

Chronic Exercise Preserves Lean Muscle Mass in Masters Athletes

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DOI: 10.3810/psm.2011.09.1933

Abstract: Aging is commonly associated with a loss of muscle mass and strength, resulting in falls, functional decline, and the subjective feeling of weakness. Exercise modulates the morbidities of muscle aging. Most studies, however, have examined muscle-loss changes in sedentary aging adults. This leaves the question of whether the changes that are commonly associated with muscle aging reflect the true physiology of muscle aging or whether they reflect disuse atrophy. This study evaluated whether high levels of chronic exercise prevents the loss of lean muscle mass and strength experienced in sedentary aging adults. A cross-section of 40 high-level recreational athletes (“masters athletes”) who were aged 40 to 81 years and trained 4 to 5 times per week underwent tests of health/activity, body composition, quadriceps peak torque (PT), and magnetic resonance imaging of bilateral quadriceps. Mid-thigh muscle area, quadriceps area (QA), subcutaneous adipose tissue, and intramuscular adipose tissue were quantified in magnetic resonance imaging using medical image processing, analysis, and visualization software. One-way analysis of variance was used to examine age group differences. Relationships were evaluated using Spearman correlations. Mid-thigh muscle area ($P = 0.31$) and lean mass ($P = 0.15$) did not increase with age and were significantly related to retention of mid-thigh muscle area ($P < 0.0001$). This occurred despite an increase in total body fat percentage ($P = 0.003$) with age. Mid-thigh muscle area ($P = 0.12$), QA ($P = 0.17$), and quadriceps PT did not decline with age. Specific strength (strength per QA) did not decline significantly with age ($P = 0.06$). As muscle area increased, PT increased significantly ($P = 0.008$). There was not a significant relationship between intramuscular adipose tissue ($P = 0.71$) or lean mass ($P = 0.4$) and PT. This study contradicts the common observation that muscle mass and strength decline as a function of aging alone. Instead, these declines may signal the effect of chronic disuse rather than muscle aging. Evaluation of masters athletes removes disuse as a confounding variable in the study of lower-extremity function and loss of lean muscle mass. This maintenance of muscle mass and strength may decrease or eliminate the falls, functional decline, and loss of independence that are commonly seen in aging adults.

Keywords: lean muscle mass; active aging; disuse atrophy; masters athlete

Introduction

Advances in medical technology, nutrition, and public health have led to a dramatic lengthening of the average lifespan over the past century. However, Americans are living longer and more sedentary lives. With the aging of the “Baby Boomer” generation, the proportion of people aged > 65 years in the United States will represent 19.3% of the population by 2030.¹ Our modern lifestyle has led to more people having sedentary jobs and fewer recreational activities. Thus, living longer does not necessarily mean living well, as one-third of aging Americans become disabled.²

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The good news, however, is that many of the diseases and infirmities exclusively attributed to aging are more accurately related to the effects of sedentary living. Sedentary seniors decline twice as fast as their active counterparts, and their highest level of conditioning affects their overall level of decline.³ A growing subset of older individuals has maintained higher functional capacity and quality of life through exercise. Exercise improves quality of life by decreasing body fat (BF) and obesity rates, increasing muscle strength, improving balance, gait, and mobility, decreasing the likelihood of falling, improving psychological health, reducing arthritis pain, and reducing the risk of developing coronary heart disease, hypertension, osteoporosis, cancer, and diabetes.⁴⁻⁷

Between the ages of 40 and 50 years, we can lose > 8% of our muscle mass; this loss accelerates to > 15% per decade after age 75 years.^{8,9} Loss of muscle mass is often accompanied by loss of strength and functional decline. The reasons for these declines are unclear. In a longitudinal study of aging skeletal muscle, Frontera et al¹⁰ found a 14.7% decline in muscle cross-sectional area in men over a 12-year period. Several authors¹¹⁻¹³ have documented increased fat infiltration into muscle with age. Although there is a clinical impression that the composition changes and muscle mass loss are associated with functional decline, results have been inconsistent in the literature. Visser et al,¹⁴ in conjunction with the National Institutes of Health Dynamics of Health, Aging, and Body Composition (Health ABC) study, recently documented an association between lower-leg muscle mass and greater fat infiltration in the muscle, with poorer lower-extremity performance in older men and women. Baumgartner et al¹⁵ found that elderly patients with low muscle mass were 3 to 4 times more likely to report a disability, have balance abnormalities, and use an assistive device for ambulation. Goodpaster et al¹⁶ found that high fat infiltration into muscle was associated with poor knee extensor strength and decreased muscle contractility, muscle fiber recruitment, and muscle metabolism. A greater muscle fat content has also been associated with glucose intolerance and diabetes mellitus.^{17,18}

Although the Health ABC study is examining the physical changes associated with aging in healthy 70- to 79-year-olds, there is a relative paucity of research examining ways to slow the seemingly inevitable decline from vitality to disability that accompanies aging. In the current study, we proposed that high-level recreational athletes, known as masters athletes (athletes who train 4 to 5 times per week), participating in chronic high-level exercise may not demonstrate the same loss of total lean muscle mass and lower-extremity performance witnessed with sedentary aging. Masters athletes

continue to exhibit high levels of functional capacity and quality of life throughout their lifespan. In this observation of a cross-section of masters athletes, the confounding variables of muscle disuse and sedentary living are removed in the study of lower-extremity function and loss of lean muscle mass in aging adults.

Materials and Methods

Study Population

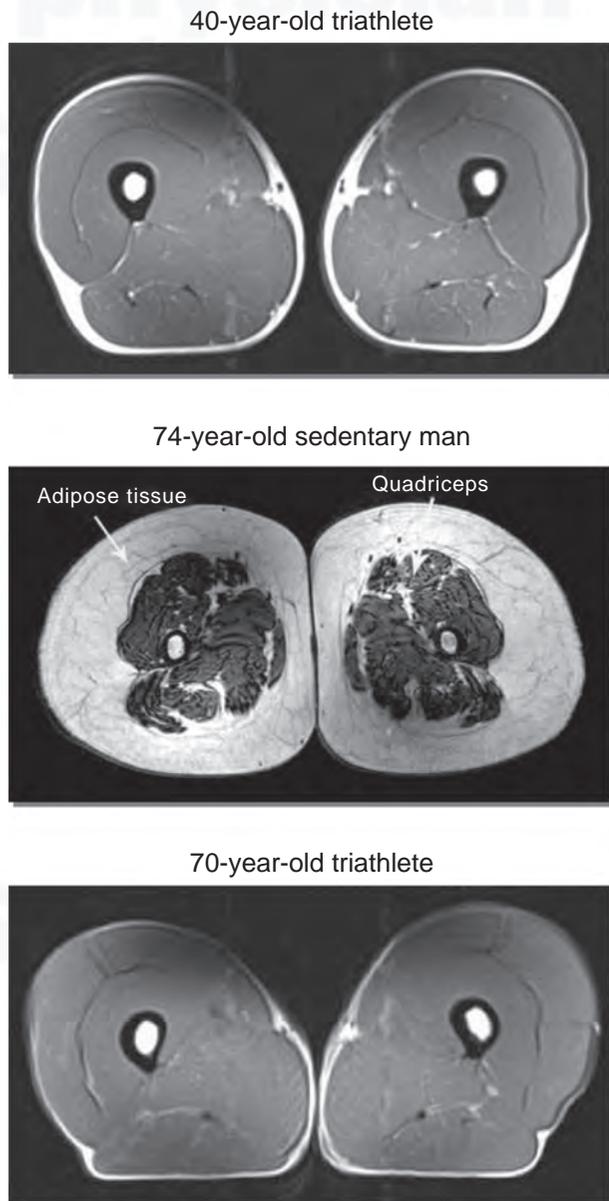
Forty masters athletes (20 men and 20 women) were included in this study. Subjects were included if they were aged ≥ 40 years, trained for fitness and sports competitions ≥ 4 to 5 times per week, and did not have current sports-related injuries that limited their ability to compete in sports competitions. Many were age-group winners for their sport. The subjects were primarily composed of runners/track and field participants, bikers, and swimmers. Five men and 5 women were recruited in each 10-year age category (40–49 years, 50–59 years, 60–69 years, and ≥ 70 years). The subjects were recruited from a population of individuals who previously sought treatment at the University of Pittsburgh Medical Center (UPMC) and participants in UPMC Performance and Research Initiative for Masters Athletes (PRIMA) programs. They were also recruited by flyers posted in local bike shops, at races, and at other competitive events in Pittsburgh, PA and the surrounding area. The University of Pittsburgh Institutional Review Board approved the protocol. All volunteers gave written consent.

Subject Testing

The masters athletes completed a survey capturing health history and details of their activity level and competition. Lower-extremity performance was measured bilaterally through a maximum voluntary isometric quadriceps torque test using an isokinetic dynamometer (Biodex System 3 Pro, Shirley, NY) with the force-sensing arm secured to the ankle and the knee positioned at 75° of flexion. Subjects were asked to exert as much force as possible while extending the knee against the force-sensing arm of the dynamometer. Each subject performed several warm-up repetitions at varying intensities followed by 3 maximum voluntary contractions. Lower-extremity performance was tested bilaterally.

Body composition, including the masters athletes' body volume and body density, were measured with the Bod Pod Body Composition System (Life Measurement Instruments, Concord, CA). This system uses air-displacement plethysmography to determine BF percentage, fat mass (FM), and lean mass (LM). While sitting in the device, subjects

Figure 1. Typical quadriceps MRI scan of a 40-year-old triathlete compared with the quadriceps MRI scans of a 70-year-old triathlete and a 74-year-old sedentary man. Note the significant visual difference between the SCAT and IMAT of the sedentary man versus masters athletes.



Abbreviations: IMAT, intramuscular adipose tissue; MRI, magnetic resonance imaging; SCAT, subcutaneous adipose tissue.

removed all jewelry and wore minimal clothing, such as a bathing suit or spandex shorts and a sports bra for females, as well as a swim cap. Initially, 2 measurements of body volume were recorded, followed by a third measurement conducted with a breathing tube to calculate lung volume. Body fat percentage was calculated using 3 different equations depending on the subject's sex and ethnicity: Siri was used for all Caucasians, Ortiz for African American women, and Shutte for African American men. Intrasubject reliability within the

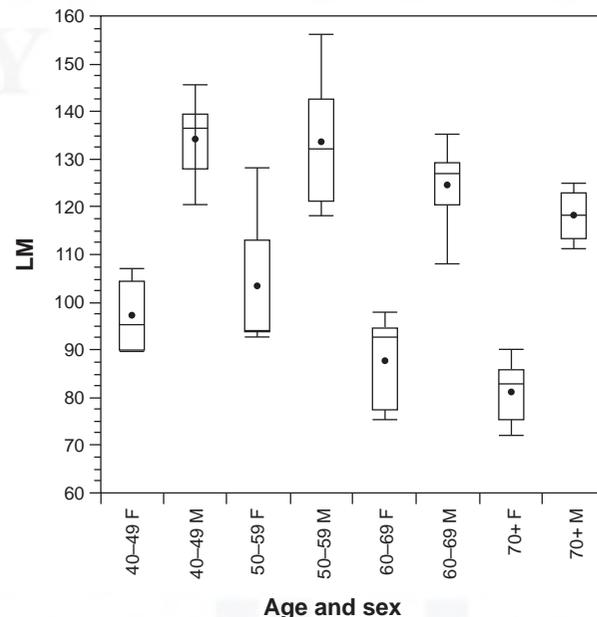
laboratory demonstrated an interclass correlation coefficient of 0.98 and standard error of measurement of 0.47 BF.

Bilateral magnetic resonance imaging (MRI) scans of both thighs were conducted. The MRI scans were performed on a 3.0 Tesla scanner (Siemens Trio, Berlin, Germany) using the whole body transmit/receive coil; T2 fat images were acquired at mid-thigh (acquisition parameters: 5 slices; TR = 1500 ms; TE = 5 ms; flip angle = 90°; FOV = 20°). Mid-thigh total muscle area (TMA), quadriceps area (QA), subcutaneous adipose tissue (SCAT), and intramuscular adipose tissue (IMAT) were determined from the MRI using medical imaging processing, analysis, and visualization (MIPAV) software (National Institutes of Health, Bethesda, MD). Examples of thigh MRI scans are presented in Figure 2.

Statistical Analysis

One-way analysis of variance (ANOVA) testing was performed to examine differences across age groups with both sexes combined. Due to the small sample size, analyses of differences across sex and individual age groups at the same time were not performed. Sex differences (all ages combined) were performed using independent t tests. On the ANOVA tests, if assumptions were not met, comparisons between groups were performed with the Welch adaptation of the ANOVA test. Post-hoc tests were performed with the Tukey-Kramer honestly significant adjustment. Pairwise correlations were performed with the Spearman rho correlation. The

Figure 2. Lean mass by age group and sex. When both sexes were pooled together, LM was not significant between age groups. Men had more overall LM than women. Group mean is represented by a dot and median as a line inside the box, which corresponds with 50% of the distribution.



Abbreviation: LM, lean mass.

Table 1. Subject Characteristics, Body Composition, and Physical Fitness

Age Group	40–49 Years		50–59 Years		60–69 Years		≥ 70 Years	
N	10		10		10		10	
Sex	5 F	5 M	5 F	5 M	5 F	5 M	5 F	5 M
Age, years	47.0 ± 2.8 ^a	44.8 ± 3.2	52.0 ± 2.5 ^b	56.8 ± 2.6	65.0 ± 3.0 ^c	65.4 ± 2.2	74.8 ± 3.7 ^d	76.3 ± 3.3
Weight, lb	123.4 ± 12.5	149.2 ± 12.7	126.8 ± 13.4	161.6 ± 22.1	121.3 ± 17.1	148.4 ± 17.1	123.7 ± 11.9	150.6 ± 17.7
BMI, kg/m ²	20.3 ± 1.5	20.34 ± 1.3	20.9 ± 1.7	22.9 ± 3.5	21.6 ± 2.7	21.6 ± 2.0	22.7 ± 0.8	23.2 ± 2.2
Body fat, %	21.0 ± 5.7 ^a	10.0 ± 2.9	18.6 ± 6.2 ^a	17.2 ± 3.7	28.1 ± 7.2	15.6 ± 5.0	34.2 ± 3.9 ^b	21.1 ± 5.8
Fat mass, lb	26.2 ± 3.9 ^a	15.0 ± 2.4	23.5 ± 3.7	28.3 ± 3.9	34.7 ± 5.9	24.0 ± 4.6	42.5 ± 3.4 ^b	32.4 ± 6.1
Muscle mass, lb	97.2 ± 7.9	134.1 ± 9.3	103.3 ± 15.2	133.3 ± 15.0	87.6 ± 10.1	124.4 ± 9.6	81.2 ± 7.1	118.2 ± 6.2

Data presented as mean ± standard deviation.

^{a,b,c,d}Significant age-group differences when all sexes are grouped together (one-way analysis of variance).

alpha level was set a priori to 0.05. Statistical analyses were performed using JMP 5.0.1.2 for Macintosh (Cupertino, CA).

Results

Subject Characteristics

As described in the Methods section, a total of 40 volunteers (20 women and 20 men) were enrolled in this cross-sectional analysis. The mean age was 60.1 ± 11.5 years (range, 40–81 years). Subject characteristics detailed by age group and sex are presented in Table 1.

Differences Between Age Groups (Sexes Combined)

Per design, age was significantly different between groups. Although age groups did not differ in body weight, body mass index (BMI) tended to be higher in the group aged ≥ 70 years compared with the group aged 40 to 49 years. Those aged ≥ 70 years had a higher BF percentage and FM (Table 1). The LM was not significantly different across the age groups ($P = 0.15$) (Figure 2). Mid-thigh total muscle area was not different between age groups ($P = 0.12$). Quadriceps area was approximately 20% lower in the group aged ≥ 70 years compared with the groups aged 40 to 49 years and 50 to 59 years ($P = 0.03$). The SCAT and IMAT were not significantly different among groups ($P = 0.41$ and $P = 0.31$, respectively) (Figure 3).

Peak torque (PT) from the dominant leg was significantly different between the groups ($P = 0.0002$). While the group aged 40 to 49 years was not statistically significant from all other groups, the group aged 50 to 59 years was higher than the group aged 60 to 60 years and ≥ 70 years. The 2 later groups were not different from one another (Figure 4). Specific PT, computed as the ratio of PT divided by the QA (PT/QA) followed the same pattern as the PT, and was significantly higher in the group aged 50 to 59 years compared with the groups aged 60 to 69 years

and ≥ 70 years ($P = 0.01$) (Figure 5). The ratio of PT divided by IMAT (PT/IMAT) was not significant between groups.

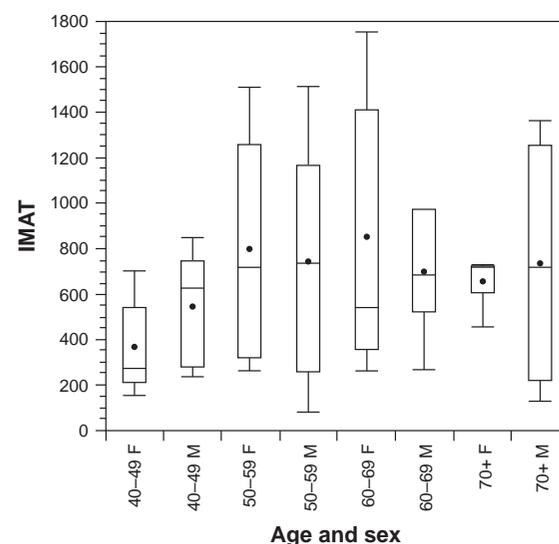
Sex Differences (Ages Combined)

Men were heavier than women ($P < 0.001$), but did not differ in BMI. Women had a higher BF percentage ($P < 0.001$) and tended to have more FM ($P = 0.05$) than men. Men had more LM than women ($P < 0.001$) (Figure 2). Men had greater TMA and QA than women (both $P < 0.001$). Women had more SCAT than men ($P < 0.001$). Neither IMAT nor PT differed between sexes (Figures 3, 4). The PT/QA was significantly higher in women ($P = 0.04$) (Figure 5), but PT/IMAT was not.

Correlations

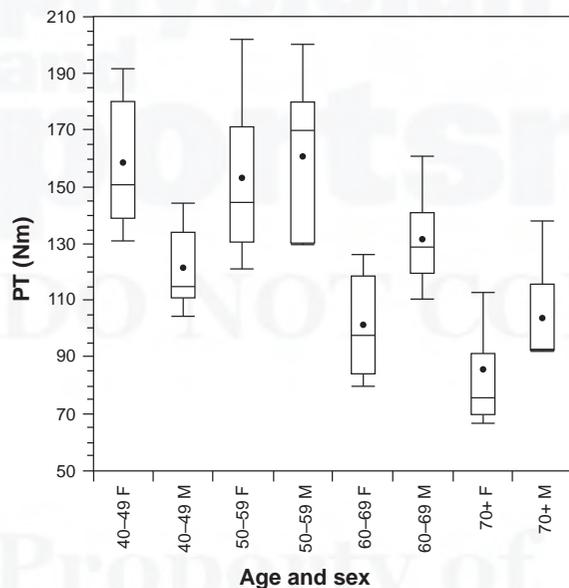
When all subjects were pooled together, age was significantly correlated with BMI, BF percentage, TMA, QA, PT,

Figure 3. Intramuscular adipose tissue by age group and sex. When both sexes were pooled together, IMAT was not significantly different between groups ($P = 0.31$). There were no differences between men and women. Group mean is represented by a dot and median as a line inside the box, which corresponds with 50% of the distribution.



Abbreviation: IMAT, intramuscular adipose tissue.

Figure 4. Peak torque by age group and sex. When both sexes were pooled together, PT changed significantly at 60 years; the 2 younger groups were different than the 2 older groups. Group mean is represented by a dot and median as a line inside the box, which corresponds with 50% of the distribution.



Abbreviation: PT, peak torque.

PT/IMAT, PT/QA, and tended to be correlated with LM and SCAT (Table 2). As TMA and QA increased, PT increased significantly. There was no significant relationship between IMAT or LM and PT.

Discussion

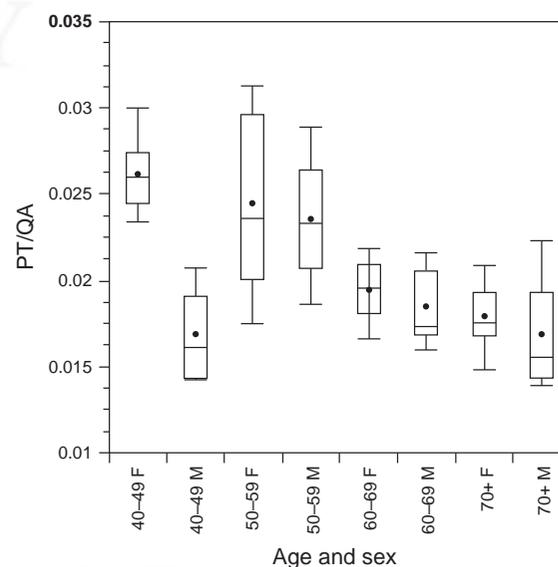
It is commonly believed that with aging comes an inevitable decline from vitality to frailty. This includes feeling weak and often the loss of independence. These declines may have more to do with lifestyle choices, including sedentary living and poor nutrition, than the absolute potential of musculo-skeletal aging. In this study, we sought to eliminate the confounding variables of sedentary living and muscle disuse, and answer the question of what really happens to our muscles as we age if we are chronically active. This study and those discussed here show that we are capable of preserving both muscle mass and strength with lifelong physical activity.

We found that chronic intense exercise preserved muscle mass and prevented fat infiltration of muscle in masters athletes. Although changes in body composition were observed, including increased total BF, there was no decline in absolute muscle mass and the fat infiltration of muscle itself, IMAT, was not increased. These findings are in contrast with studies conducted in well-functioning men and women aged 70 to 79 years who are not considered masters athletes. In a study by Delmonico et al,¹⁹ both aging men and women were reported

to have experienced an age-related increase in fatty infiltration of mid-thigh skeletal muscle. The preservation of muscle mass and lack of fatty infiltration in the muscles of our subjects are dramatically illustrated in Figure 1.

More important perhaps than mere retention of muscle mass and integrity was the retention of muscle strength in the masters athletes. We studied masters athletes aged 40 to 81 years and observed no difference in quadriceps PT until participants entered the 60- to 69-year-old age group. There was no significant difference in PT in the 60-, 70-, and 80-year-old age groups. Thus, although PT did decline beginning at around age 60 years, the decline did not significantly increase with further aging. This observation was also true with examination of specific strength per muscle area. Our data are consistent with those of McCrory et al,²⁰ who measured the thigh muscle strength in senior athletes aged > 60 years. When compared with healthy controls, they found that the athletes were significantly stronger than the sedentary controls and that their strength did not decline with age. The study by McCrory et al²⁰ reported no decline in strength in the oldest age group when compared with the 60- to 69-year-old age group. This is consistent with our findings that the significant change in PT did not occur until the beginning of the 60- to 69-year-old age group and that there was no further decline after 60 years. Differences in PT were not significant until age 60 when they dropped. After the initial change, people older than

Figure 5. Specific PT by age group and sex. Specific PT changed significantly at age > 60 years. There was no significant difference between athletes aged > 60 years. Group mean is represented by a dot and median as a line inside the box, which corresponds with 50% of the distribution.



Abbreviations: PT, peak torque; QA, quadriceps area.

Table 2. Pairwise Correlations

Variables	1	2	3	4	5	6	7	8	9	10	11
1. Age	–	–	–	–	–	–	–	–	–	–	–
2. BMI, kg/m ²	0.45 ^a	–	–	–	–	–	–	–	–	–	–
3. BF, %	0.54 ^a	0.57 ^a	–	–	–	–	–	–	–	–	–
4. LM, kg	–0.31 ^b	0.07	–0.65 ^a	–	–	–	–	–	–	–	–
5. TMA, mm ²	–0.32 ^a	0.2	–0.54 ^a	0.82 ^a	–	–	–	–	–	–	–
6. QA, mm ²	–0.42 ^a	0.05	–0.62 ^a	0.85 ^a	0.93 ^a	–	–	–	–	–	–
7. SCAT, mm ²	0.30 ^b	0.38 ^a	0.86 ^a	–0.69 ^a	–0.55 ^a	–0.58 ^a	–	–	–	–	–
8. IMAT, mm ²	0.26	0.34 ^a	0.30 ^b	0.1	0.09	0.003	0.25	–	–	–	–
9. PT, Nm	–0.60 ^a	–0.06	–0.38 ^a	0.43 ^a	0.47 ^a	0.46 ^a	–0.24	0.01	–	–	–
10. PT/IMAT	–0.45 ^a	–0.36 ^a	–0.45 ^a	0.11	0.11	0.19	–0.37 ^a	–0.91 ^a	0.36 ^a	–	–
11. PT/QA	–0.37 ^a	–0.07	0.01	–0.08	–0.1	–0.15	0.18	0.02	0.79 ^a	0.26	–

Correlations are Spearman rho, ^aP < 0.05, ^bP < 0.01.

Abbreviations: BF, body fat; IMAT, intermuscular adipose tissue; LM, lean mass; PT, peak torque; PT/IMAT, ratio of PT divided by IMAT; PT/QA, ratio of PT divided by QA; QA, quadriceps area; SCAT, subcutaneous adipose tissue; TMA, total muscle area.

60 did not decline significantly again. These findings are of significant importance, especially when considered in context with findings from the Health ABC study of participants aged 70 to 79 years, which showed that older adults with reduced muscle strength have higher mortality.²¹ The ability to retain muscle mass and strength in the upper decades of life via the simple modality of chronic exercise bodes well for our ability to intervene and prevent the functional declines experienced with sedentary aging.

Chronic exercise is prophylactic against age-related functional decline, as exercise at any age stimulates protein synthesis and increased muscle mass and strength.^{22,23} Multiple human interventional studies have shown the remarkable adaptive capability of aging muscle. Trappe et al²⁴ observed a > 50% increase in the knee extension strength of aging men with 6 months of resistance training. Our study and those of McCrory et al,²⁰ Louis et al,²¹ and Faulkner et al²² document the positive effect of lifelong exercise on aging muscle. Aging muscle is thus capable of not only getting stronger with short-term interventions initiated in the upper decades, but is able to maintain its strength and integrity across the lifespan with chronic exercise.

Interestingly, the effects of maintenance of muscle strength and function observed with chronic exercise are shown in the athletic performance literature. Wright and Perricelli²⁵ found no significant decline in the running performance times of top senior athletes (at all race lengths, 100–10 000 m) until age 75 years. Tanaka and Seals²⁶ made this observation in swimmers. These findings are supported by several other studies of senior athletes and suggest that lifestyle factors, such as muscle disuse and disease, incur a significant influence on functional capacity. If these factors are minimized or eliminated by active aging, seniors should

be able to remain functionally independent until the upper decades of life.

Maintaining lean muscle mass and strength as we age is more about health than athletic competition. As previously noted, the health care and social costs of loss of lean muscle mass, weakness, and senior disability are staggering. According to Janssen et al,^{27,28} \$18.5 billion in health care costs were directly attributable to sarcopenia in 2000. This accounted for approximately 1.5% of all health care expenditures for the year.^{27,28} Broken down into individual dollar costs, this represented \$800 to \$900 per sarcopenic person. With the aging of the American population, these individual and societal costs will only increase. Harnessing the benefits of acute resistance training intervention or chronic exercise to maintain and build muscle mass and strength, thus preventing loss of independent function and disability, is not only logical but becomes a social imperative. A mere reduction of 10% in sarcopenia prevalence would result in savings of \$1.1 billion (dollars adjusted to 2000 rate) per year in US health care costs.

Study Limitations

By taking a cross-section of some of the most highly active aging adults, this study removed muscle disuse as a confounding variable in evaluating the lower-extremity function and loss of lean muscle mass in aging adults. A longitudinal study that followed chronic exercisers over a lifetime of physical activity and tracked their IMAT and strength would present stronger evidence as to the role of chronic exercise in the maintenance of muscle function. In addition, studying masters athletes partially limits the applicability of these data to the general population of aging adults who do not aggressively exercise 4 to 5 times

per week. Our results, however, can be used as evidence to recommend chronic exercise as a means to improve the lower-extremity functioning of aging adults in order to promote the maintenance of functional mobility. Another limitation to this study was that participants engaged in chronic exercise over a long period before reaching the age of 40 years. Therefore, it is challenging to speculate as to whether the benefits from chronic exercise observed in masters athletes is possible for lifelong sedentary adults who begin exercising after age 40 years. Some researchers have found that older adults can achieve better muscle strength and functional performance from exercise training regardless of their age and baseline functioning.²⁹ Finally, it is possible that a larger-scale study of masters athletes, stratified by the type of sports-related exercise training conducted, may have provided other important statistically significant findings.

Conclusion

The loss of lean muscle mass and the resulting subjective and objective weakness experienced with sedentary aging imposes significant but modifiable personal, societal, and economic burdens. As sports medicine clinicians, we must encourage people to become or remain active at all ages. This study, and those reviewed here, document the possibility to maintain muscle mass and strength across the ages via simple lifestyle changes.

Conflict of Interest Statement

Andrew P. Wroblewski, MBS, BS, Francesca Amati, MD, PhD, Mark A. Smiley, MBA, BS, Bret Goodpaster, PhD, and Vonda Wright, MD, MS, disclose no conflicts of interest.

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