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ORIGINAL ARTICLE

Muscle Power Versus Strength as a Predictor of Mortality in Middle-Aged and Older Men and Women

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Abstract

Objective: To assess whether muscle power (force times velocity) outperforms strength as a risk indicator and predictor of mortality.

Participants and Methods: Anthropometric, clinical and vital status, muscle power, and strength data were assessed in 3889 individuals aged 46 to 75 years (2636 [67.8%] men) who were participants in the CLINIMEX Exercise prospective cohort between February 13, 2001, and October 31, 2022. Study participants were stratified by sex and categorized into 4 groups according to the distribution of the results of relative muscle power and strength (adjusted for body weight) measured, respectively, by handgrip and upper row movement tests.

Results: Death rates were 14.2% (373 of 2636) and 8.9% (111 of 1253) for men and women, respectively, during a median (IQR) follow-up of 10.8 years (6.7 to 15.5 years). In multivariable Cox proportional hazards regression analyses, the hazard ratios (95% CIs) for mortality comparing the lowest vs highest categories of relative muscle power were 5.88 (2.28 to 15.17; $P<.001$) and 6.90 (1.61 to 29.58; $P=.009$) for men and women, respectively. The corresponding hazard ratios (95% CIs) for relative strength were 1.62 (0.89 to 2.96; $P=.11$) and 1.71 (0.61 to 4.80; $P=.31$), respectively. Sex-specific results of risk prediction analyses revealed that improvements in C index provided by relative power over relative strength were 0.0110 (95% CI, 0.0039 to 0.0182) in men and 0.0112 (95% CI, −0.0040 to 0.0265) in women.

Conclusion: In this large prospective study, relative muscle power was a stronger predictor of mortality than relative strength in middle-aged and older men and women. Evaluating and training muscle power could be of clinical and practical relevance.

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Cardiorespiratory (aerobic) fitness is a well-established predictor of mortality[1-3] and has been recently proposed as a clinical vital sign.[4] In the past 20 years, growing evidence has also indicated that poor levels of nonaerobic physical fitness components (eg, strength, flexibility, and balance),[5] as assessed by simple tests such as handgrip,[6,7] number of completed push-ups,[8] ability to sit and rise from the floor,[9] the ability to complete 10-second one-legged stance,[10] and the Flexitest,[11] are related to premature death in middle-aged and older individuals.

One of the most notable effects of aging is a natural decrease in muscle function, which significantly impacts autonomy, morbidity, and mortality.[12] Numerous studies have linked handgrip strength (an indicator of muscle strength) to mortality risk.[6,7,13] However, similar evidence is scarce for muscle power.[14,15] This discrepancy may

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occur because assessing muscle strength with a handgrip test is simpler than measuring muscle power. Nonetheless, as a product of force and velocity,[16] muscle power could be a more crucial factor than strength, not only for explosive types of sports performance, such as tennis smashing or shot putting, but also undoubtedly for many daily living activities, such as picking up bags of goods, ascending a flight of stairs,[17] and rising from the floor[9] or a chair. Indeed, every time an individual performs a movement against gravity or inertia, it is muscle power rather than muscle strength that is the most important variable in terms of muscle function.[18,19]

To the best of our knowledge, it is unknown whether measuring maximal muscle power would add prognostic information on survival as compared with handgrip strength. Thus, a direct comparison of the impact of these 2 measures of upper body muscle function on mortality in middle-aged and older populations is worth carrying out. The availability of vital data and same-visit assessments of single best efforts on muscle power and strength in a large cohort allowed us to test the hypothesis that muscle power outperforms strength in predicting mortality. This study represents a natural progression of our research focus on the impact of physical fitness in health outcomes and aims to contribute insights into the potential value of muscle power on longevity.

PARTICIPANTS AND METHODS

Study Design, Setting, and Participants

This study utilized data from the CLINIMEX Exercise open prospective cohort.[10,11,20-22] Between February 13, 2001, and October 31, 2022, a total of 7217 individuals (following exclusion of athletes[23]) voluntarily underwent a comprehensive medical-functional evaluation including a maximal cardiopulmonary exercise test and several tests of physical fitness at a private clinic in Rio de Janeiro, Brazil. The purpose of the evaluation was to assess their health and physical fitness levels and to provide advice regarding exercise and/or sports practice. As identified by the evaluators, the large majority of participants were White, belonged to the upper socioeconomic and education strata of the country, and were primarily referred by their attending physicians.

After selecting those between 46 and 75 years old in the cohort, the current study included 3889 individuals with available data for main variables and selected covariates. This final sample included only individuals without locomotor or musculoskeletal symptoms or clinical restrictions that could preclude or impair muscle function testing. All evaluations throughout the 22-year period were conducted consistently by a team of 5 highly skilled sports and exercise physicians.

Muscle Function (Power and Strength) Assessment

Our protocols for measuring the best single effort's maximal muscle power and strength in this cohort have been reported previously.[24-29] In brief, upper body muscle power was assessed in watts using a pulley device while performing an upper row movement using a FitroDyne digital device (Fitronics Ltd) that registers movement of the stack lifted and calculates mean power in the concentric phase as a product of mean vertical velocity and gravitational force. In the standing position with the legs fully extended and the left foot positioned slightly ahead of the right, the participants completed the upper row movement. To obtain the maximal power value, the evaluator selected a weight that would be easily lifted at an "average" velocity. On completing this step, the participant was asked to repeat the same movement as fast as possible, and the value of power in watts was recorded. In sequence, after a minimum interval of 20 seconds, 5 kg was added to the pile and the individual was instructed to lift the weight again as fast as possible in the same movement, and this step was repeated until the product of force (weight lifted) times velocity diminished. Upper body muscle strength was assessed in kilogram-force (kgf) by handgrip test using a Takei digital dynamometer. In a standing position with the arms fully extended and aligned with the longitudinal axis of the body, the

participant performed 2 consecutive attempts on each side, and the highest of all 4 was chosen to represent the final value in kilogram-force. Long-term experience in our clinic and previous studies have confirmed the reliability of these techniques to quantify maximum muscle power and strength.[26,30] (see Supplemental Online Materials [available online at https://youtu.be/TCBGOK1OhkQ] for a demonstration video of muscle function testing).

The best result in a single attempt or movement was chosen to represent the muscle power and strength, subsequently divided by body weight and termed *relative muscle power* (rPOW) and *relative strength* (rSTR), respectively.

Additional Variables

Other variables ascertained included age, sex, height, weight, waist circumference measured at the umbilical level, and waist-height ratio (WHr). Clinical information at baseline was used to classify the health status of the individuals as healthy or unhealthy. Healthy individuals were free of cancer, cardiovascular and respiratory diseases, chronic kidney failure, diabetes mellitus, obesity, and dyslipidemia.

Mortality Outcomes

Vital status—alive or deceased—and main cause of death according to *International Classification of Diseases, Tenth Revision* codes was last censored on October 31, 2022, from the official records of the Health Secretary of Rio de Janeiro State. Consistent with previous recent studies made with this cohort,[10,11,20] deaths due to COVID-19 and external causes were purposely excluded before further analysis. The duration of follow-up was calculated in years as the time between the evaluation and last censored dates. All individuals read and signed a consent form allowing the evaluation to be undertaken and the results obtained to be used in deidentified form for research purposes. Both the evaluation and research protocols were formally registered with relevant governmental bodies and approved by an external research ethics committee.

Statistical Analyses

Sex-specific results were reported given the expected differences in values of rPOW and rSTR between men and women. Baseline characteristics were presented as mean ± SD for continuous variables and count (percentage) for categorical variables. To evaluate the dose-response relationships of rPOW and rSTR with mortality risk, trend plots were generated showing lines representing the partial log hazard (the trend), facilitating the interpretation of the potential protective effects of muscle strength and muscle power on mortality across the sexes. A spline approach was employed to capture complex, nonlinear associations. Hazard ratios (HRs) with 95% CIs for mortality were estimated using Cox proportional hazards regression models, after confirming no major departure from the assumptions of the proportionality of hazards using Schoenfeld residuals. Results for rPOW and rSTR, separated by sex, were initially presented as deciles and, in sequence, Kaplan-Meier curves were constructed and log-rank tests were used to analyze survival times across cutoffs of rPOW and rSTR. Four practical, rounded cutoff values were selected for rPOW, corresponding to 1.50 or less, 1.51 to 2.50, 2.51 to 3.50, and greater than 3.50 for men and 1.00 or less, 1.01 to 1.50, 1.51 to 2.00, and greater than 2.00 for women. Similarly, for rSTR, the cutoff values were 0.270 or less, 0.271 to 0.400, 0.401 to 0.535, and greater than 0.535 for men and 0.180 or less, 0.181 to 0.270, 0.271 to 0.400, and greater than 0.400 for women. These cutoff values align approximately with the percentiles 1 to 10, 11 to 50, 51 to 90, and 91 to 100 of the sample distribution for rPOW and rSTR, ensuring consistency across sexes and practicality in application. The groups reflect meaningful variation in the data and are supported by the dose-response relationships observed for both rPOW and rSTR, which were approximately linear with mortality risk in

men and women. To separately assess the independence of the associations in men and women, HRs were progressively adjusted for using 3 models: model 1, age; model 2, model 1 plus WHr; and model 3, model 2 plus histories of coronary artery disease, hypertension, dyslipidemia, diabetes, obesity, and health status. The confounders were selected based on their previously established roles as risk factors for mortality, previously published associations with mortality in the CLINIMEX study,[9-11] or their potential as confounders based on known associations with mortality and observed associations with the exposures using the available data. We used the WHr instead of body mass index because this measure has been proposed as a better cardiometabolic disease risk marker[31] and it was more related to mortality risk than body mass index in a preliminary analysis of our study population.

To compare the predictive ability of rPOW with that of rSTR for mortality in men and women separately, we calculated measures of discrimination for censored time-to-event data (Harrell C index)[32] and reclassification.[33,34] The C index is appropriate for time-to-event data and provides the probability that the model correctly predicts the order of failure of randomly selected pairs of individuals. A C index of 1.0 indicates perfect prediction of the order of failure (in this case mortality), whereas a C index of 0.5 is achieved purely by chance. To investigate the change in C index on the addition of rPOW or rSTR, 2 risk prediction models were fitted: 1 based on a model containing established risk factors (ie, age, WHr, and medical histories of coronary artery disease, hypertension, dyslipidemia, diabetes, obesity, and health status) and the second model with these risk factors plus rPOW or rSTR. Changes in the C index for models including and not including information on rPOW or rSTR and the comparisons in C index between rPOW and rSTR when added to the model of conventional risk factors were conducted according to the methodology of DeLong et al[35] and with the Stata command "somersd" (StataCorp). The 95% CIs for C indices and their changes were derived from jackknife standard error. Second, we calculated the continuous net reclassification improvement (NRI).[34] Additionally, the integrated discrimination improvement (IDI) was calculated, which integrates the NRI over all possible cutoffs.[33] We also tested for differences in the −2 log likelihood of prediction models with and without inclusion of rPOW or rSTR. All statistical analyses were conducted using Stata statistical software, version MP 17 (StataCorp) and R version 4.0.4 (R Foundation for Statistical Computing), with significance level set at 5%. Figure 1 was drawn using Prism version 10.2 (GraphPad).

RESULTS

Of the 3889 study participants, 2636 (67.8%) were men and 1263 (32.2%) were women (Table 1). The mean ± SD age was 59±8 years and virtually identical for men and women (P=.21). Results for muscle function were significantly higher in men than in women: rPOW was 2.54±0.76 W/kg vs 1.46±0.50 W/kg (P<.001) and rSTR was 0.40±0.10 kgf/kg vs 0.27±0.09 kgf/kg (P<.001). All results of anthropometric measurements and prevalence of comorbidities were higher in men than in women. Detailed results for each 1 of the 4 groups of rPOW and rSTR for men and women are presented in Supplemental Tables S1-S4 (available online at http://www.mayoclinicproceedings.org).

Associations of rPOW and rSTR With Mortality

During an overall median (IQR) follow-up period of 10.8 years (6.7 to 15.5 years), 484 of the 3889 participants (12.4%) died—373 of 2636 men (14.2%) and 111 of 1253 (8.9%) women. There were trends for decreasing death rates from the lowest to the highest muscle function deciles (P<.001 for trends) that were numerically higher for rPOW—nearly 20 times higher—than for rSTR and approximately 4 times higher in men and in women. Kaplan-Meier survival curves in men and women illustrated lower survival probability for the

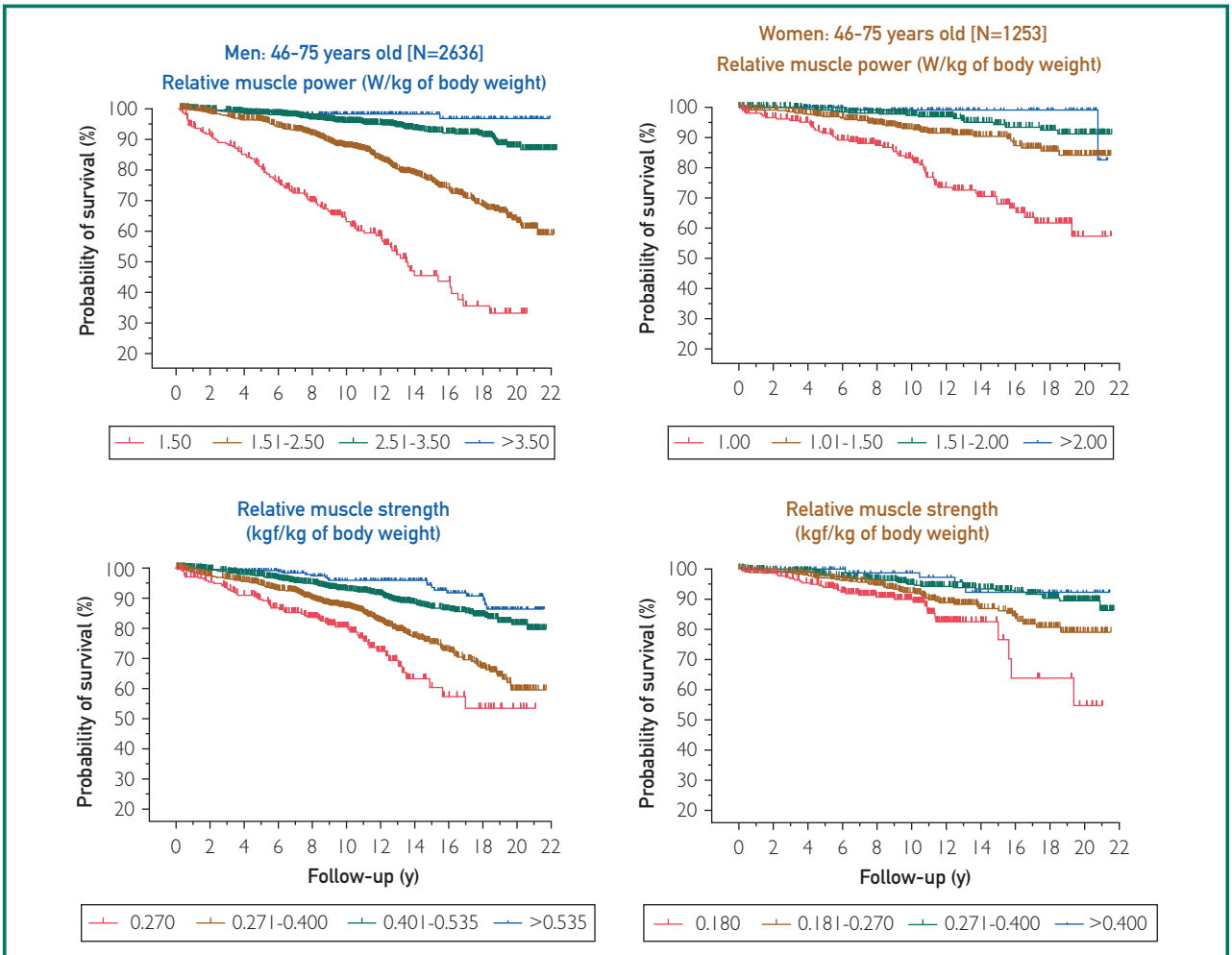

FIGURE 1. Survival curves for relative muscle power and strength in 2636 men and 1253 women.

groups with lower values in rPOW and rSTR as compared with other groups, in both men and women ($P<.001$ for log-rank tests) (Figure 1). For better clarity of this illustration, the number at risk at 4-year intervals for the 4 groups are only presented as supplemental materials (Supplemental Figures S1 and S2, available online at http://www.mayoclinicproceedings.org). Figure 2 depicts a dose-response analysis revealing evidence of inverse linear relationships of rPOW and rSTR with the risk of all-cause mortality in both men and women.

In the model adjusted for age and WHr, the HR (95% CI) for mortality comparing the bottom vs top groups of rPOW was 7.38 (2.86 to 19.03) and 7.05 (1.64 to 30.40), respectively, for men and women. On further adjustment for clinical variables, risk estimates were attenuated to 5.88 (2.28 to 15.17; $P<.001$) in men and minimally attenuated to 6.90 (1.61 to 29.58; $P=.009$) in women. The corresponding adjusted HRs (95% CIs) for rSTR were 1.68 (0.92 to 3.08) and 1.62 (0.89 to 2.96; $P=.11$), respectively, for men and 1.69 (0.60 to 4.75) and 1.71 (0.61 to 4.80; $P=.31$) for women (Table 2).

Relative Muscle Power and Strength and Mortality Risk Prediction

The sex-specific results on risk prediction analyses are presented in Table 3. In men, there was a significant increase in the C

TABLE 1. Baseline Characteristics for 3889 Men and Women Aged 46-75 Years[a,b]

Variable	Men	Women	*P* value
Sex	2636 (67.8)	1253 (32.2)	NA
Age (y)	58.7±8.3	59.0±8.3	.21
Relative muscle power (W/kg)	2.54±0.76	1.46±0.50	<.001
Relative muscle strength (kgf/kg)	0.40±0.10	0.27±0.09	<.001
Height (cm)	174.0±6.9	161.0±6.5	<.001
Weight (kg)	84.9±14.8	68.2±13.4	<.001
Body mass index (kg/m^2)	27.9±4.2	26.3±5.1	<.001
Waist-height ratio	0.57±0.07	0.54±0.08	<.001
Coronary artery disease: yes	938 (35.6)	169 (13.5)	<.001
Arterial hypertension: yes	1208 (45.8)	423 (33.8)	<.001
Dyslipidemia: yes	1316 (49.9)	512 (40.9)	<.001
Obesity: yes	674 (25.6)	251 (20.0)	<.001
Diabetes mellitus: yes	385 (14.6)	113 (9.0)	<.001
Health status: healthy[c]	329 (12.5)	201 (16.0)	.002
Deaths: yes	373 (14.2)	111 (8.9)	<.001
Follow-up (y)	10.9±5.6	11.0±5.9	.50

[a]NA, not applicable.
[b]Data are presented as No. (percentage) of participants or mean ± SD.
[c]Individuals were classified as healthy if at baseline they were free of cancer, cardiovascular and respiratory diseases, diabetes mellitus, dyslipidemia, and obesity.

index of 0.0133 (95% CI, 0.0050 to 0.0216; *P*=.002) on addition of information on rPOW to an all-cause mortality risk prediction model containing established risk factors. The −2 log likelihood was significantly improved on addition of rPOW (*P*<.001 for comparison). The continuous NRI and IDI were 40.26% (95% CI, 25.89% to 54.64%; *P*<.001) and 0.0337 (95% CI, 0.0227 to 0.0447; *P*<.001), respectively.

On addition of rSTR to the risk score in the same sample of men, the C index change was 0.0023 (95% CI, −0.0013 to 0.0058; *P*=.22); difference in −2 log likelihood (*P*=.002); NRI, 14.18% (95% CI, 0.34% to 28.01%; *P*=.045); and IDI, 0.0109 (95% CI, 0.0063 to 0.0156; *P*<.001). The improvement in C index provided by rPOW was 0.0110 higher (95% CI, 0.0039 to 0.0182; *P*=.003) than that of rSTR in men.

In women, there was a significant increase in C index of 0.0227 (95% CI, 0.0058 to 0.0397; *P*=.009) on addition of information on rPOW to the risk prediction model. The −2 log likelihood was significantly improved on addition of rPOW (*P*<.001 for comparison). The continuous NRI and IDI were 45.24% (95% CI, 18.98% to 71.49%; *P*=.001) and 0.0122 (95% CI, −0.0008 to 0.0251; *P*=.065), respectively. On addition of rSTR to the risk score in the same sample of women, the C index change was 0.0114 (95% CI, −0.0013 to 0.0242; *P*=.079); difference in −2 log likelihood (*P*=.013); NRI, 14.58% (95% CI, −8.94% to 38.10%; *P*=.22); and IDI, 0.0066 (95% CI, −0.0005 to 0.0137; *P*=.070). The improvement in C index provided by rPOW was 0.0112 higher (95% CI, −0.0040 to 0.0265; *P*=.15) than that of rSTR in women.

DISCUSSION

Previous studies with the CLINIMEX Exercise cohort have highlighted the prognostic merit of several exercise- and physical fitness−related variables on survival.[9-11,22,36] Novel results from the current study add to the body of knowledge on the association between physical fitness and survival in confirming our hypothesis that rPOW

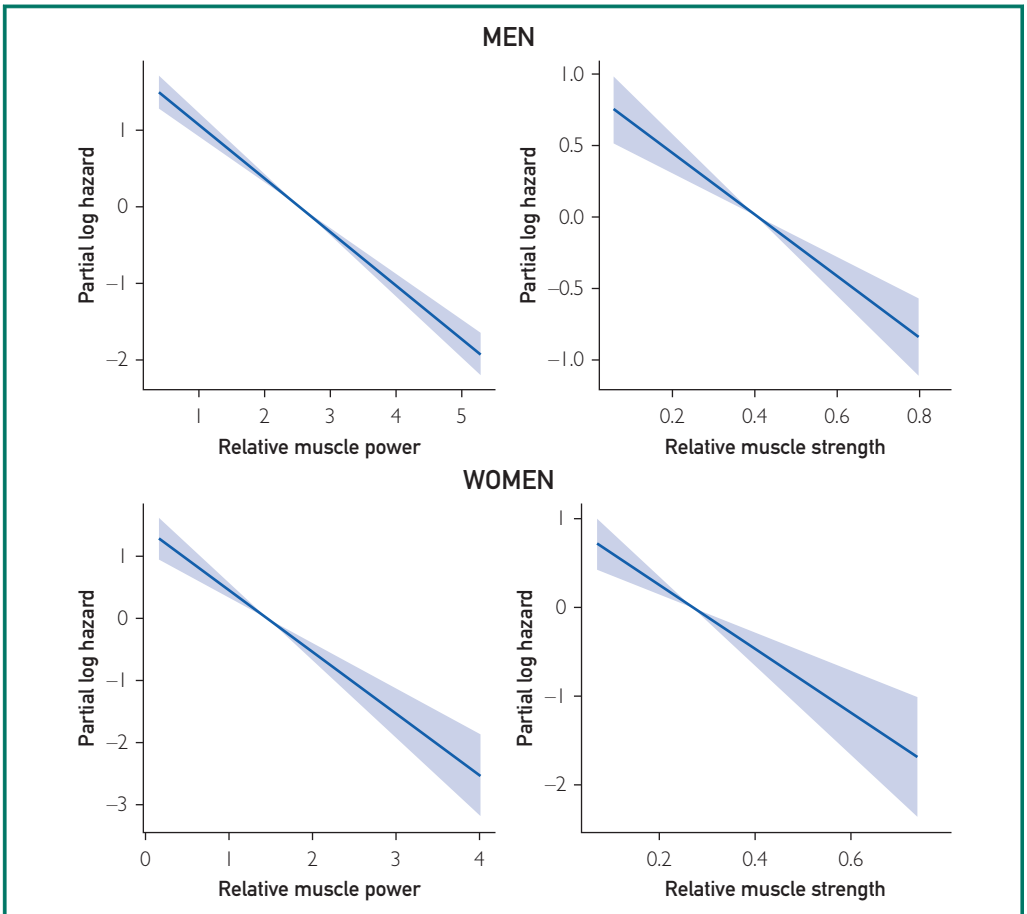

FIGURE 2. Relationship between relative muscle strength and power and mortality in middle-aged and older men and women.

significantly outperforms rSTR as a risk indicator and predictor of natural and non-COVID-19 mortality in 46- to 75-year old men and women. Additionally, our findings are aligned with several previous studies indicating that rSTR, as assessed by handgrip test,[6] could be a predictor of survival in middle-aged and older men and women.

There was an approximate linear trend for the inverse relationship between both measures of muscle function and mortality as shown in Figure 2. Interestingly, although mean rPOW and rSTR values were approximately 75% and 50% higher in men as compared with women, respectively, of similar median age, the ratio of death rates between the bottom and top groups did not vary by sex, with unadjusted HRs of 20 to 25 and 3 to 4 times for rPOW and rSTR, respectively. However, our findings indicate that the HR values were much higher for rPOW than for rSTR after similar adjustments for several covariates. As seen in both men and women, the results of several statistical tests, C statistics, NRI, and IDI for rPOW compared with rSTR underscore the importance of incorporating muscle power assessments in clinical practice for better mortality risk prediction and reclassification. These observations suggest that assessing muscle power could potentially replace or supplement handgrip strength testing.

There are several studies suggesting a detrimental effect of aging on muscle mass and function[37,38] and its relationship with relevant health outcomes, including risk of

TABLE 2. Associations of Relative Muscle Power and Strength With Mortality in 2636 Men and 1253 Women Aged 46-75 Years[a,b]

Exposure	Events/total	Model 1, HR (95% CI)	*P* value	Model 2, HR (95% CI)	*P* value	Model 3, HR (95% CI)	*P* value
MEN							
Relative muscle power (watts/kg of body weight)							
Group 1 (≤1.50)	95/227	9.40 (3.72-23.76)	<.001	7.38 (2.86-19.03)	<.001	5.88 (2.28-15.17)	<.001
Group 2 (1.51-2.50)	210/1054	3.92 (1.58-9.70)	.003	3.31 (1.32-8.28)	.010	2.67 (1.07-6.69)	.036
Group 3 (2.51-3.50)	63/1068	2.00 (0.80-4.99)	.14	1.83 (0.73-4.57)	.20	1.59 (0.63-3.98)	.32
Group 4 (>3.50)	5/287	1 (Reference)		1 (Reference)			
P value for trend			<.001		<.001		<.001
Relative muscle strength (kgf/kg of body weight)							
Group 1 (≤0.270)	57/242	2.56 (1.48-4.42)	.001	1.68 (0.92-3.08)	.090	1.62 (0.89-2.96)	.11
Group 2 (0.271-0.400)	190/1062	1.89 (1.15-3.11)	.011	1.50 (0.90-2.51)	.12	1.47 (0.88-2.46)	.14
Group 3 (0.401-0.535)	108/1047	1.18 (0.72-1.96)	.51	1.06 (0.64-1.76)	.83	1.10 (0.66-1.82)	.72
Group 4 (>0.535)	18/285	1 (Reference)		1 (Reference)		1 (Reference)	
P value for trend			<.001		.005		.015
WOMEN							
Relative muscle power (watts/kg of body weight)							
Group 1 (≤1.00)	52/215	8.35 (1.97-35.42)	.004	7.05 (1.64-30.40)	.009	6.90 (1.61-29.58)	.009
Group 2 (1.01-1.50)	41/497	3.98 (0.95-16.66)	.058	3.55 (0.84-14.96)	.084	3.63 (0.86-15.24)	.079
Group 3 (1.51-2.00)	16/382	2.49 (0.57-10.84)	.23	2.36 (0.54-10.29)	.25	2.43 (0.56-10.59)	.24
Group 4 (>2.00)	2/159	1 (Reference)		1 (Reference)		1 (Reference)	
P value for trend			<.001		<.001		<.001
Relative muscle strength (kgf/kg of body weight)							
Group 1 (≤0.180)	30/231	2.30 (0.87-6.08)	.094	1.69 (0.60-4.75)	.32	1.71 (0.61-4.80)	.31
Group 2 (0.181-0.270)	46/442	1.55 (0.61-3.95)	.36	1.23 (0.46-3.25)	.68	1.19 (0.45-3.13)	.73
Group 3 (0.271-0.400)	30/466	1.03 (0.40-2.67)	.95	0.93 (0.36-2.42)	.88	0.89 (0.34-2.33)	.82
Group 4 (>0.400)	5/114	1 (Reference)		1 (Reference)		1 (Reference)	
P value for trend			<.001		.005		.003

[a]HR, hazard ratio.

[b]Model 1 was adjusted for age; model 2 was adjusted for model 1 plus waist-height ratio; model 3 was adjusted for model 2 plus histories of coronary artery disease, hypertension, dyslipidemia, diabetes, obesity, and health status.

falls[19,39] and mortality.[13,14,40,41] It is well-accepted that losses in muscle mass and function may start as early as the end of fourth decade of life and quickly progress with seniority,[27,42] with an apparently larger detrimental aging effect for power than for strength.[43]

There are several ways to assess strength and power components of muscle function.[27,44-46] While in clinical settings the best result from several attempts of a handgrip test is by far the most common mode of evaluation of maximal muscle strength,[27,47] timed movements for repeated actions such as the 5-times sit-to-stand test,[15] 30-second chair rise,[48] Timed Up and Go,[49] Wingate test,[45] and arm cranking for 10 to 15 seconds at 4 different loads[50] have been used as proxies for muscle power or anaerobic power/capacity. However, in quantifying muscle power in multiple movements or repetitions against time, all these tests primarily estimate or indirectly assess mean muscle power during a given period of 5 to 30 seconds. In contrast, in our study, muscle power was quantified by the best single as fast as possible repetition of an upper rowing movement, yielding a more objective result that is likely more appropriate compared with the best result in 4 attempts of a handgrip strength test. Moreover, in our study, to compare the impact of rPOW and rSTR on risk of mortality, both were tested on the upper part of the body, unlike

TABLE 3. Measures of Risk Discrimination and Reclassification on Addition of Relative Muscle Power and Strength to a Model Containing Conventional Risk Factors in 2636 Men and 1253 Women Aged 46-75 Years[a]

Variable	Men	Women
Relative muscle power (watts/kg of body weight)		
Discrimination		
C index (95% CI): conventional risk factors	0.7836 (0.7587 to 0.8085)	0.7503 (0.7033 to 0.7972)
C index (95% CI): conventional risk factors plus muscle power	0.7969 (0.7718 to 0.8220)	0.7730 (0.7290 to 0.8170)
C index change (95% CI)	0.0133 (0.0050 to 0.0216)	0.0227 (0.0058 to 0.0397)
P value	.002	.009
P value for difference in −2 log likelihood	<.001	<.001
Reclassification		
Continuous net reclassification index (95% CI)	40.26% (25.89% to 54.64%)	45.24% (18.98% to 71.49%)
P value	<.001	.001
Integrated discrimination index (95% CI)	0.0337 (0.0227 to 0.0447)	0.0122 (−0.0008 to 0.0251)
P value	<.001	.065
Relative muscle strength (kgf/kg of body weight)		
Discrimination		
C index (95% CI): conventional risk factors	0.7836 (0.7587 to 0.8085)	0.7503 (0.7033 to 0.7972)
C index (95% CI): conventional risk factors plus muscle strength	0.7859 (0.7607 to 0.8111)	0.7617 (0.7172 to 0.8062)
C index change (95% CI)	0.0023 (−0.0013 to 0.0058)	0.0114 (−0.0013 to 0.0242)
P value	.22	.079
P value for difference in −2 log likelihood	.002	.013
Reclassification		
Continuous net reclassification index (95% CI)	14.18% (0.34% to 28.01%)	14.58% (−8.94 to 38.10)
P value	.045	.22
Integrated discrimination index (95% CI)	0.0109 (0.0063 to 0.0156)	0.0066 (−0.0005 to 0.0137)
P value	<.001	.070

[a]The model with conventional risk factors included age, waist-height ratio, histories or diagnosis of coronary artery disease, hypertension, dyslipidemia, diabetes, and obesity and by health status.

most other studies[51,52] that have measured muscle power in the lower body and muscle strength in the upper body. These 2 important methodological distinctions preclude any direct comparison between our results and those from other studies.

Resistance training is typically prescribed by the numbers of movements (exercises), by sets and repetitions plus the interval of the time between sets, and, only very rarely, when the velocity or the time of execution of one repetition is detailed or controlled. Because power is force times velocity,[16] performing the same movement with the same load could nevertheless vary the power substantially by changing the velocity of execution. Growing evidence has suggested that velocity-based or power training,[53-56] in which the repetitions are performed as fast as possible in the concentric phase of muscle contraction at moderate or heavy loads, could be superior to traditional resistance training and it has been used increasingly for both sports and clinical applications at all ages and for men and women.

Strengths and Limitations

Notable strengths of our study were (1) the prospective cohort design and long-term follow-up, (2) the availability of muscle function and vital status data from a large open cohort including men and women, (3) the use of measurements of muscle power and strength both similarly performed in the upper part of the body, utilizing well-standardized assessment protocols and the same testing devices, obtained from a single best attempt during the same clinic visit by only 5 well-trained physicians over 22 years, and (4) the availability of data on

anthropometric and clinical variables along with vital status data that were used as covariates. It is also worth emphasizing that to answer our research question—if muscle power outperforms muscle strength in predicting mortality—we directly compared 2 indicators of muscle function measured in the same participants, which minimized the potential influence of other variables.

The limitations of this study also deserve consideration. The design of our study does not permit an explanation of the mechanisms that make rPOW a more powerful indicator of mortality than rSTR. Decreases in muscle function may vary according to different muscle groups.[57] However, due to practical reasons, our measurements of muscle power and strength were limited to the best single attempt and performed without using exactly the same muscles of the upper limbs and trunk. Although the vertical jump test is a simple way to evaluate rPOW,[58] it is obviously not appropriate for routine and safe application in an older population such as the one used in our study.

There were relatively fewer women than men in our study, which could account for the modest estimates with marginal statistical significance observed in women. One potential limitation of our study is the absence of lean body mass or muscle mass data, which could have allowed for a more accurate adjustment of muscle power and muscle strength values. Although we analyzed these metrics relative to body weight, body weight alone may not fully account for differences in muscle mass and adiposity, which are critical determinants of muscle function.[58] Moreover, we were unable to control for cardiorespiratory (aerobic) fitness and for the past or current levels of physical activity, exercise or sports practice, and the experience level of our participants.

Clinical Implications

The term *sarcopenia* was coined few decades ago and has been progressively incorporated into the medical glossary.[59] Consistent with the Greek root of the term, sarcopenia was initially proposed as exclusively representing loss of muscle mass; however, more recent definitions of sarcopenia have encompassed loss of muscle strength as one of the components of this clinical entity.[47] Conversely, the Global Leadership Initiative in Sarcopenia has recently rejected the inclusion of muscle power as an essential component of sarcopenia due to poor concordance among 107 specialists.[47] Considering our findings that rPOW outperforms rSTR as a predictor of mortality in men and women aged 46 to 75 years and recognizing that resistance training is the best available intervention to counteract muscle loss for a more tailored and precise prescription of resistance exercise, terms should adhere to the specifics of the objective being primarily targeted, that is, sarcopenia (low muscle mass) or dynapenia (low muscle strength or low muscle power).[60] This distinction could be particularly relevant in frail patients, in whom dynapenia tends to be highly prevalent and clinically relevant.

The 2 most obvious implications of our findings are (1) the assessment of muscle power could be advisable and prognostically relevant in various clinical settings and (2) it is appropriate that power or velocity-based type of training should be emphasized for health purposes.

Future Studies

Two major questions remains to be addressed in future studies: (1) whether assessing muscle power as the best result in a single repetition of upper arm row movement, as in this study, or in several movements or in other muscle groups will provide additional predictive value beyond aerobic fitness and other nonaerobic physical fitness components in determining mortality and (2) whether power training per se, ie, performing repetitions as fast as possible, will induce specific or additional benefits impacting mortality as compared with conventional resistance training.

CONCLUSION

In this prospective study in a large cohort of middle-aged and older men and women undergoing a single best effort in upper body

muscle testing, rPOW was a stronger risk indicator and predictor of mortality than rSTR.

POTENTIAL COMPETING INTERESTS

The authors report no competing interests.

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SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mayoclinicproceedings.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **HR,** hazard ratio; **IDI,** integrated discrimination improvement; **NRI,** net reclassification improvement; **rPOW,** relative muscle power; **rSTR,** relative strength; **WHr,** waist-height ratio

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MAYO CLINIC PROCEEDINGS

EDITORIAL

The Need for Speed: Improving Muscle Power for Longevity

See also page 1319

Cardiorespiratory and Skeletal Muscle Fitness to Promote Longevity

Cardiorespiratory (aerobic) fitness (CRF), often quantified by peak oxygen consumption, is a powerful predictor of cardiovascular disease (CVD) as well as of all-cause and CVD-related mortality.[1] However, nonaerobic physical fitness components, including muscle strength, flexibility, and balance, have also been found to predict the risk for premature death in middle-aged and older individuals. We and others have previously comprehensively reviewed the established role of muscle strength in stratifying cardiovascular and metabolic risks and its significant association with CVD, CVD-related mortality, and all-cause mortality.[2] This suggests that an assessment of CRF should be paired with other metrics, such as muscle strength (Figure), to ultimately provide a stronger prognostication in both apparently healthy individuals and those with established diseases.

Muscle Power: A Novel Predictor of Survival

In this issue of *Mayo Clinic Proceedings*, Araújo et al[3] compared the role of muscle strength with muscle power. The study leveraged data from the large, prospective CLINIMEX Exercise cohort. The cohort included 3899 participants, predominantly men (67.7%) aged 46 to 75 years, who were observed for a median of 10.8 years. The authors compared the effects of relative muscle power (rPOW) with relative muscle

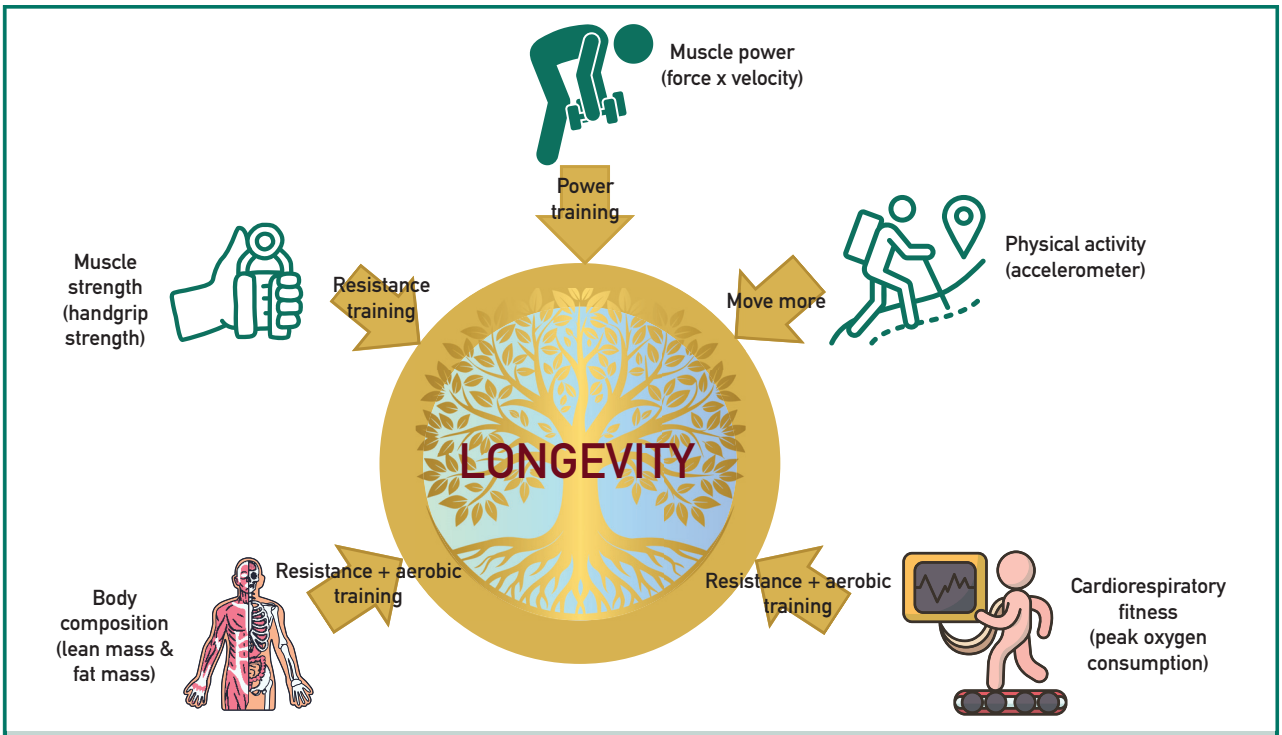

FIGURE. Determinants of longevity. Key determinants of longevity and associated lifestyle interventions that target these factors to enhance health span and overall survival.

strength (rSTR). Relative muscle power was assessed by an upper row movement using a FitroDyne digital device (Fitronics Ltd),[3] whereas rSTR was measured by the commonly used handgrip test.[1] Both measures were adjusted for body weight to account for body size differences.

The authors found that rPOW was a significantly stronger predictor of all-cause mortality than rSTR.[3] In multivariable Cox proportional hazards regression analyses, extensively adjusted for age, waist-height ratio, and multiple comorbidities, the hazard ratios (HRs) for mortality comparing the lowest vs highest categories were substantially higher for rPOW than for rSTR. Specifically, for men, the HR for rPOW was 5.88 (95% CI, 2.28 to 15.17) compared with 1.62 (95% CI, 0.89 to 2.96) for rSTR. For women, the HR for rPOW was 6.90 (95% CI, 1.61 to 29.58) compared with 1.71 (95% CI, 0.61 to 4.80) for rSTR. Risk prediction analyses also found that rPOW provided a significantly greater improvement in predictive accuracy over rSTR, particularly in men. A dose-response analysis further supported these findings, with a clear inverse relationship for both rPOW and rSTR with mortality risk, with a stronger trend observed for rPOW.

Muscle Strength vs Muscle Power: When Speed Makes the Difference

The superior predictive power of rPOW strongly indicates that the dynamic aspect of muscle function, the ability to generate force quickly (force times velocity), may be more critical for long-term survival and functional independence than static maximal force alone. In essence, rPOW describes the ability to perform movements not just with force but also with speed and efficiency. Whereas strength measures maximal force, power incorporates the dimension of speed.

Importantly, aging is characterized by a physiologic decline in muscle strength; however, muscle power might decline even earlier and more rapidly than strength. Many essential activities of daily living, such as quickly rising from a chair, climbing stairs, or reacting to prevent a fall, demand rapid force production, not just the capacity for maximal force. As individuals age, the velocity component of muscle function is often observed to decline more rapidly than maximal strength. Therefore, a metric that captures power might serve as a more sensitive and earlier indicator of functional reserve. This functional reserve impairment may increase the risk of adverse events (eg, falls leading to fractures, inability to perform activities of daily living, and reduced physical activity).

Muscle Strength vs Muscle Power to Diagnose Sarcopenia

Sarcopenia is defined as a reduction in skeletal muscle mass, muscle strength, and function. Several definitions for sarcopenia have been proposed over the years, and the Global Leadership Initiative in Sarcopenia recently rejected the use of muscle power as one of the main diagnostic criteria for sarcopenia based on the available evidence.[4] The study by Araújo et al clearly challenges this decision and emphasizes the urgent need to further investigate the role of muscle power compared with muscle strength across different diverse populations, including those who are apparently healthy and those with established diseases. If power is a better predictor of mortality than strength, a definition of sarcopenia that excludes power might be missing a critical component of functional decline that directly affects survival. This suggests that the current diagnostic criteria may not fully capture the most prognostically relevant aspects of age-related muscle loss, potentially leading to misclassification of at-risk individuals or the implementation of suboptimal interventions that do not adequately address the dynamic functional deficits.

Shifting Paradigms in Assessment and Intervention

The study provides compelling evidence that incorporating muscle power assessment can significantly improve mortality risk prediction, particularly in men. This suggests that rPOW could be a valuable if not essential addition to standard clinical assessments for middle-aged and older adults. Whereas

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handgrip strength offers convenience and cost-effectiveness, the superior prognostic information derived from power measurements may justify the adoption of dynamic power assessment tools in clinical practice.

A recent meta-analysis of randomized controlled trials including 566 older adults suggested that power training might provide greater functional benefits than traditional strength training.[5] The findings of the study further support this earlier meta-analysis. Whereas previous exercise training work has highlighted that resistance training is effective for improving muscle strength and modulating CVD risk factors, the current study refines this understanding by suggesting that the modality of resistance training (eg, power training) may better promote longevity. Moreover, instead of merely asking, How much can you lift? clinicians should also consider asking, How *fast* can you lift it? This shift could lead to more targeted and effective exercise interventions that directly address the specific functional declines associated with aging, moving beyond general exercise advice to specific, evidence-based prescriptions (Figure).

Limitations and Future Directions

Importantly, this study did not assess physical activity and CRF. Future studies should rigorously investigate whether the prognostic effects of muscle power remain independent after adjustment for these strong, established risk factors.[6] Moreover, the study did not provide data on body composition, particularly lean soft tissues, the best surrogate for skeletal muscle mass.[7] Whereas rPOW and rSTR were adjusted for body weight, direct lean soft tissue measures would provide a more precise understanding of how muscle quality (eg, force/power per kilogram of muscle mass) contributes to the observed associations. Moreover, we currently lack a clinically available measure of rPOW that could be readily adapted to the clinical setting. This represents a key area for future development.

Conclusion

The authors are to be congratulated for providing compelling and novel evidence that proposes muscle power as a superior predictor of mortality compared with muscle strength in middle-aged and older adults.[3] This finding should prompt a critical reevaluation of current clinical assessment practices, including the diagnosis of sarcopenia, moving toward the integration of muscle power measurements as an important prognostic indicator. Furthermore, it strongly advocates for a greater emphasis on power-oriented training in exercise prescriptions, refining the guidance provided to individuals seeking to optimize their health and extend their lifespan. Future randomized controlled trials are urgently needed to answer these important questions.

POTENTIAL COMPETING INTERESTS

The authors report no competing interests.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used Gemini (Google) to assist with improving the readability of the manuscript draft. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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