Association of Muscle Strength With the Risk of Alzheimer Disease and the Rate of Cognitive Decline in Community-Dwelling Older Persons

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Background: Loss of muscle strength is common and is associated with various adverse health outcomes in old age, but few studies have examined the association of muscle strength with the risk of Alzheimer disease (AD) or mild cognitive impairment (MCI).

Objective: To test the hypothesis that muscle strength is associated with incident AD and MCI.

Design: Prospective observational cohort study.

Setting: Retirement communities across the Chicago, Illinois, metropolitan area.

Participants: More than 900 community-based older persons without dementia at the baseline evaluation and in whom strength was measured in 9 muscle groups in arms and legs, and in the axial muscles and summarized into a composite measure of muscle strength.

Main Outcome Measures: Incident AD and MCI and the rate of change in global cognitive function.

Results: During a mean follow-up of 3.6 years, 138 persons developed AD. In a proportional hazards model adjusted for age, sex, and education status, each 1-U increase in muscle strength at baseline was associated with about a 43% decrease in the risk of AD (hazard ratio, 0.57; 95% confidence interval, 0.41-0.79). The association of muscle strength with AD persisted after adjustment for several covariates, including body mass index, physical activity, pulmonary function, vascular risk factors, vascular diseases, and apolipoprotein E4 status. In a mixed-effects model adjusted for age, sex, education status, and baseline level of global cognition, increased muscle strength was associated with a slower rate of decline in global cognitive function (P < .001). Muscle strength was associated with a decreased risk of MCI, the precursor to AD (hazard ratio, 0.67; 95% confidence interval, 0.54-0.84).

Conclusion: These findings suggest a link between muscle strength, AD, and cognitive decline in older persons.


Although Alzheimer disease (AD) is characterized clinically by a progressive deterioration in memory and other cognitive abilities, it is associated with various noncognitive features, including affective manifestations (eg, depressive symptoms) and impaired motor function (eg, gait impairment). Recent data suggest that these noncognitive features may be early signs of AD, as they often predict the onset of clinical AD. Although grip strength is related to the risk of AD, few studies have examined grip strength, and the more general association of muscle strength (measured in multiple body regions) with incident AD remains unknown. Furthermore, body mass index (BMI) and physical activity are related to the risk of AD, yet it is unclear whether the association of muscle strength with AD is independent of these important confounding variables.

We used data from the Rush Memory and Aging Project, a longitudinal study of aging, to examine the association of muscle strength with incident AD in more than 900 well-characterized persons initially free of dementia. Participants underwent structured evaluations of muscle strength, including strength testing of 9 muscle groups in the extremities and axial muscle strength based on maximum inspiratory pressure and maximum expiratory pressure and on detailed annual cognitive evaluations. Furthermore, because progressive cognitive decline is the hallmark of AD, we examined the relation between muscle strength and cognitive decline. Finally, we examined the association of muscle strength with the risk of incident mild cognitive impairment (MCI), the earliest manifestation of AD.
ASSESSMENT OF MUSCLE STRENGTH

A composite measure of muscle strength derived from testing in 11 muscle groups (including arms, legs, and 2 axial muscles) was used in this study, as previously described. Appendicular muscle strength was measured using a handheld dynamometer (model 01163, Lafayette Manual Muscle Test System; Lafayette Instrument Co USA, Lafayette, Indiana) in the upper extremities (abduction, flexion, and extension in both arms) and in the lower extremities (hip flexion, knee extension, plantar flexion, and ankle dorsiflexion in both legs). Grip and pinch strength were measured bilaterally using the hydraulic hand and pinch dynamometer (Jamar; Lafayette Instrument Co USA). Axial strength was measured using a handheld device containing a pressure-sensitive transducer to assess maximal pressures generated during inspiration (maximum inspiratory pressure) and expiration (maximum expiratory pressure). Bilateral measures were averaged, and the scores from each muscle group were converted to $\tilde{z}$ scores using sex-specific numbers and spacing of evaluations, or missing data at some visits. Tests were converted to $\tilde{z}$ scores of all 19 tests were averaged and the $\tilde{z}$ scores from the Stroop Test, a 15-item Judgment of Line Orientation, and a 16-item Standard Progressive Matrices. To compute the composite, the raw scores on each of the individual tests were converted to $\tilde{z}$ scores using the baseline mean (SD) of the entire cohort, and the $\tilde{z}$ scores of all 19 tests were averaged. Further psychometric information on this composite is given in previous publications.

ASSESSMENT OF GLOBAL COGNITION

Cognitive function was assessed at each evaluation via 21 tests. The Mini-Mental State Examination scores were used to describe the cohort, and Complex Ideational Material was used for diagnostic classification. Scores on the following 19 tests were used to create a composite measure of global cognition: immediate and delayed recall of story A from Logical Memory, immediate and delayed recall of the East Boston Story, Word List Memory, Word List Recall, Word List Recognition, a 15-item Boston Naming Test, Verbal Fluency, a 15-item reading test, Digit Span Forward, Digit Span Backward, Digit Ordering, Symbol Digit Modalities Test, Number Comparison, 2 indexes from the Stroop Test, a 15-item Judgment of Line Orientation, and a 16-item Standard Progressive Matrices. To compute the composite, the raw scores on each of the individual tests were converted to $\tilde{z}$ scores using the baseline mean (SD) of the entire cohort, and the $\tilde{z}$ scores of all 19 tests were averaged. Further psychometric information on this composite is given in previous publications.

ASSESSMENT OF COVARIATES

Age, sex, race/ethnicity, and education status were recorded at baseline. Weight and height were measured and recorded at each visit, and BMI was calculated as weight in kilograms divided by height in meters squared. Vascular diseases included stroke, claudication, and myocardial infarction, and vascular risk factors included smoking, hypertension, and diabetes mellitus; the numbers of diseases and risk factors present at baseline were used in analyses. Pulmonary function was tested using a handheld spirometer that measured vital capacity, forced expiratory volume, and peak expiratory flow. Physical activity was evaluated using questions from the 1985 Health Interview Survey.

STATISTICAL ANALYSIS

Pearson product moment correlations were used to examine bivariate associations, and $t$ tests were used to compare men vs women and participants who did vs those who did not develop AD. A proportional hazards model with time to AD as the outcome was used to examine the association of muscle strength with the risk of incident AD; this model controlled for age, sex, and education status. We also examined the influence of important covariates, conducted a series of sensitivity analyses, and, finally, examined the association of strength with the risk of MCI.

Mixed-effects models were used to examine the association of muscle strength with cognitive decline. Therefore, we estimated the mean change in the group (conditional on covariates) as in standard fixed-effects repeated-measures models, and the mixed-effects model included random coefficients that provided estimates of individual differences from the group. Each participant was assumed to follow the average path of the group except for random effects that caused the baseline level of cognition to be lower or higher and the rate of change in cognition to be faster or slower. The variance-covariance matrix for the random coefficients was not assumed to be of a restricted form, and we assumed that residual error was normally distributed and independent of the random effects. A major strength of this approach is the ability to model all data available for each participant regardless of length of follow-up, number and spacing of evaluations, or missing data at some evaluations.

The mixed-effects model controlled for age, sex, and education status and included terms for time, time squared, muscle...
strength, and the interaction of muscle strength with time. We also tested for nonlinearity in the association of the strength measure with cognition, but because this was not significant, the term for time squared–muscle strength was not retained in the final models. All models were validated graphically and analytically, and programming was performed using commercially available statistical software (SAS, version 8; SAS Institute Inc, Cary, North Carolina).30

**RESULTS**

**METRIC PROPERTIES OF THE COMPOSITE MEASURE OF MUSCLE STRENGTH**

Muscle strength ranged from −1.600 to 3.300 U (mean [SD], 0.006 [0.660] U), with higher scores reflecting greater strength. Muscle strength was negatively associated with age (r=−0.35, P<.001) and was positively associated with global cognition (r=0.20, P<.001).

**MUSCLE STRENGTH AND THE RISK OF AD**

Over a mean of 3.6 follow-up years, 138 participants (14.2% of 970) developed AD. Participants who developed AD were older, had lower cognitive function, and showed decreased strength in several muscles compared with participants who did not (Table). In the core proportional hazards model adjusted for age, sex, and education status, muscle strength was associated with the risk of developing AD, such that each 1-U increase in muscle strength (based on 11 muscle groups) at baseline was associated with about a 43% decrease in the risk of AD (hazard ratio [HR], 0.57; 95% confidence interval [CI], 0.41-0.79). **Figure 1** shows that a participant having a high level of muscle strength (90th percentile [score, 0.850]) had about a 61% decreased risk of developing AD compared with a participant having a low level of muscle strength (10th percentile [score, −0.810]).

Next, because prior studies12,13 have shown that grip strength is related to the risk of AD and it is possible that our finding was driven by grip strength, we constructed a proportional hazards model to simultaneously examine the relative predictive association of the components of strength (ie, grip strength and all other measures of upper extremity strength, lower extremity

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Table. Baseline Characteristics of Participants Who Developed vs Those Who Did Not Develop Alzheimer Disease (AD)a

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Developed AD (n = 138)</th>
<th>Did Not Develop AD (n = 832)</th>
<th>P Valueb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>84.5 (6.0)</td>
<td>79.8 (7.3)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Education, y</td>
<td>14.5 (3.0)</td>
<td>14.8 (7.2)</td>
<td>.90</td>
</tr>
<tr>
<td>Muscle strength, lb,c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm abduction</td>
<td>3.5 (2.4)</td>
<td>4.0 (2.2)</td>
<td>.02</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>11.6 (4.7)</td>
<td>12.9 (5.4)</td>
<td>.004</td>
</tr>
<tr>
<td>Elbow extension</td>
<td>9.6 (3.5)</td>
<td>10.8 (3.9)</td>
<td>.001</td>
</tr>
<tr>
<td>Grip</td>
<td>43.2 (17.6)</td>
<td>49.3 (18.0)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Pinch</td>
<td>9.9 (5.1)</td>
<td>10.9 (5.0)</td>
<td>.03</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>9.8 (4.1)</td>
<td>10.6 (4.7)</td>
<td>.03</td>
</tr>
<tr>
<td>Knee extension</td>
<td>9.9 (3.8)</td>
<td>10.8 (4.1)</td>
<td>.02</td>
</tr>
<tr>
<td>Ankle plantar flexion</td>
<td>14.6 (4.5)</td>
<td>15.2 (5.2)</td>
<td>.13</td>
</tr>
<tr>
<td>Ankle dorsiflexion</td>
<td>10.4 (4.0)</td>
<td>11.7 (5.0)</td>
<td>.001</td>
</tr>
<tr>
<td>Pulmonary function, cm H2O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum expiratory pressure</td>
<td>60.8 (25.2)</td>
<td>68.1 (24.5)</td>
<td>.002</td>
</tr>
<tr>
<td>Maximum inspiratory pressure</td>
<td>33.8 (18.4)</td>
<td>41.7 (20.8)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Body mass indexc</td>
<td>26.3 (4.1)</td>
<td>27.5 (5.5)</td>
<td>.004</td>
</tr>
<tr>
<td>Physical activity, h/vwk</td>
<td>3.1 (3.8)</td>
<td>3.1 (3.6)</td>
<td>.80</td>
</tr>
<tr>
<td>Vascular risk factors, No. of conditions present</td>
<td>1.1 (1.0)</td>
<td>1.2 (1.0)</td>
<td>.70</td>
</tr>
<tr>
<td>Vascular diseases, No. of conditions present</td>
<td>0.4 (0.6)</td>
<td>0.3 (0.6)</td>
<td>.40</td>
</tr>
<tr>
<td>Mini-Mental State Examination score</td>
<td>26.3 (2.8)</td>
<td>28.3 (1.8)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Global cognition score</td>
<td>−0.41 (0.49)</td>
<td>0.22 (0.48)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

a Men represented 19.5% (among participants who developed AD) and 80.5% (among participants who did not develop AD) of the cohort (P=.03).

b Statistical significance is based on t test or χ2 test, as appropriate.

c To convert pounds to kilograms, multiply by 1.6.

d Calculated as weight in kilograms divided by height in meters squared.

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MUSCLE STRENGTH AND CHANGE IN GLOBAL COGNITIVE FUNCTION

Because AD develops slowly over many years and its hallmark is change in cognitive function, we examined the association of muscle strength with cognitive decline. At baseline, scores on the composite measure of global cognition (based on 19 tests) ranged from −1.80 to 1.40 (mean [SD], 0.12 [0.54]), with higher scores indicating better performance. We constructed a mixed-effects model that controlled for age, sex, and education status and included terms for time, time squared, muscle strength, and the interaction of muscle strength with time to examine the association of strength with cognitive decline. Scores on the composite measure of global cognition showed linear and nonlinear decline (P < .05 for both). Furthermore, each 1-U increase in muscle strength at baseline was associated with about a 0.040-U decrease in the rate of decline in global cognition (P < .001). Figure 2 shows that the rate of cognitive decline for a participant with a high level of muscle strength (90th percentile [score, 0.850 U]) was considerably slower than that of a participant with a low level of muscle strength (10th percentile [score, −0.810 U]). The addition of covariates did not substantially affect the association between muscle strength and the rate of cognitive decline (data not shown).

MUSCLE STRENGTH AND THE RISK OF MCI

Finally, because it is widely recognized that most persons who develop AD transition through an early stage of impairment referred to as MCI, we excluded participants with any evidence of cognitive impairment at baseline, and the association of muscle strength with AD persisted (HR, 0.48; 95% CI, 0.30-0.77). Finally, we repeated the core analysis after excluding participants in the bottom 15% in terms of muscle strength at baseline, and the association of muscle strength with AD persisted (HR, 0.57; 95% CI, 0.33-0.90).

SENSITIVITY ANALYSES

We conducted a series of sensitivity analyses to address the possibility that the findings were driven by the inclusion of participants with very early and undiagnosed AD or participants with the lowest function at baseline. We repeated the core analysis after sequentially excluding participants who developed AD in the first year of follow-up (n = 32) and then in the first or second year of follow-up (n = 74); in these analyses, the association of muscle strength with AD was not substantially changed (HR, 0.59; 95% CI, 0.40-0.86; and 0.61; 0.37-1.03; respectively). Next, we repeated the core analysis after excluding participants in the bottom 15% in terms of cognition at baseline, and the association of muscle strength with AD persisted (HR, 0.48; 95% CI, 0.30-0.77). Finally, we repeated the core analysis after excluding participants in the bottom 15% in terms of muscle strength at baseline, and the association of muscle strength with AD persisted (HR, 0.57; 95% CI, 0.33-0.90).
In more than 900 well-characterized community-based older persons without dementia, we found that greater muscle strength was associated with a decreased risk of developing AD. This finding persisted in sensitivity analyses in which we excluded participants who developed AD in the early follow-up years and participants with the lowest function at baseline and in models that controlled for BMI, physical activity, pulmonary function, vascular risk factors, vascular diseases, and the presence of the apolipoprotein E4 allele. Furthermore, muscle strength was associated with the rate of cognitive decline, such that participants with greater strength at baseline exhibited a considerably slower rate of decline. Finally, in an analysis that excluded participants with dementia or MCI at baseline, muscle strength was associated with the risk of developing MCI, the earliest manifestation of cognitive impairment. Overall, these data show that greater muscle strength is associated with a decreased risk of developing AD and MCI and suggest that a common pathogenesis may underlie loss of muscle strength and cognition in aging.

Although the clinical hallmark of AD is declining cognition, motor signs that frequently accompany AD often precede and predict the clinical diagnosis of AD. Loss of muscle strength and mass also are common in aging, and frailty and BMI changes are associated with the risk of AD. While measures of frailty and BMI can be obtained inexpensively, they do not inform about the role of muscle mass vs muscle strength in the risk of AD, and recent data suggest that muscle strength is associated with cognition independent of muscle mass. To date, data on muscle strength and AD are limited. One study reported that grip strength was predictive of cognitive decline in older Mexican Americans, but this study likely included persons with mild dementia at baseline. In a cohort of Catholic clergy, it was found that grip strength was associated with incident AD. Although these findings are important and motivated the present study, grip strength may not fully capture the association of muscle strength (measured more comprehensively) with the risk of AD. We quantified muscle strength in all 4 extremities and in the axial muscles among a large cohort of older persons and found that greater muscle strength was associated with a reduced risk of AD. Furthermore, in analyses of the components of muscle strength, axial muscle strength was associated with the risk of AD even after accounting for grip strength, suggesting that comprehensive assessments of strength may be useful for identifying persons at risk for cognitive impairment. Finally, muscle strength was associated with a substantially decreased risk of MCI, suggesting a temporal relation whereby impaired muscle strength precedes the development of cognitive impairment in age-related cognitive impairment.
Author Contributions: Study concept and design: Boyle, Buchman, and Bennett. Acquisition of data: Buchman and Bennett. Analysis and interpretation of data: Boyle, Buchman, Wilson, Leurgans, and Bennett. Drafting of the manuscript: Boyle and Buchanan. Critical revision of the manuscript for important intellectual content: Boyle, Buchanan, Wilson, Leurgans, and Bennett. Statistical analysis: Boyle and Leurgans. Obtained funding: Buchanan and Bennett. Administrative, technical, and material support: Buchanan and Wilson. Study supervision: Bennett.

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