrophy, improves muscle endurance, and improves functional capacity and quality of life [176]. Although evidence is limited by variation among interventions, intensity, and duration, training patients with COPD does not appear to affect respiratory function directly.

In the acute setting of COPD exacerbation, resistance training appears to be feasible, prevents deterioration of skeletal muscle function, and improves anabolic signaling without evidence of adverse effects [177]. In addition, resistance training may be more feasible in patients who are limited by dyspnea and therefore unable to perform the extended bouts of traditional aerobic training often involved in pulmonary rehabilitation.

Rheumatology and immunology — Data on resistance training in the setting of autoimmune diseases, such as the seronegative spondyloarthropathies, systemic lupus erythematosus, polymyalgia rheumatica, the autoimmune myopathies, and inflammatory bowel disease are quite limited. The effects of strength training on rheumatoid arthritis (RA) are best understood.

As with all chronic inflammatory conditions, RA causes interference with anabolic signaling resulting in progressive muscle wasting and dysfunction ("rheumatoid cachexia") [178]. Reductions in strength ranging from 25 to 70 percent have been observed in patients with RA compared with healthy age-matched controls. Reductions in strength occur out of proportion to losses in total muscle bulk, likely reflecting intrinsic muscular dysfunction. This progressive functional impairment combined with joint pain promotes inactivity and further disability [179].

In patients with RA, progressive resistance training increases muscle strength and muscle hypertrophy, improves overall functional capacity, and helps address other disease complications, such as osteoporosis, dyslipidemia, and insulin resistance. In particular, higher-intensity interventions have been shown to have greater effects than low-intensity interventions, without exacerbating joint pain or disease activity in individuals with controlled disease [180-183]. (See 'Osteopenia and osteoporosis' above and 'Cardiovascular disease risk factors' above.)

Renal — Chronic kidney disease (CKD) and end-stage renal disease (ESRD) produce a chronic inflammatory state associated with various adverse metabolic and neurohormonal changes. These changes induce resistance to anabolic stimuli by modulating cell signaling mechanisms involved in muscle protein synthesis and breakdown [184]. The resultant hypercatabolic state results in chronic muscle wasting (sarcopenia), bone loss, and functional decline, which is further exacerbated by inactivity and by the institution of a low-protein diet in the setting of CKD. (See "Overview of the management of chronic kidney disease in adults" and "Osteoporosis in patients with chronic kidney disease: Diagnosis and evaluation" and "Overview of chronic kidney disease-mineral and bone disorder (CKD-MBD)" and "Chronic kidney disease and coronary heart disease".)

The importance of exercise, and resistance training in particular, is underemphasized among patients with CKD/ESRD, despite a growing body of evidence showing clinically meaningful benefit in this population. Evidence from randomized clinical trials shows that progressive resistance training increases muscular strength and hypertrophy, improves health-related quality of life, and prevents the catabolic effects of a low-protein diet in CKD and ESRD patients [185-188]. The data for other outcomes are mixed, limited primarily by trial design, including small sample sizes, short durations (eg, 8 to 12 weeks or less), timing of intervention (intra- versus inter-dialysis), and low-intensity interventions. Given the current understanding of the pathophysiology of anabolic resistance in healthy aging populations, the changes associated with CKD suggest that low-to-moderate intensity interventions are less likely than higher intensity training to induce the anabolic responses necessary to reverse muscle wasting and bone mineral density losses.

It is critical to note that the healthy resistance-trained individual may develop and carry greater skeletal muscle mass relative to their untrained counterparts. This increased muscle mass results in an increase in baseline serum creatinine levels, often outside the traditional reference range. Such increases should not be interpreted as evidence of renal injury induced by resistance training. (See "Assessment of kidney function".)

Neurology — The role of resistance training in the rehabilitation of neurodegenerative disorders is attracting increased attention, but the data remain incomplete. Our discussion is limited to rehabilitation after stroke and preservation of function in Parkinson disease, the best-studied areas.

Stroke — Stroke is a leading cause of chronic disability, often due to muscle weakness and hemiparesis. This disability results in progressive functional impairment, inactivity, and immobilization— particularly of the hemiparetic limb. Emerging evidence shows a number of structural and metabolic changes at the level of skeletal muscle after acute stroke, including atrophy, alterations in myosin expression, chronic inflammatory signaling and consequent oxidative damage [189]. These changes result in progressive wasting, impaired function, and disability.

Most stroke rehabilitation occurs in the subacute phase, and there is little guidance on exercise thereafter. Available evidence suggests that progressive resistance training is feasible, safe, and effective for improving muscle strength and reducing functional limitations in both paretic and non-paretic extremities in patients with chronic stroke [190-193]. Higher intensity interventions tend to produce greater effects, and several studies have shown strength improvements to be persistent at long-term follow-up [194]. The available data are generally limited by highly variable resistance training interventions, timing of intervention, and follow-up; the optimal timing and prescription for these interventions has therefore not been established.

Parkinson disease — The role of resistance training for improvement of function in patients with Parkinson disease has drawn considerable attention. Although this body of work is incomplete and methodologically limited, on balance the data indicate that training for strength is safe, feasible, and beneficial in this population [195-197]. A 2013 meta-analysis found evidence for improvements in strength and walking performance but not for other physical performance outcomes [198]. Another 2013 meta-analysis reported improvements in strength, fat-free mass, endurance, mobility, and performance in functional tasks [199]. Individual studies suggest improvements in postural control and gait initiation [200], bradykinesia [201], and overall physical function [202]. Individual responses to training are likely to vary widely, and strength and conditioning professionals must work closely with clinicians and patients to tailor programs to individual needs and limitations. We find no compelling evidence that training has a meaningful impact on the underlying neurodegenerative pathophysiology of Parkinson disease. (See "Nonpharmacologic management of Parkinson disease".)

Psychiatry — A 2018 systematic review and meta-analysis of 33 trials on the effects of resistance training on depressive symptoms found evidence of a significant reduction in symptoms, with a moderate effect size [203]. A 2017 meta-analysis of 17 studies showed resistance training to have a significant effect on reducing symptoms of anxiety in both healthy patients and those with diagnosed mental illness [204]. Effect sizes were greater for reducing symptoms in healthy patients but otherwise did not vary based on whether strength ultimately improved as a result of training, suggesting an independent mechanism of benefit outside of muscular strengthening. (See "Complementary and alternative treatments for anxiety symptoms and disorders: Physical, cognitive, and spiritual interventions", section on 'Physical activities'.)

WHAT ARE THE RISKS OF STRENGTH TRAINING?

We recommend that strength training be conducted with carefully titrated loads and judicious progression, on stable surfaces, and without exposure to impacts or unexpected or impulsive joint forces or moments. When so administered, strength training is extremely safe [16,205-207]. When injuries or acute pathologic conditions are sustained from strength training, often these can be attributed to poor programming or technique used by the trainee or trainer.

The risks of any particular strength training program for any particular patient are primarily due to individual patient attributes, exercise selection, progression, equipment, coaching, and the overall model of training. A complete examination of this topic is beyond the scope of the present discussion. Here we take a systems-based approach to discussing some of the specific risks that must be managed in any strength training program.

Cardiovascular disease — While habitual resistance exercise provides numerous benefits as described above, such activity can acutely and transiently increase the risk of sudden cardiac death and acute myocardial infarction in individuals at risk. Among individuals below 30 to 40 years of age, these risks most commonly involve hereditary or congenital heart disease (structural, coronary, valvular, or conduction system disease). Among older individuals, such risks are most often related to coronary artery disease (CAD), resulting in acute plaque rupture or malignant cardiac arrhythmias.

Coronary artery disease — For patients with CAD, many clinicians have concerns regarding the hemodynamic changes during resistance exercise precipitating a cardiovascular event. Most of the available data describing these risks is in the context of general exercise rather than resistance training specifically. The rate of exercise-induced cardiovascular events in young athletes and in ostensibly healthy adults is extremely low. However, vigorous exercise (typically defined as >6 METs; equivalent to jogging) increases cardiovascular risk during or immediately after exercise in young individuals with inherited disease and adults with occult or known cardiovascular disease.

Despite growing evidence demonstrating the benefits of resistance training in the setting of stable coronary disease, a 2017 meta-analysis found that reporting of adverse cardiac events was poor, with notable gaps in reporting for females, older adults, and long-term outcomes for high-intensity, progressive resistance training [208]. Based on the available evidence, for patients with asymptomatic coronary disease the benefits of resistance training appear to outweigh the risks. Patients with stable angina should avoid exercise intensities that provoke symptoms, while patients with unstable or progressive symptoms should abstain from exercise and seek immediate medical attention. (See 'Coronary artery disease and myocardial infarction' above.)

Hypertension — Risks of resistance training in the setting of hypertension reflect many of the same concerns discussed above related to CAD. According to the American College of Sports Medicine guidelines, only high-risk individuals with hypertension (symptomatic hypertension or those with known cardiovascular, pulmonary, renal, or metabolic disease) who are planning to engage in moderate- to high-intensity exercise are recommended to undergo medical evaluation prior to exercise. However, there is no evidence demonstrating an increased risk of adverse events **during** exercise secondary to exercise-induced hypertension. Similarly, the available evidence does not show a significant effect of resistance training on blood pressure (BP) for up to 24 hours after an exercise session. Of note, the American Heart Association considers a resting systolic BP (SBP) >200 mmHg or diastolic BP (DBP) >110 mmHg to be a relative contraindication to exercise stress testing [209-211].

Cardiovascular medications — Patients with cardiovascular disease are commonly prescribed a number of medications that may have implications for exercise in general and for resistance training in particular.

Lipid-lowering agents, such as statins and fibrates, predispose to myalgias, myopathy, and rarely, rhabdomyolysis. Fortunately, these complications are relatively uncommon. A patient initiating a resistance training program may experience delayed-onset muscle soreness in the early phases of training. This is a brief, self-limited condition and should not be interpreted as a medication side effect. Training should be initiated and progressed gradually, and unusually persistent or worsening muscle soreness associated with edema, dark urine, or other complaints concerning for rhabdomyolysis should be referred for immediate evaluation and treatment. A history of rhabdomyolysis does not represent a contraindication to the subsequent initiation of resistance training. (See "Statin muscle-related adverse events" and "Clinical manifestations and diagnosis of rhabdomyolysis".)

Antihypertensives have several important considerations pertaining to resistance training. Diuretics increase the risk of dehydration and hypovolemia, which can impair performance and the physiologic response to training, but also increase the risk of orthostasis, falls, and renal insufficiency. Attention should therefore be paid to ensuring adequate hydration before and during exercise sessions for patients on diuretics. Beta blockers and nondihydropyridine-type calcium channel blockers impair the chronotropic response to exercise and may therefore limit physical performance but also serve to limit the increase in rate-pressure product during exercise, which may prevent angina in susceptible patients with CAD. (See "Exercise in the treatment and prevention of hypertension".)

There is insufficient direct evidence to inform recommendations concerning resistance training in post-aortic dissection patients or in patients with ventricular or arterial aneurysm or known uncorrected cerebrovascular anomalies. The majority of recommendations advise against high-load resistance training or training to failure due to the acute increases in BP that occur during these activities, and pending further study. we concur with these recommendations [212].

Endocrine-metabolic — The risks of resistance training in patients with diabetes include hypoglycemia and hyperglycemia, complications of CAD, complications of proliferative retinopathy, and potential musculoskeletal injuries due to peripheral or autonomic neuropathy.

Patients with type 2 diabetes are commonly prescribed oral or injectable hypoglycemic medications, while patients with type 1 diabetes usually take injectable insulins or continuous insulin pump therapy. Exercise-induced hypoglycemia (both immediate and post-exercise hypoglycemia) is common among patients with type 1 diabetes and, to a lesser extent, those with type 2 diabetes. Reductions in basal and/or bolus insulin therapy, as well as strategic ingestion of peri-workout carbohydrate, may be required to avoid this effect [98]. The hypoglycemic response to exercise among diabetics varies widely, and therefore, it is important to monitor serum glucose closely when initiating a strength training program. (See "Hypoglycemia in adults with diabetes mellitus", section on 'Exercise-induced hypoglycemia'.)

Diabetes is a cardiac risk equivalent, and there is a high incidence of CAD in this population. In addition, patients with microvascular complications of diabetes appear to have an impaired cardiovascular response to exercise. Therefore, it is important to be aware of the patient's cardiac status prior to engaging in exercise due to the risk for ischemia and dysrhythmia. (See 'Coronary artery disease and myocardial infarction' above.)

Overall, exercise does not appear to accelerate the development or progression of diabetic retinopathy, and exercise-related improvements in glycemic control could conceivably reduce the risk of retinopathy. However, in the setting of established, advanced proliferative diabetic retinopathy, acute exercise-induced elevations in BP may precipitate hemorrhagic complications due to impaired autoregulation of ocular blood flow. Unfortunately, there is no clear threshold for SBP above which the risk of hemorrhagic complications increases and below which intense resistance exercise is deemed safe [213].

Patients with peripheral or autonomic neuropathy may be at increased risk for falls and orthostatic hypotension during exercises performed while standing or which involve significant changes in body position, and this should be considered when designing and executing a strength training program.

Musculoskeletal — Like any form of exercise, resistance training poses a risk of acute musculoskeletal injury, such as muscle strain, tendon sprain or rupture, ligament tear, and acute low back pain (LBP). Resistance training may also result in acute exacerbation of pain from chronic conditions, such as tendinopathy, osteoarthritis, and other rheumatologic ailments. The shoulder, low back, knee, elbow, and wrist are the most commonly affected areas.

Literature is limited and adverse events tend to be under-reported in studies of resistance training [214]. However, the available evidence and our clinical experience suggest that rates of musculoskeletal injury among participants in well-designed and properly coached programs are extremely low. As an example, a 2017 systematic review of the epidemiology of injury across weight-training sports (including powerlifting and bodybuilding) known for the use of heavy loading in order to maximize muscle strength and size reported relatively low rates of injury compared to common team sports. Bodybuilding had an injury rate of 0.12 to 0.7 injuries per lifter per year, or 0.24 to 1.0 injury per 1000 participation hours [215]. A systematic review of competitive powerlifters, a sport contested using 1-repetition maximum loads, reported a rate of approximately 1.0 to 4.4 injuries per 1000 participation hours, which is also low compared to that observed in most sports [216]. From this perspective, it appears that the benefits of resistance training likely outweigh such risks.

Back pain — As discussed above, patients with acute or subacute LBP, with or without radiculopathy, are likely to improve over time regardless of treatment [217]. Bedrest is ineffective, and appears to be inferior to staying active for reducing pain and improving functional outcomes [218,219]. (See 'Back pain' above.)

Despite long-standing concern among clinicians, the size of a lumbar disc herniation and degree of disc displacement do not appear to be predictive of subjective symptom severity or of long-term outcomes in patients with sciatica [220,221]. In addition, although the available evidence is not specifically focused on resistance training, exercise does not appear to increase the risk of LBP exacerbations compared with non-exercising control populations.

Available evidence pertaining to the role of exercise for LBP, combined with the extensive health benefits of resistance training, suggest that initiation or continuation of resistance exercise is a reasonable approach for these patients, depending on individual patient preference and other factors. Patients **without** high-risk features of LBP should be encouraged to participate in graded exercise to improve self-efficacy, reduce kinesophobia, and obtain the numerous other health benefits of exercise described above. Exercise type, frequency, and intensity should be modified based on the patient's symptoms and tolerance. (See "Evaluation of low back pain in adults" and "Exercise-based therapy for low back pain" and "Practical guidelines for implementing a strength training program for adults".)

Rhabdomyolysis — Rhabdomyolysis is a syndrome in which skeletal muscle breakdown leads to release of intracellular muscle contents into the circulation [222,223]. Prolonged strenuous muscular exertion far in excess of an individual's level of training adaptation increases the risk of exertional rhabdomyolysis (ER). In particular, risk increases when the exercise is unfamiliar, repetitive, or involves numerous eccentric (muscle-lengthening) contractions [224]. Rhabdomyolysis unrelated to trauma is uncommon, with an incidence of 29.9 per 100,000 patient-years, though the specific contribution from strength training is not known [223].

Rhabdomyolysis is characterized clinically by myalgias, red to brown urine due to myoglobinuria, and elevated serum muscle enzyme concentrations (eg, creatine kinase). The severity of rhabdomyolysis ranges from asymptomatic, self-limited elevations in serum muscle enzymes and mild myalgia after exercise (eg, delayed-onset muscle soreness [DOMS]) to life-threatening disease associated with extreme serum enzyme elevations, electrolyte imbalances, and acute kidney injury [222]. (See "Clinical manifestations and diagnosis of rhabdomyolysis".)

It is important to identify those who may be at elevated risk for developing ER. Factors that increase risk include:

- Patient or athlete is new to strength training or beginning a new, more demanding program.
- Patient is returning to strength training after an injury, illness, or prolonged absence.
- Strength training is to be performed in conditions of high heat and humidity.
- Genetic factors, including sickle cell disease or trait, inherited myopathy, or other muscle enzyme deficiencies/mitochondrial defects [225].
- Personal or family history of malignant hyperthermia or rhabdomyolysis.

Other risk factors for ER include the use of medications or supplements with sympathomimetic effects, recent systemic infection, and certain metabolic diseases [224,226]. (See "Causes of rhabdomyolysis".)

Despite the increased risk of ER in these populations, no guidelines suggest that training is contraindicated for them. The risks and benefits of strength training in these populations should be assessed on a case-by-case basis by the clinician and discussed with the patient.

ER can be avoided easily by following appropriate precautions, including proper hydration and sensible programming that emphasizes gradual, incremental increases in training volume, intensity, and exposure to new movements. The principles and implementation of a proper strength training program are reviewed separately. (See 'Strength training: Definition and key principles' above and "Practical guidelines for implementing a strength training program for adults".)

SUMMARY AND RECOMMENDATIONS

- Muscular strength is the ability to produce force against a resistance and thus is a fundamental fitness attribute that influences all others, including power, endurance, mobility, and balance. In addition, increased muscular strength protects against injury and frailty. (See 'Why is strength important?' above.)
- Strength (or resistance) **training** is a rational, explicit program of carefully chosen exercises performed over an extended period and designed to increase the subject's ability to produce muscular force in useful movement patterns. This goal cannot be realized by sporadic, unplanned, random bouts of exercise. The Stress-Recovery-Adaptation model provides a useful conceptual framework for strength training programs. Training stress is based on the principle of progressive overload—a steady increase in the applied training stress—which produces a corresponding increase in physiologic and performance adaptation. Recovery and adaptation depend upon proper nutrition, adequate sleep, active rest between training days, and stress management. (See 'Strength training: Definition and key principles' above.)
- The benefits of properly performed strength training are myriad, including: increased strength and power, improved body composition (eg, reduced visceral fat, increased lean muscle mass and bone density), increased anaerobic capacity, improved energy utilization (eg, increased insulin sensitivity), and improvements in a host of risk factors for cardiovascular disease. (See 'What are the benefits of strength training?' above.)
- In addition to its general health benefits, properly performed strength training can help to prevent or improve a large number of medical conditions, including diabetes, cardiovascular disease, sarcopenia, and osteoporosis. These effects are discussed in detail in the text. (See 'What medical conditions improve with strength training?' above.)
- Strength training should be performed with carefully titrated loads and judicious progression, on stable surfaces, and without exposure to impacts or unexpected or impulsive joint forces or moments. When so administered, strength training is extremely safe. However, as with any strenuous physical activity, participants entail some risk. These risks are described in the text. (See 'What are the risks of strength training?' above.)

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Conflict of interest policy