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Resistance Training Frequency Confers Greater Muscle Quality in Aged Individuals: A Brief NHANES Report

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Abstract

Aims Sarcopenia, the age-related decline in skeletal muscle mass, results in a loss of strength and functional capacity, which subsequently increases the risk of disease, disability frailty, and all-cause mortality. Skeletal muscle quality (MQ), i.e., strength per unit muscle mass, is the ability of muscle to perform its functions, and evidence indicates it is a more influential variable underlying age-related declines in muscle function than losses in muscle mass. Resistance training (RT) is known for enhancing skeletal MQ, improving health span, and reducing mortality. However, to the best of our knowledge, no studies have examined the relationship between RT frequency and MQ in an aged population. Thus, this study was designed to test the hypothesis that greater MQ in older individuals is associated with RT frequency.

Methods and Results Utilizing data from 2,391 older adults in the National Health and Nutrition Survey (NHANES; 1999-2002), a secondary analysis of data was performed to see if an association existed between RT frequency and MQ in persons aged 55 years and older. Data were analyzed using analysis of covariance (ANCOVA) with three different models. Individuals were stratified into two groups based on how many days per week they performed RT: Insufficient (i.e., < two days per week) or sufficient (≥ two days per week). Muscle quality was calculated by taking the average peak force (Newtons) obtained from an isokinetic dynamometer and dividing it by lean mass, excluding bone mineral content (grams), obtained from dual-energy X-ray absorptiometry. The alpha level was set at <0.05.For persons aged 55 and over, a statistically significant association was found between sufficient RT and greater MQ in both unadjusted as well as adjusted models that accounted for various demographic, behavioral, and clinical characteristics (p<0.05 for all). However, when limited to those 65 and older, no statistically significant associations were observed between sufficient RT and greater MQ (p>0.05 for all). When partitioned according to those 55 to 64 years of age and those 55 to 79 years, a statistically significant association was again observed (p<0.05 for all). No statistically significant associations were observed for individuals 65-79 years of age or those 80 years of age and older (p>0.05 for all).

Conclusions Sufficient amounts of RT are associated with greater MQ in selected older individuals. A need exists for future randomized controlled trials that examine the dose-response relationship between resistance training and MQ in older adults.

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Introduction

Sarcopenia, defined as the age-related loss of skeletal muscle mass and muscle performance [1], is a major health problem associated with a number of adverse outcomes. These include, but are not limited to, disability, frailty, poor quality of life and premature all-cause mortality [2-4]. This issue is especially important given the aging of our population worldwide. For example, by 2050, it is estimated that at least 25% of the population will be over the age of 65, with prevalence rates as high as 40% in certain regions [5]. In the United States, an estimated 20% of the labor force is over the age of 55 but by 2020, that percentage is projected to increase to 25% [6]. Not surprisingly, sarcopenia is associated with significant healthcare and socio-economic costs [7]. Given the former, it is critical to examine interventions aimed at preventing and/or attenuating the negative effects of sarcopenia.

Aging is associated with the progressive decline of physiological and biomechanical functions that potentially leads to a loss of functional capacity. With advanced age, there are reductions in physical activity, specifically load-dependent movements that contribute to declines in motor function, metabolic quality of skeletal muscle, and a loss of muscle mass [8]. In particular, muscle quality (MQ), defined as muscle strength or power per unit muscle mass, has been demonstrated by our lab as well as others to be a particularly sensitive indicator of age-related negative outcomes, and perhaps more functionally important than the actual amount of muscle mass for describing alterations in muscle performance as a consequence of sarcopenia [2, 9]. In fact, several recent studies support the notion that a linear relationship exists between MQ status and overall mortality [1, 10, 11].

Regular physical activity, including resistance training, has provided the most convincing evidence to date regarding the preservation of function with aging [12]. Several studies have demonstrated the benefits of regularly-structured physical exercise as an effective, therapeutic approach to mitigate sarcopenic outcomes with aging [13-16]. Evidence suggests that high-intensity resistance training (RT) is the most potent intervention for attenuating the deleterious effects of sarcopenia, thus making it a potentially effective form of “physiotherapy” specifically directed at mitigating age-related decrements in muscle function [17]. Along those lines, multiple studies have indicated that RT is associated with decreased overall mortality [3, 4, 11, 18].

Despite the increasing evidence highlighting RT for improving MQ as well as functional and health-related outcomes, to the best of our knowledge, no studies have examined the relationship between sufficient levels of RT and MQ in a nationally representative cohort of aged individuals over an extended period of time. Therefore, the purpose of this study was to examine the association between RT and MQ in aged individuals. We hypothesized that those persons who engaged in sufficient levels of RT activities, defined as two or more times per week based upon previous evidence in older individuals [13, 19-21], would be associated with greater MQ.

Methods

Study Population and Design

This study was conducted using data from the National Health and Nutrition Examination Survey (NHANES), an ongoing program of studies conducted by the Centers for Disease Control and Prevention’s (CDC) National Center for Health Statistics. The purpose of NHANES is to measure the lifestyle, health, and nutrition behavior of a nationally representative sample of U.S. citizens [22]. Specific to this project, NHANES data for calculating MQ, i.e., muscle performance and muscle mass data, were available for a four-year period and two data collection cycles spanning the years 1999-2002. For this study, only individuals that were 55 years of age and older were included in the data that was available for the 1999-2000 and 2001-2002 cycles.

Of 21,004 individuals that had data reported from the two NHANES cycles, a total of 3,737 were above the age of 55. After excluding those persons who did not have complete data and/or did not participate in one or both of the muscle RT and muscle mass measurements (n=1,346), a final sample of 2,391 (1,220 males and 1,171 females) was used for the present study. Written consent was previously obtained from each NHANES participant and approved by the National Center for Health Statistics Research Ethics Review Board under protocol #98-12.

Measurement Methods

The exposure variable (independent variable) was identified in NHANES as physical activity in which subjects were asked about their participation in RT-based activities performed in the past 30 days that was specifically designed to strengthen muscles (e.g., lifting weights, push-ups, sit-ups, etc.), and how frequently they did these activities. No advice was given by the NHANES staff on how to appropriately define RT performance; participants simply reported whether they engaged in any muscle RT activities and how many days per week they participated in RT. For the current study, frequency of training per week was dichotomized as either insufficient (less than two days per week) or sufficient (two or more days per week).

Based on the available data in NHANES, MQ was calculated from muscle strength, measured by the average peak force in Newtons using a knee dynamometer, as well as leg muscle mass, (i.e., leg lean mass using dual-energy X-ray absorptiometry (DXA) (model QDR-4500A, Hologic, Inc., Bedford, MA, USA). Covariates included gender, age, race/ethnicity, educational attainment, annual household income, pregnancy (yes/no), number of alcoholic drinks, smoking status, blood pressure, glucose readings, cardiovascular disease status, and % leg fat.

Body composition (lean body mass, fat mass, total mass) was measured using DXA following the manufacturer’s acquisition procedures. Dual-energy X-ray absorptiometry scans were administered to eligible survey participants in the NHANES mobile examination centers. The scan for each survey participant was reviewed and analyzed by the University of California, San Francisco, Department of Radiology, using standard radiologic techniques and study-specific protocols developed for

NHANES. Soft tissue measures included leg fat mass (grams), lean mass including bone mineral content (grams), leg lean mass excluding bone mineral content (grams), and percent (%) body fat obtained for the legs. An isokinetic Kin Com MP dynamometer (Chattanooga Group, Inc., Chattanooga, TN, USA) was used to evaluate the strength of the knee extensors and flexors. Average peak force (Newtons) of the quadriceps and hamstrings was assessed at 60 degrees per second. Muscle quality was calculated by taking the measured average peak force in Newtons and dividing it by leg lean mass in grams, excluding bone mineral content.

Statistical Analysis

SAS SUDAAN 11.0.1 statistical software (Research Triangle Institute, Research Triangle Park, NC, USA) was used for all data analysis. Appropriate sample weights were used in calculating statistically reliable estimates in all analyses given that NHANES data were obtained using a complex, multistage sampling design that involves stratification, clustering, and oversampling of specific population subgroups. Standard errors were estimated using Taylor series linearization. Associations for various cohort characteristics with sufficient RT and MQ were assessed using chi-squared tests for categorical variables and analysis of variance (ANOVA) as well as ordinary least squares (OLS) regression for continuous variables. The association between sufficient RT and MQ was calculated by an analysis of covariance (ANCOVA). Four different models were produced: 1) unadjusted estimates; 2) adjustments for age, gender, and race/ethnicity; and 3) adjustment for model 2 covariates (age, gender, and race/ethnicity) as well as alcohol use, smoking status, and cardiovascular disease. 4) adjustment for models 2 and 3 covariates as well as % leg fat. Sensitivity analysis for older ages were conducted based on previously used classification for age, with 65+ defined as elderly [23]. All reported p-values were two-sided, and alpha was set to 0.05.

Results

A total of 2,391 participants were included in the analyses (1,220 males, 1,171 females). Table 1 shows the association between selected study participant characteristics with muscle strength and MQ. Statistically significant associations were found between muscle strength and education level, annual household income, alcohol intake, and smoking status, and % leg fat. Statistically significant associations were also found between MQ and age, race/ethnicity, education level, annual household income, alcohol intake, cardiovascular disease risk, and % leg fat.

When the analysis was performed using the entire study population, i.e., those individuals 55 years of age or older, there was a statistically significant association between sufficient RT of two or more sessions per week and increased MQ in models 1-3, with a trend for a statistically significant association in model 4 (p=0.053) (Table 2). When results were categorized according to participants 55 to 64 years of age a statistically significant association between sufficient RT and increased MQ for models 1 and 2as well as a trend for statistical significance (p=0.06) in model 3 was observed However, no statistically significant association was observed for model 4. For those 55 to 79 years of age, a statistically significant association was observed for models 1-3 but not model 4 Results for those 65 years of age and older are shown in Table 4. As can be seen, no statistically significant associations were observed between RT and increased MQ for any of the models (p>0.05 for all). Similar findings were observed when the analysis was limited to those 65 to 79 years of age as well as those ≥ 80 years of age (Table 5)

Table 1 Association between participant characteristics, muscle strength and muscle quality in those ≥ 55 years of age.

	Sampled (n=2,391)	Muscle Strength			Muscle Quality	
		Insufficient Percent[a]	Sufficient Percent[a]	P-value[b]	Mean[a] (95%CI)	P-value[c]
Age (years)						
55-64	932	45.6	52.7	0.1952	19.60 (19.09-20.10)	**<0.0001***
65-74	858	33.7	29.7		18.12 (17.61-18.64)	
75+	601	20.7	17.6		16.02 (15.36-16.69)	
Gender						
Male	1,220	46.2	51.4	0.1697	18.25 (17.73-18.77)	0.3934
Female	1,171	53.8	48.6		18.50 (17.95-19.06)	
Race/ethnicity						
White	1,397	81.8	85.7	0.1714	18.49 (17.98-18.99)	**0.0002***
Black	393	7.7	6.5		16.80 (16.23-17.38)	
Hispanic/others	601	10.5	7.8		18.70 (17.77-19.63)	
Education						
<12th years	906	27.6	17.3		17.81 (17.23-18.38)	
High S Grad.	543	27.6	15.0	**<0.0001***	18.43 (17.65-19.21)	**0.0084***
Some college	507	23.8	29.1		18.44 (17.95-18.93)	
College+	432	21.0	38.6		18.93 (18.17-19.69)	
Income (thousands)						
0-25	801	33.7	18.2		17.22 (16.55-17.89)	
25-45	525	25.8	22.1	**0.0011***	18.24 (17.52-18.95)	**0.0001***
45-75	387	21.9	25.3		18.91 (18.17-19.65)	
75+	326	18.7	34.3		19.23 (18.54-19.93)	
Alcoholic intake						
No drink	610	29.9	16.9	**0.0038***	17.70 (17.11-18.28)	**0.0032***
1 drink/day	706	36.7	49.0		18.61 (18.25-18.98)	
2 drinks/day	644	33.4	34.1		18.83 (18.17-19.48)	
Smoking status						
Current	321	15.3	5.5	**0.0002***	18.99 (18.30-19.69)	0.0560
Former	961	39.2	46.7		18.40 (17.77-19.03)	
Never	1,104	45.6	47.8		18.20 (17.63-18.78)	
Blood pressure						
No controlled	1,901	79.2	75.7	0.3694	18.33 (17.85-18.81)	0.3422
Controlled	457	20.8	24.3		18.76 (17.90-19.61)	
Glucose						
No controlled	191	12.7	11.5	0.7252	17.58 (16.34-18.82)	0.1708
Controlled	997	87.3	88.5		18.36 (17.90-18.82)	
CVD						
Yes	235	9.5	7.4	0.2404	17.24 (16.51-17.97)	**0.0017***
No	2,156	90.5	92.6		18.50 (18.04-18.97)	
Leg fat %						
<30%	798	29.5	38.6		18.78 (18.17-19.40)	
30-<40%	659	26.6	26.1	**0.0367***	17.95 (17.36-18.55)	**0.0460***
≥40%	935	43.9	35.4		18.37 (17.80-18.93)	

Notes: [a], percent means weighted; [b], derived from chi-square tests; [c], derived from ANOVA or regression; CI, confidence intervals; CVD, cardiovascular disease; *, statistically significant (P <0.05).

Table 2 Association between frequency of resistance training and muscle quality in those ≥55 years of age (n=2,391).

	Insufficient[a] (n=2,075)	Sufficient[b] (n=316)	P-value[c]
Muscle Quality	Mean (95% CI)	Mean (95% CI)	
Model 1[d]	18.22 (17.75-18.68)	19.43 (18.68-20.18)	**0.0032***
Model 2[e]	18.25 (17.82-18.67)	19.25 (18.60-19.90)	**0.0050***
Model 3[f]	18.31 (17.92-18.70)	19.16 (18.45-19.86)	**0.0175***
Model 4[g]	18.34 (17.97-18.71)	18.99 (18.30-19.68)	**0.0533****

Notes: [a,] Insufficient, <2 times per week, [b,] Sufficient, ≥ 2 times per week; [c,] P-value derived from ANCOVA; [d,] unadjusted; [e,] adjusted for age, gender, race/ethnicity; [f,] adjusted for age, gender, race/ethnicity, alcohol, smoking status, and cardiovascular disease; [g,] adjusted for age, gender, race/ethnicity, alcohol, smoking status, cardiovascular disease, and % leg fat; CI, confidence intervals; [*,] statistically significant (P < 0.05); **, trend for statistical significance (P <0.10).

Table 3 Association between frequency of resistance training and muscle quality partitioned by age 55.

	55-64 years			55-79 years		
	Insufficient[a] (n=801)	Sufficient[b] (n=131)	P-value[c]	Insufficient[a] (n=1,768)	Sufficient[b] (n=268)	P-value[a]
Muscle Quality	Mean (95% CI)	Mean (95% CI)		Mean (95% CI)	Mean (95% CI)	
Model 1[d]	19.39 (18.88-19.89)	20.74 (19.70-21.77)	**0.0128***	18.48 (18.03-19.01)	19.76 (19.01-20.51)	**0.0014***
Model 2[e]	19.41 (18.93-19.89)	20.62 (19.64-21.60)	**0.0198***	18.51 (18.10-18.93)	19.57 (18.88-20.25)	**0.0043***
Model 3[f]	19.47 (18.99-19.96)	20.58 (19.50-21.67)	0.0593**	18.59 (18.19-18.99)	19.41 (18.64-20.17)	**0.0329***
Model 4[g]	19.54 (19.09-20.00)	20.23 (19.26-21.20)	0.1724	18.62 (18.24-19.00)	19.21 (18.45-19.97)	**0.1143**

Notes: [a,] Insufficient, <2 times per week, [b,] Sufficient, ≥ 2 times per week; [c,] P-value derived from ANCOVA; [d,] unadjusted; [e,] adjusted for age, gender, race/ethnicity; [f,] adjusted for age, gender, race/ethnicity, alcohol, smoking status, and cardiovascular disease; [g,] adjusted for age, gender, race/ethnicity, alcohol, smoking status, cardiovascular disease, and % leg fat; CI, confidence intervals; [*,] statistically significant (P-value < 0.05); CI, confidence intervals; [*,] statistically significant (P-value < 0.05); **, trend for statistical significance (P <0.10).

Table 4 Association between frequency of resistance training and muscle quality in participants ≥65 of age, (n=1,459).

	Insufficient[a] (n=1,274)	Sufficient[b] (n=185)	P-value[c]
Muscle Quality	Mean (95% CI)	Mean (95% CI)	
Model 1[d]	17.24 (16.69-17.79)	17.97 (17.03-18.91)	0.1723
Model 2[e]	17.23 (16.71-17.76)	17.99 (17.14-18.85)	0.1257
Model 3[f]	17.21 (16.69-17.72)	17.78 (16.94-18.62)	0.2039
Model 4[g]	17.22 (16.71-17.72)	17.73 (16.87-18.60)	0.2635

Notes: [a,] Insufficient, <2 times per week, [b,] Sufficient, ≥ 2 times per week; [c,] P-value derived from ANCOVA; [d,] unadjusted; [e,] adjusted for age, gender, race/ethnicity; [f,] adjusted for age, gender, race/ethnicity, alcohol, smoking status, and cardiovascular disease; [g,] adjusted for age, gender, race/ethnicity, alcohol, smoking status, cardiovascular disease, and % leg fat; CI, confidence intervals.

Table 5. Association between frequency of resistance training and muscle quality categorized by age.

	65 to 79 years			≥ 80 years		
	Insufficient[a] (n=967)	Sufficient[b] (n=137)	P-value[a]	Insufficient[a] (n=307)	Sufficient[b] (n=48)	P-value[c]
Muscle Quality	Mean (95% CI)	Mean (95% CI)		Mean (95% CI)	Mean (95% CI)	
Model 1[d]	17.56 (17.02-18.11)	18.39 (17.42-19.37)	0.1256	15.74 (14.84-16.63)	16.29 (15.20-17.38)	0.3909
Model 2[e]	17.56 (17.05-18.08)	18.39 (17.47-19.32)	0.1118	15.80 (14.98-16.61)	15.93 (14.79-17.06)	0.8377
Model 3[f]	17.57 (17.04-18.10)	18.04 (17.03-19.05)	0.3626	15.50 (14.75-16.25)	16.17 (14.94-17.39)	0.3709
Model 4[g]	17.58 (17.06-18.10)	17.97 (16.92-19.02)	0.4634	15.49 (14.72-16.25)	16.27 (15.06-17.48)	0.2906

Notes: [a] Insufficient, <2 times per week, [b] Sufficient, $\geq$ 2 times per week; [c] P-value derived from ANCOVA; [d] unadjusted; [e] adjusted for age, gender, race/ethnicity; [f] adjusted for age, gender, race/ethnicity, alcohol, smoking status, and cardiovascular disease; [g] adjusted for age, gender, race/ethnicity, alcohol, smoking status, cardiovascular disease, and % leg fat; CI, confidence intervals.

Discussion

To the best of our knowledge, this is the first secondary analysis of NHANES data that has attempted to characterize the association between sufficient levels of RT and greater MQ in older adults. The results of our study suggest that frequency of RT and increased MQ is associated with select age groups. For example, statistically significant associations and statistical trends were found between sufficient frequency of RT and MQ in those 55 years of age and older as well as when stratified according to those 55 to 64 and 55 to 79 years of age. However, when limited to those 65 years of age and older as well as stratification according to 65 to 79 and ≥ 80 years of age, no statistically significant associations were observed between RT and MQ. Given the results and acknowledging the limitation that these activities were unsupervised/without instruction, this suggests that as one gets older, specific, appropriate exercise prescription may be a critical component forenabling skeletal muscle to undergo adaptation and achieve the beneficial effects of RT.

While muscle mass has historically been the primary focus of RT and other therapeutic options for improving muscle function in aging individuals, recent efforts support the notion that MQ is a more precise indicator of age-related negative health outcomes and perhaps more functionally relevant than the overall amount of muscle mass present for describing alterations in muscle performance as a consequence of sarcopenia [2, 9]. In fact, muscle strength seems to decline at a faster rate than muscle mass, suggesting that decreases in MQ is the result of reduced functional capacity [24]. Sarcopenia has many negative consequences, including, but not limited to, declines in mobility, increased risk of disability, increased susceptibility to musculoskeletal disorders, a higher prevalence of frailty, and premature all-cause mortality [3, 4, 24, 25]. Recent research suggests that various measures of MQ are predictors of longevity and/or mortality in older adults [10, 11]. Resistance training appears to be the primary therapeutic measure for improving MQ and overall muscle function, and subsequently counteracting and/or attenuating the negative consequences of sarcopenia [2, 10, 11]. The results of the present study suggest that such an association exists in selected adult humans 55 years of age and older.

The lack of a statistically significant association in those 65 years of age and older may be the result of one or more of the following factors. First, the variable of sufficient versus insufficient RT activities was based on a self-reported questionnaire administered by NHANES staff without any oversight or supervision as to any of the parameters of their exercise program. In a recent meta-analysis conducted by Lacroix et al. [26], they reported that supervised resistance training induced larger effects on muscle strength and power compared to unsupervised resistance training. In addition, our laboratory has previously shown in rodents that while younger skeletal muscle displays a robust ability to adapt to multiple RT paradigms, aged muscle exhibits an inability to adapt properly to a non-specific, generalized exercise program; yet, by titrating the parameters of the exercise prescription (e.g., frequency, intensity) for aged muscle, there is an observed restoration of lipid peroxidation levels and MQ to a younger phenotype [13, 14]. Furthermore, recent findings from our laboratory also suggest that altering the exercise prescription in aged muscle has an effect on muscle performance, mass and overall quality, findings which were supported by concomitant alterations in growth and remodeling signaling pathways in skeletal muscle that are underlying these performance-related changes of muscle (unpublished results). Therefore, the results of the present study in combination with previous data suggest that as individual's age, they become more susceptible to untoward effects of the specific exercise stimulus presented to them, and thus, appropriately modified exercise prescription may be a critical component underlying improvements in MQ. When prescribed in the proper manner, RT appears to be capable of promoting muscle adaptation (i.e., improvements in muscle mass and performance) in older individuals. However, inappropriately applied RT programs may result in a lack of significant muscle maladaptation.

While the results of the present study are important, there were some potential limitations that should be considered when interpreting the results. First, because the data was self-reported via answers to a questionnaire, there is an inherent self-report bias that is inherent with this type of analysis (e.g., social desirability, etc.) that may have led to some inaccurate answers. In addition, based on the nature of this study and results, we were unable to control any parameters of the exercise prescription, including intensity and the types of exercise performed. However, the fact that the results of the present study showed an association between enhanced MQ with a sufficient frequency of training suggests that these associations may be even stronger if the exercise prescription was supervised given the recent findings that supervised exercise leads to larger effects in measures of muscle strength and power in older adults [26].

In conclusion, our findings in an NHANES population-based cohort of adult humans 55 years of age and older suggests that frequency of RT is associated with greater MQ in selected age groups. Given that exercise, particularly RT, is the most accessible, efficacious intervention to maximize skeletal muscle size and strength in the treatment of sarcopenia, a need exists for additional, well-designed, randomized controlled trials in older adults focusing on characterizing those parameters (e.g., mode, frequency, intensity, etc.) that augment adaptive responses in skeletal muscle before any degree of certainty can be reached regarding RT and MQ in older adults.

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Conflict of interest

None declared.

Publications Disclaimers:

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention

References

1. Brown JC, Harhay MO, Harhay MN. Sarcopenia and mortality among a population-based sample of community-dwelling older adults. J Cachexia Sarcopenia Muscle. 2016;7:290-8.
2. Fragala MS, Kenny AM, Kuchel GA. Muscle quality in aging: a multi-dimensional approach to muscle functioning with applications for treatment. Sports Med. 2015;45:641-58.
3. Beaudart C, Zaaria M, Pasleau F, Reginster JY, Bruyere O. Health outcomes of sarcopenia: A systematic review and meta-analysis. PLoS One. 2017;12:e0169548.
4. Kelley GA, Kelley KS. Is sarcopenia associated with an increased risk of all-cause mortality and functional disability? Exp Gerontol. 2017;96:100-3.
5. Seals DR, Justice JN, LaRocca TJ. Physiological geroscience: targeting function to increase healthspan and achieve optimal longevity. J Physiol. 2016;594:2001-24.
6. Baker BA. An old problem: Aging and skeletal muscle strain injury. J Sport Rehabil. 2017;26):180-8.
7. Harper S. Economic and social implications of aging societies. Science. 2014;346:587-91.
8. Welle S. Cellular and molecular basis of age-related sarcopenia. Can J Appl Physiol. 2002;27:19-41.
9. McGregor RA, Cameron-Smith D, Poppitt SD. It is not just muscle mass: a review of muscle quality, composition and metabolism during ageing as determinants of muscle function and mobility in later life. Longev Healthspan. 2014;3:9.
10. Brown JC, Harhay MO, Harhay MN. The muscle quality index and mortality among males and females. Ann Epidemiol. 2016;26:648-53.
11. Srikanthan P, Karlamangla AS. Muscle mass index as a predictor of longevity in older adults. Am J Med. 2014;127:547-53.
12. Seals DR, Melov S. Translational geroscience: emphasizing function to achieve optimal longevity. Aging (Albany NY). 2014;6:718-30.
13. Rader EP, Naimo MA, Layner KN, Triscuit AM, Chetlin RD, Ensey J, Baker BA. Enhancement of skeletal muscle in aged rats following high-intensity stretch-shortening contraction training. Rejuvenation Res. 2017;20:93-102.
14. Cutlip RG, Baker BA, Geronilla KB, Mercer RR, Kashon ML, Miller GR, Murlasits Z, Alway SE. Chronic exposure to stretch-shortening contractions results in skeletal muscle adaptation in young rats and maladaptation in old rats. Appl Physiol Nutr Metab. 2006;31:573-87.
15. Yarasheski KE. Managing sarcopenia with progressive resistance exercise training. J Nutr Health Aging. 2002;6:349-56.
16. Tucker LA. Physical activity and telomere length in U.S. men and women: An NHANES investigation. Prev Med. 2017;100:145-51.
17. Cholewa J, Guimaraes-Ferreira L, da Silva Teixeira T, Naimo MA, Zhi X, de Sa RB. Lodetti A, Cardozo MQ, Zanchi NE. Basic models modeling resistance training: an update for basic scientists interested in study skeletal muscle hypertrophy. J Cell Physiol. 2014;229:1148-56.
18. Kraschnewski JL, Sciamanna CN, Poger JM, Rovniak LS, Lehman EB, Cooper AB, Ballentine NH, Ciccolo JT. Is strength training associated with mortality benefits? A 15-year cohort study of US older adults. Prev Med. 2016;87:121-7.
19. Borde R, Hortobagyi T, Granacher U. Dose-response relationships of resistance training in healthy old adults: A systematic review and meta-analysis. Sports Med. 2015;45:1693-720.
20. Stec MJ, Thalacker-Mercer A, Mayhew DL, Kelly NA, Tuggle SC, Merritt EK, Brown CJ, Windham ST, Dell'Italia LJ, Bickel SC, Roberts BM, Vaughn KM, Isakova-Donahue I, Many GM, Bamman MM. Randomized, four-arm, dose-response clinical trial to optimize resistance exercise training for older adults with age-related muscle atrophy. Exp Gerontol. 2017;99:98-109.

21. Fisher JP, Steele J, Gentil P, Giessing J, Westcott WL. A minimal dose approach to resistance training for the older adult; the prophylactic for aging. Exp Gerontol. 2017;99:80-6.
22. https://www.cdc.gov/nchs/nhanes/about_nhanes.htm. About the National Health and Examination Survey. 2017.
23. Sabharwal S, Wilson H, Reilly P, Gupte CM. Heterogeneity of the definition of elderly age in current orthopaedic research. Springerplus. 2015;4:516.
24. Barbat-Artigas S, Rolland Y, Zamboni M, Aubertin-Leheudre M. How to assess functional status: a new muscle quality index. J Nutr Health Aging. 2012;16:67-77.
25. Keevil VL, Romero-Ortuno R. Ageing well: a review of sarcopenia and frailty. Proc Nutr Soc. 2015;74:337-47.
26. Lacroix A, Hortobagyi T, Beurskens R, Granacher U. Effects of supervised vs. unsupervised training programs on balance and muscle strength in older adults: A systematic review and meta-analysis. Sports Med. 2017;47:2341-61.
27. von Haehling S, Ebner N, Morley JE, Coats AJS, Anker SD. Ethical guidelines for authorship and publishing in the Journal of Cachexia, Sarcopenia and Muscle - Clinical Reports. J Cachexia Sarcopenia Muscle Clinical Reports 2016; 1;e28:1-2.