SUCCESSFUL AGING

Preserving Mobility in Older Adults

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Age-related loss of strength contributes to impaired mobility and increases the risk of falls. Recent research has focused on 2 approaches to preventing age-related loss of strength—promoting physical activity and exercise (especially strength training) and using trophic factors to enhance muscle performance. Epidemiologic evidence strongly supports a role of regular physical activity in successful aging by preserving muscle performance, promoting mobility, and reducing fall risk. Randomized controlled trials provide convincing evidence that strength and endurance training improve muscle performance in older adults. Evidence is rapidly accumulating from randomized trials that endurance, strength, and balance training promote mobility and reduce fall risk, though exercise effects differ according to the type of exercise, details of the exercise program, and the target group of older adults. Because lifetime regular physical activity is recommended for all older adults, a reasonable strategy (especially for weak adults) is an activity program that includes strength training. In contrast, insufficient evidence exists to recommend the long-term use of trophic factors to preserve muscular performance. An intervention that merits additional study is avoiding the use of psychoactive drugs because drugs like benzodiazepines appear to be risk factors for inactivity and may have unrecognized direct effects on muscular performance. Because chronic illness is a risk factor for inactivity and disuse muscle atrophy, randomized trials comparing strength training with other interventions would be useful in understanding whether strength training has advantages in preserving muscle performance and improving health-related quality of life in a variety of chronic illnesses such as depressive illness.

(Buchner DM. Preserving mobility in older adults. In: Successful Aging. West J Med 1997; 167:258–264)

We are all interested in preserving the health of our largest tissue: muscle. Muscle accounts for 45% of body weight. If the roughly 450 skeletal muscles in our body (containing some 250 million muscle fibers) contracted all at once, they would produce a force of 25 tons.[1] In the healthy state, our muscles work remarkably well. They can be switched on within milliseconds. They convert chemical energy (either fat or carbohydrate) to mechanical work, with complete silence, at 40% efficiency (roughly the same efficiency of a diesel engine).[1] They can operate both aerobically and anaerobically. Muscle and its neural control are also remarkably "plastic." Muscle strength declines by a few percentage points with each day of strict bed rest. With physical activity, muscles hypertrophy. With practice, muscles contract just the right amount at just the right time.

Aging poses a challenge to preserving muscular performance. Scientific studies for more than 100 years have confirmed the obvious: skeletal muscle strength and coordination decline with age. This decline is partly responsible for the decline in mobility and an increased risk of falls.

In this article I review what is known about preserving skeletal muscular performance, in particular as it relates to preserving mobility and preventing falls in older adults. For the most part, I have ignored the many determinants of mobility and falls that do not involve skeletal muscle.

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This work was supported in part by grants from the Centers for Disease Control and Prevention (R48/CCR002181) and the National Institute on Aging (UO1/AG09095); support was also provided by the Department of Veterans Affairs, Health Services Research and Development Service. The views expressed in this article are those of the author and do not necessarily represent the viewpoints of the sponsoring agencies.

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ABBREVIATIONS USED IN TEXT

FICSIT = Frailty and Injuries: Cooperative Studies of Intervention Techniques
HR = heart rate
HRR = heart rate reserve
Vo_2max = maximum oxygen consumption

Conceptual Model and Terminology

Our conceptual framework for discussing mobility and falls comes from the Nagi model of disability.[2] The causes of disability (etiologic agents) are termed "risk factors." Their effects are measured at four levels:

- Pathology (or disease) is measured at the cell and tissue levels. Examples of measures of muscle at this level are the fiber cross-sectional area, the ratio of type I to type II fibers, and measures of muscle enzyme levels.
- Impairment (or physiologic impairment) is measured at the organ and organ system level. Measures of the physiologic capacity (physiologic reserve) of muscle include maximum force (strength), maximum power, and maximum oxidative capacity. We regard measures of physical fitness (muscle strength, aerobic capacity, anaerobic capacity, body composition, and flexibility) as measures of physiologic capacity. (Physiologic aspects of balance and coordination are also measured at this level, such as visual acuity, vestibular function, sensory neuropathy, and patterns of motor nerve innervation and stimulation of muscle.)
- Functional limitations are measured at the level of the whole person and describe behavioral ability. We restrict our interest in functional limitations to measures of mobility, such as measures of the ability to stand, sit, walk, turn, transfer, and climb. (Functional aspects of balance and coordination are measured at this level, such as the ability to stand on one leg, reach, hop, and hit a baseball.)
- Disability is measured at the level of the person-environment interaction. The environment encompasses both physical and social aspects. We focus on one measure of disability—fall incidence, which depends on the person-environment interaction.

The main risk factors of interest are physical activity and exercise. Physical activity is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure."[94] Exercise is "a subset of physical activity defined as planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness."[94]

There is an intuitive causal chain across levels of the model. For example, inactivity causes muscle fiber atrophy, which causes muscle weakness, which in turn causes a slow unsteady gait, and this leads to falls. Feedback loops and other causal pathways are possible, however.

Two Obvious Interventions

Much of the research in the past decade on muscular performance and mobility has addressed either exercise or trophic factors.

Exercise

An obvious hypothesis is that exercise, particularly strength training, preserves muscular performance and mobility. This hypothesis was the rationale for what appears to be the first study of strength training in older adults published in 1961.[3] As obvious as this idea is, it was not seriously studied until the late 1980s. In the 1970s, the public health focus was on aerobic training, and strength training was not perceived as having much value.[4] It was questioned whether muscles in older persons could even respond to exercise training, as illustrated by a study in the early 1980s concluding that the muscles of older adults did not hypertrophy in response to strength training.[5]

Trophic Factors

The idea that hormones and anabolic steroids can enhance muscular performance is also an old idea. In 1977 a controlled trial of the anabolic steroid stanozolol claimed that anabolic steroids have been widely recommended in the management of debility in older adults with chronic diseases,[6] including diseases like osteoporosis.[7] In the 1980s, the emphasis shifted away from anabolic steroids to hormones, termed "trophic factors": estrogen, testosterone, and growth hormone. The interest in growth hormone was stimulated by the new industrial capacity to produce large quantities of hormone. A highly publicized study promoted interest in growth hormone by abetting the perception of growth hormone as an antiaging pill that removed skin wrinkles, decreased fat, and increased muscle mass.[8]

Major Research Findings and Recommendations of the Past Decade

Epidemiologic Plausibility of the Physical Activity Hypothesis

In the past decade, epidemiologic studies have addressed the association between all possible pairs of measurements in the causal chain of the physical activity hypothesis: physical activity improves muscle strength, which improves mobility, which in turn decreases the fall risk. A brief review of this evidence is important to arguing that regular physical activity (as opposed to only exercise programs) sustains mobility and prevents falls. The randomized controlled trial evidence for this hypothesis is not as comprehensive or complete and deals almost entirely with exercise programs as opposed to physical activity. The issue is of public health importance because most older adults who do sufficient activity to meet public health recommendations do not follow formal exercise programs.

Higher levels of physical activity are associated with greater muscular performance,[9–11] better mobility,[12–14] and a lower risk of falls.[15–17] There is some concern that high levels of physical activity may increase the fall risk[18] and fall injury risk.[19] Even after accounting for the morbidity due to falls, however, physically active adults appear to have less disability.[20]

Greater muscle strength is associated with better mobility[21–24] and a lower risk of falls.[25–27] The relationship between strength and mobility (as measured by gait speed) is nonlinear.[22,23] A nonlinear relationship makes intuitive sense: whereas professional athletes may be several times stronger than average adults, athletes do not walk several times faster than the average adult. Most of their strength is physiologic reserve not used during normal walking.

Finally, better mobility is also associated with a lower risk of falls.[16–18,28] Indeed, measures of mobility such as gait speed have moderately high correlations (0.5 to 0.6) with questionnaire measures of overall physical functional limitations and disability.[22,29]

Effects of Strength Training on Muscle Physiology

There is conclusive evidence that strength training increases skeletal muscle strength in older adults. A 1993 meta-analysis demonstrating the positive effect of training on strength was able to locate 18 studies.[32] The studies are not limited to the "young-old," as studies in 80- and 90-year-old adults also report increases in strength with resistance training.[30,31] Several studies show that muscular hypertrophy, including hypertrophy of type II fibers, occurs with training.[32]

High-intensity strength training produces substantially greater gains in strength,[32] which is consistent with basic principles of exercise physiology. High-intensity training involves training where muscles are exercised near or to the point of exhaustion, usually by setting the weight lifted at each repetition at 60% to 80% of the maximal weight a person can lift. Variation in the intensity of training across studies appears to be the major reason that exercise-related gains in strength vary over such a large range (20% to 200%). Other reasons for variation in reported results include differences in the duration of training and in the method used to measure strength. Even frail older adults can tolerate strength training at high intensity.[30,31]

Effects of Endurance Exercise on Muscle Function

The fitness response to an endurance training program in previously sedentary, healthy older adults is comparable to that of younger subjects[33] and usually on the order of 10% to 30% change over several months to a year. When older and younger adults are trained in the same program at the same relative intensity, their increments in maximum oxygen consumption (Vo_2max) are similar.[34] Healthy older adults can tolerate endurance training at high intensity (75% to 85% of heart rate reserve (HRR): HRR = 0.85 (HR max [maximum heart rate] – HR rest) + HR rest). The Vo_2max is the product of maximal cardiac output and maximal ability of muscle to extract oxygen. Long-term training appears to affect both components of the Vo_2max.[33]

Effects of Strength and Endurance Training on Mobility

Several randomized trials report that strength or endurance training (or both) improves gait speed by a modest amount.[35–37] Other trials have failed to find an effect.[38,39] The variation in results can be partly explained by a variation in frequency, duration, and intensity of training. Also, as explained earlier, if strength and endurance capacities are already adequate, further increases in capacity would not be expected to change relatively basic tasks like walking speed. This may explain why studies in nursing home patients have generally found an effect of exercise on gait speed[31,32,40] and why community trials may not.[38,39] Further research is needed to determine if exercise improves performance in high-level mobility tasks in elderly persons in the community, as existing research focuses on basic tasks.

The extent that strength training improves mobility by improving balance is unclear. A study comparing strength and balance training found that strength training had no effect on balance.[41] Like many other studies,[42–44] the study did report that balance training improved balance. It is possible that the effect of strength training on balance depends on the target group, with strength training improving balance in weak adults in a nursing home[31] but not in community adults.[39] It is likely that the effect of strength and endurance training on balance depends on the amount that balance is "stressed" during the exercises. Strength training that simultaneously stresses balance has been proposed.[45] A study of endurance training provided mild support to the hypothesis that the amount of movement during endurance training determines the effect of the training on balance.[35]

Effects of Exercise Training on Fall Risk

The National Institute of Aging funded a set of randomized trials, called FICSIT (Frailty and Injuries: Cooperative Studies of Intervention Techniques), in part to address whether exercise reduces the risk of falls. A meta-analysis of seven FICSIT trials reported that exercise reduced the fall risk by about 10% (adjusted fall incidence ratio, 0.90).[46] An interesting aspect of the findings is that balance training seemed to be particularly effective in reducing fall risk. A major strength of this meta-analysis was that it was preplanned, so that falls and case-mix variables were measured in a roughly comparable way at all FICSIT sites. The meta-analysis has been criticized for including interventions involving more than just exercise. Three studies of exercise have not reported a beneficial effect of exercise on fall risk,[47–49] though the statistical power of these studies was limited. The Musculoskeletal Injuries Group of the Cochrane Collaboration has planned a meta-analysis of this literature.

A commonly expressed concern of older adults and practitioners is that exercise will increase the risk of falls in older adults. Although some debate whether exercise reduces fall risk, an extremely important conclusion from this literature is that exercise does not increase the overall risk of falls. This is not to say that older adults do not fall during exercise, because they do. The evidence shows that the short periods of increased risk of falls during exercise training is more than compensated for by a reduced risk of falls during the rest of the day.

Of course, the public health goal is to reduce the incidence of fall injuries. Falls are a surrogate outcome for fall injuries. It has not been shown that reducing the incidence of falls results in fewer fall injuries. That is, the possibility that exercise mainly prevents falls that do not result in injury has not been ruled out.

Exercise-related Injuries

A review of exercise intervention studies in older adults found that major injuries are rare in research studies.[50] Minor injuries are occasionally reported, but are almost always self-limited. An exception is a study that promoted jogging.[51] Little is known about the risk of injury in nonresearch community programs, but injury risk appears controllable.

Because of the high prevalence of arthritis in older adults, the question frequently arises as to whether exercise makes arthritis worse. As shown by consensus guidelines that recommend exercise and physical activity for patients with knee osteoarthritis,[52] the existing evidence strongly favors the conclusion that exercise benefits patients with osteoarthritis. A large study found that strength and endurance training had similar benefit when compared with a control condition.[53] A recent randomized trial in rheumatoid arthritis addressed whether to decrease the exercise load because of arthritis pain. Subjects who did not reduce the exercise load had similar improvements and symptoms as subjects who did reduce the exercise load.[54]

Growth Hormone, Muscle, and Mobility

The initial enthusiasm caused by the report that growth hormone supplementation increased lean body mass has waned.[8] Administering growth hormone subcutaneously can cause side effects such as carpal tunnel syndrome and glucose intolerance.[55,56] Studies have failed to find an effect of growth hormone use on strength, either by itself or in combination with strength training.[56–58] One study reported that growth hormone supplementation has no effect on mobility and functional limitations.[57] Ongoing studies are addressing whether drugs that stimulate the endogenous release of growth hormone from the pituitary gland are useful. These drugs may have fewer side effects and different physiologic effects from those of subcutaneous injections of growth hormone.

Estrogen, Muscle, and Mobility

A possible effect of the use of estrogen on muscle and mobility is only one of many factors affecting the decision to provide estrogen to postmenopausal women. Evidence about the effect of hormone replacement therapy on muscle strength is limited and inconsistent. Studies report that the strength of premenopausal women varies during the menstrual cycle.[59,60] An epidemiologic study reported that estrogen use is associated with the preservation of muscle strength in postmenopausal women.[61] Hormone replacement therapy increased isometric back strength in one study,[62] but other studies report no effect of hormone replacement on muscle strength or mobility.[63,64]

Testosterone, Muscle, and Mobility

Supraphysiologic doses of testosterone increase muscle strength by a modest amount (5% to 20%) in young men.[65,66] Testosterone replacement in younger hypogonadal men improves muscular performance also by a modest amount,[67,68] but less information is available on older hypogonadal men.[69] The effects of testosterone on mobility and functional limitations are unclear. Enthusiasm for long-term testosterone replacement is mitigated by a concern about side effects such as cancer. A recent review discusses trophic factor use in older adults in more detail.[70]

Vitamins

Older adults commonly take vitamin tablets. I was unable to locate studies addressing whether vitamin use affects strength in older adults, with one exception. A study reported that vitamin D_3 use did not affect muscular performance.[71]

Public Health Recommendations

The health problems caused by physical inactivity are substantial, and inactivity is second only to tobacco use in causing premature death in the United States.[72] Only 20% to 25% of older adults meet the Centers for Disease Control and Prevention's criteria for sufficient levels of physical activity.[73] Even though it is obvious that strength training could preserve muscular performance in older adults, only 5% to 6% of older men and 1% to 3% of older women report doing activities to increase muscle strength like weight lifting.[73]

Healthy People 2000, the US Preventive Services Task Force, and the recent US Surgeon General's report on physical activity all recommend regular physical activity for older adults.[73–75] In particular, the Surgeon General's report affirmed the accumulating evidence favoring the health benefits of strength training in older adults:

> Recent recommendations from experts also suggest that cardiorespiratory endurance activity should be supplemented with strength-developing exercises at least twice per week for adults, in order to improve musculoskeletal health, maintain independence in performing the activities of daily life, and reduce the risks of falling.

Emerging Interventions and Issues in Preserving Muscle and Mobility

Improved Measurement

Muscle power is more logically related to functional limitations in older adults than the peak force of a muscle. Some data suggest that older adults have a greater reduction in muscle power than suggested by data limited to peak force.[76] Routine measurements of muscle power may improve our understanding of how to preserve the physiologic capacity of muscle with age.

Existing performance measures of mobility in older adults focus on simple tasks like standing, sitting, and turning. More sophisticated measures, which include a greater variety and difficulty of tasks, are being developed.[77] These measures may allow a more precise assessment of the effects of interventions on mobility.

Sarcopenia Research

The age-related loss of skeletal muscle has been called sarcopenia. Whereas inactivity and a few diseases like polio and stroke are obvious causes of sarcopenia, it is possible that other contributory causes exist. Some have suggested that contraction-induced injury contributes to sarcopenia.[78] Others suggest that oxidative stress contributes to its occurrence.[79] Interventions to prevent these contributory causes are possible. For example, caloric restriction that has been demonstrated to prolong life in rodents may also reduce the incidence of sarcopenia due to oxidative stress.[79]

Program Options

Because many older adults prefer home-based exercise or physical activity, options for inexpensive strength training at home are being developed and studied.[45,53,80,81] As might be expected in the developmental phase, some programs show more promising results than others.[53,81]

Psychoactive Drugs

Psychoactive drugs are risk factors for mobility problems and falls. In particular, the use of benzodiazepines impairs balance in older adults[82,83] and increases the prevalence of falls and hip fracture.[28,84,85] Studies that explore the mechanism by which psychoactive drugs increase the risk of falls report an interesting association between drug use and muscle weakness.[85] We could not locate an intervention study in older adults of the effects of benzodiazepines on muscular performance, but studies in young adults report that one-time or short-term use of benzodiazepines reduces muscle power and maximal exercise levels.[86,87] The use of these drugs also is a risk factor for inactivity because older adults who take psychoactive drugs are less active and less adherent in exercise programs.[88] The use, however, of antidepressants is best considered separately from that of other psychoactive drugs, along the lines of the adage of the baby and the bathwater. Their use may improve physical activity levels by reducing psychomotor retardation caused by depressive illness.

Alcohol

Excessive alcohol use can cause an alcoholic myopathy. Studies of persons with alcoholism report a greater-than-normal age-related loss of strength.[89] The effects and the mechanism of the effects of moderate alcohol use on muscular performance are unclear. Interestingly, studies have reported better muscular performance and physical fitness in both old and young women who drink than in those who abstain.[90,91]

Excess Disability

Primary diseases of muscle like muscular dystrophy are unusual. If present, they are diagnosed before old age. An obvious hypothesis is that muscle wasting in older adults with chronic illness is not a direct effect of the illness, is due to inactivity caused by the illness, and therefore causes excess disability that can be prevented by exercise. Muscle atrophy amplifies disability because muscular performance is profoundly affected by inactivity.

We anticipate more studies will address the role of strength training in maintaining muscle performance and mobility in different chronic conditions. To date, the most work has been done in persons with arthritis and those with diabetes mellitus. The role of strength training in other prevalent chronic conditions—heart disease, obstructive lung disease, depression, dementia, and the like—is less well studied. For example, a meta-analysis of exercise and depression reported strength training to have a much larger effect on depressive symptoms than endurance training, though only a few studies of strength training were included in the analysis.[92] A recent study in depressed older adults reported that resistance training was an effective antidepressant and also improved strength, morale, and quality of life.[93]

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