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Effects of Sedentary Behavior, Physical Activity, Frequency of Protein Consumption, Lower Extremity Strength and Lean Mass on All-Cause Mortality

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Background: No study has evaluated the potential independent and cumulative effects of physical activity, sedentary behavior, daily frequency of protein consumption, lean mass and muscular strength on mortality risk.
Methods: Data from the 1999-2002 NHANES were utilized (N = 1,079 adults 50-85 yr), with follow-up through 2011. Leg lean mass was estimated from DXA scans. Knee extensor strength was assessed using the Kin Com MP dynamometer. Physical activity and sedentary behavior were assessed via questionnaire, with the number of meals/day of ≥30 g of protein/meal assessed via a "multiple pass" 24-hour dietary interview. An index score was created (range = 0-5) indicating the number of these health characteristics each participant had.
Results: Only less sedentary behavior was independently associated with reduced mortality risk ($HR_{adjustment}$ = 0.46; 0.32-0.66). After adjustments, and compared to those with an index score of 0, those with an index score of 1, 2 and 3+, respectively, had a 34%, 49%, and 57% reduced risk of all-cause mortality.
Conclusion: While considering physical activity, sedentary behavior, daily protein frequency consumption, lean mass and muscular strength, only sedentary behavior was independently associated with mortality risk among older adults.

Key Words: Epidemiology, Muscle mass, Muscle strength, Protein distribution

INTRODUCTION

Concurrent engagement in multiple health behaviors, such as dietary behavior and regular physical activity, are favorably associated with lower extremity strength and lean mass [1], cardiovascular disease risk [2] and mortality risk [3]. Of interest in this paper is the potential independent and combined effects of five health-related parameters on mortality risk, with these including physical activity behavior, frequency of daily protein consumption, sedentary behavior, lower extremity strength, and lower extremity lean mass. Previous work has evaluated these parameters individually and demonstrated that physical activity behavior [4-9], frequency of daily protein consumption [10,11], sedentary behavior [12-19], lower extremity strength [4,20-22], and lower extremity lean mass [10,23] are associated with health outcomes, including mortality risk. We also acknowledge the potential interrelationships among these health parameters [10,24]. In concert, the aforementioned parameters are known to influence functional health, mobility, and body

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composition, but may also be independently associated with decreased mortality risk, even after adjusting for comorbidities [10,24-31]. What has yet to be evaluated, however, is whether these 5 health-related parameters are independently associated with mortality risk, or if indeed there are combined effects of these parameters on mortality risk. Thus, the purpose of this brief report was to evaluate the potential independent and combined effects of physical activity behavior, frequency of daily protein consumption, sedentary behavior, lower extremity strength, and lower extremity lean mass on all-cause mortality risk.

MATERIALS AND METHODS

1. Design and participants

Data were extracted from the 1999-2002 NHANES (only cycles with lower extremity muscle strength/lean mass data). Data from participants in these cycles were linked to death certificate data from the National Death Index. Person-months of follow-up were calculated from the date of the interview until date of death or censoring on December 31, 2011, whichever came first.

NHANES evaluates a representative sample of non-institutionalized U.S. civilians, selected by a complex, multistage probability design. NHANES is conducted by the National Center for Health Statistics (NCHS), and all procedures for data collection were approved by the NCHS ethics review board. Analyses were based on participants who provided data for the study variables and who did not have a physician-diagnosis of diabetes, coronary artery disease, musculoskeletal conditions (e.g., arthritis), on statin or anti-hypertensive medication, or consumed <600 or >4000 kcal/day. Notably, only those 50 and older were eligible for the muscle strength assessment. The analyzed sample included 1,079 consented adults (50-85 yr).

2. Peak knee extensor muscle strength

As described elsewhere [1,10], a Kin Com MP dynamometer (Chattanooga Group, Inc., Hixson, TN, USA) was used to assess voluntary peak isokinetic knee extensor strength in Newtons (at a speed of 60 degrees/second). A total of 6 measurements of muscle strength of the right quadriceps were taken: three warm-up trial measurements followed by 3 outcome measurements. If a participant completed 4-6 measures, the highest peak force was selected from trials 4 to 6; however, if a participant completed fewer than 4 measures, the highest peak force from the warm-up trials was selected. All values were gravity corrected for limb and lever arm weight [32]. Participants were defined as high strength if they were in the top quartile (i.e., >340 N) [21].

3. Leg lean mass

Leg lean mass was estimated using whole-body dual-energy x-ray absorptiometry (DXA) scans using the Hologic QDR 4500A fan beam x-ray bone densitometer (Hologic, Inc, Bedford, MA, USA) [1]. Lower extremity lean mass was calculated by summing the lower extremity lean mass (excluding bone mineral content) of the left and right legs. Notably, we included both left and right leg as the zero-order correlation of lean mass between the legs was, $r = 0.988$ ($p < 0.0001$). Participants were defined as high lean mass if they were in the top quartile (i.e., >17,545 g).

4. Frequency of protein consumption

A "multiple pass" 24-hour dietary interview format was used to collect detailed information about the participant's dietary behavior [1]. This multiple pass format included asking participants to recall all foods and beverages consumed in a 24-hour period the day before the interview; report the time in which each food was eaten and what they would call the eating occasion for the food (e.g., breakfast); food probes were used to collect detailed information for each food reported; and the final reported foods were reviewed with the respondent in chronological order. Herein, we report the total daily consumption of protein (g), carbohydrate (g), total fat (g) and energy (kcal).

Similar to other work [1], of interest in this study was the meal frequency in which participants consumed adequate levels of dietary protein throughout the day. Thus, we evaluated the summed number of meals individuals consumed ≥30 g of protein per meal. This protein frequency variable could range from 0-6 (breakfast, brunch, lunch, snack, dinner, evening snack), but because of cell size considerations at greater protein frequency (i.e., number of meals/day ≥30 g of protein per meal), we recoded this protein frequency variable as <2 or 2+ meals/day ≥30 g of protein per meal.

5. Physical activity

The present study utilized self-reported physical activity data, as opposed to objectively-measured physical activity data, given that the objectively-measured physical activity data employed in NHANES was not collected until the 2003-2004 cycle; as stated previously, cycles 1999-2002 were evaluated herein because these are the only cycles with lower extremity strength data. As described elsewhere [33], participants were asked open-ended questions about participation in leisure-time physical activity over the past 30 days. Data was coded into 48 activities, including 16 sports-related activities, 14 exercise-related activities, and 18 recreational-related activities.

For each of the 48 activities where participants reported moderate or vigorous-intensity for the respective activity, they were asked to report the number of times they engaged in that activity over the past 30 days and the average duration they engaged in that activity. For each activity, Metabolic Equivalent of Task (MET)-min-month was calculated by multiplying the number of days, by the mean duration, by the respective MET level (MET-min-month = days × duration × MET level). The MET levels for each activity are provided elsewhere [34]. Participants were defined as meeting physical activity guidelines if they engaged in at least 2000 MET-min-month [33]. As described elsewhere, this physical activity assessment has demonstrated evidence of convergent validity by positively associating with accelerometer-assessed physical activity [33].

6. Sedentary time

Detailed previously [22], participants were asked, "*Over the past 30 days, on a typical day how much time altogether did you spend sitting and watching TV or videos or using a computer outside of work*?" Response options: less than 1 hr, 1 hr, 2 hrs, 3 hrs, 4 hrs, or 5+ hrs. In alignment with the other evaluated behaviors (physical activity and protein behavior) in the present study, this sedentary behavior variable was treated as a binary variable; participants were classified as ≤4 hrs/day of sedentary behavior or 5+ hrs/day, based on recent prospective research demonstrating that this level (5+ hrs/day) of sedentary behavior is associated with an increased mortality risk [35]. Notably, we also evaluated other thresholds (e.g., <2 vs. 2+ hrs/day), but results were unchanged, and thus, we chose to utilize the 5 hr/day threshold.

This screen-based sedentary behavior item has been shown to correlate with body mass index categories [36], which may, speculatively, provide some suggestive evidence of construct validity in that previous work has demonstrated a positive association between changes in sedentary behavior and body mass index [37]. Using data from the 2003-2006 NHANES (cycles with objective 'overall' sedentary data), we computed the correlation between this self-report screen-based sedentary behavior item and identical categories (hrs/day) of accelerometer-determined sedentary behavior (counts/min <100); a weak statistically significant association ($r = 0.10$, $p < 0.0001$) was observed, which is not unexpected as this self-report screen-based sedentary item only assessed non-occupational sedentary behavior, whereas accelerometry assesses overall daily sedentary behavior. This observed correlation is within the range ($r = -0.19$ to 0.80) of a review paper documenting the concurrent validity of television viewing time and other non-occupational sedentary behaviors (referent measures included heart rate monitoring, behavioral logs and accelerometry combined with behavioral logs) [38]; notably, only 3 of the evaluated studies from this review examined the validity of self-reported television viewing time and other non-occupational sedentary behaviors. This review, did, however, demonstrate moderate-to-high reliability of these measures (the majority of the ICC's were >0.5).

7. Index variable

An index variable was created ranging from 0-5, indicating the number of positive characteristics the participant had. For example, a participant was given an index score of 5 if they: met physical activity guidelines (moderate-to-vigorous physical activity ≥2000 MET-min-month), had fewer than 5 hrs/day of leisure-time sedentary behavior, consumed 2+ meals/day ≥30 g of protein per meal, and were in the top quartile for both lower extremity lean mass and strength.

8. Statistical analyses

All analyses were performed in Stata (v. 12) and accounted for the complex survey design employed in NHANES. A Cox proportional hazard model was employed. Schoenfeld's residuals were used to verify the proportional hazards assumption. There was no evidence of collinearity in the model as the highest correlation between two independent variables was, r = 0.57 (strength and lean mass). In the models, covariates included relative protein intake (g/kg), total daily carbohydrate (g), total daily fat (g), age (continuous; y), gender (male/female), race-ethnicity (Mexican American, other Hispanic, non-Hispanic white, non-Hispanic black, and other), *mean arterial pressure* (continuous; mmHg), and *self-reported smoking status* (current, former, never). Statistical significance was established as $p < 0.05$.

RESULTS

Participants, on average, were 60.7 years, with the sample equally distributed across gender (52.8% female). The percent of participants with 2+ meals/day of ≥30 g of protein per meal was 17.3%; the mean hrs/day of sedentary behavior was 2.3; mean MVPA MET-min-month was 4045.8; mean leg mass was 15011 g; and mean peak knee extensor strength was 376 N. During the median follow-up period of 124 months (IQR = 112-137), 227 participants died. In the sample, 127,719 person-months were observed with a mortality incidence of 1.77 deaths per 1,000 person-months.

Table 1 displays the results for the weighted Cox proportional hazard model. All five parameters were inversely associated with all-cause mortality risk, but only less sedentary behavior was statistically significantly associated with reduced mortality risk after adjustments ($HR_{adjustment}$ = 0.46; 0.32-0.66; $p < 0.001$). Notably, in an unadjusted model (not shown in tabular format), only strength (HR = 0.52; 95% CI: 0.33-0.83; p = 0.009) and less sedentary behavior (HR = 0.39; 95% CI: 0.25-0.60; $p < 0.001$) were statistically significantly associated with reduced mortality risk.

With regard to the Index model, 182, 366, 312, 142, 64, and 13 participants had an index score of 0-5, respectively. As such, the index variable was recoded as 0, 1, 2, and 3+. After adjustments, and compared to those with an index score of 0, those with an index score of 1, 2 and 3, respectively, had a 34% ($HR_{adjusted}$ = 0.66; 95% CI: 0.38-1.12; p = 0.12), 49% ($HR_{adjusted}$ = 0.51; 95% CI: 0.27-0.95, p = 0.03), and 57% ($HR_{adjusted}$ = 0.43; 95% CI: 0.22-0.86; p = 0.01) reduced risk of all-cause mortality. The Kaplan-Meier survival curve depicting probability of survival across these index scores is shown in Fig. 1.

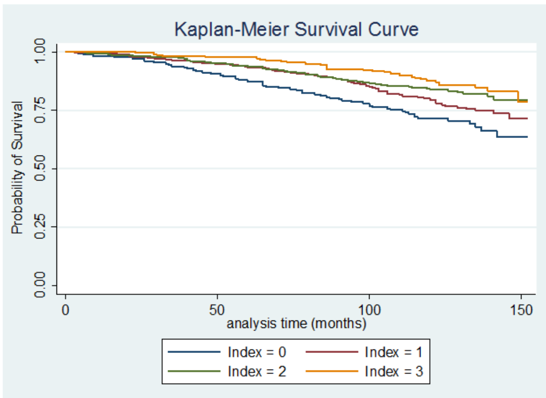

Fig. 1. Kaplan-Meier survival curve.

Table 1. Weighted multivariable Cox proportional hazard analysis

Independent Variable	Hazard Ratio	95% CI	p-value
Meets MVPA Guidelines vs. not	0.80	0.54-1.17	0.24
<5 hrs/day of sedentary behavior vs. 5+ hrs/day	0.46	0.32-0.66	<0.001
2+ meals/day 30 g of protein per meal vs. <2 meals/day	0.99	0.53-1.86	0.99
Top quartile for lean mass vs. not	0.88	0.55-1.42	0.61
Top quartile for muscular strength vs. not	0.75	0.47-1.20	0.22

In the model, covariates included *relative protein intake* (g/kg), *total daily carbohydrate* (g), *total daily fat* (g), age (continuous; y), *gender* (male/female), *race-ethnicity* (Mexican American, other Hispanic, non-Hispanic white, non-Hispanic black, and other), *mean arterial pressure* (continuous; mmHg), and *self-reported smoking status* (current, former, never).

DISCUSSION

Previous research demonstrates that physical activity behavior [4-9], frequency of daily protein consumption [10,11], sedentary behavior [12-19], lower extremity strength [4,20-22], and lower extremity lean mass [10,23] are associated with health outcomes, including mortality risk. What has yet to be examined, however, is the unique contribution of each of these parameters within the same model on mortality risk. The major finding of the present study was that sedentary behavior, unlike the other 4 health-related parameters, was independently associated with mortality risk. However, there was some evidence (via the index model) that those with more of these health characteristics had a lower mortality risk when compared to those with fewer of these health characteristics.

A potential explanation for the distinct relationship between time spent participating in sedentary behavior and risk of all-cause mortality may be consequences of the modern office environment. Technological innovations advance workplace efficiency and productivity, but may impose substantial daily movement constraints. Many Americans are employed in sedentary professions, which present a difficult obstacle to accumulating adequate physical activity [39,40]. Research indicates office workers spend more than fifty percent of their workday sitting [41], and that, on workdays, employees may engage in seated tasks for nearly two hours longer than days spent outside of the office [42]. Further, inactivity on the job may contribute to over half of total weekly sedentary time [43]. Even among those meeting physical activity guidelines, active behaviors appear to be poor compensatory strategies against the detrimental impact of prolonged rest/leisure time [44-46]. Our results align with this hypothesis, as average time spent participating in physical activity was 4045.8 MVPA MET-min-month for this sample. Thus, although participants' average activity level was well above the recommended 2000 MET-min-month [33], and was inversely associated with all-cause mortality risk, this relationship did not achieve statistical significance. Conversely, participants' average sedentary time was 2.3 hours, well below the pre-determined mortality-risk threshold of >5 hrs/day [35], yet reduced sedentary time was a statistically significant independent predictor of all-cause mortality; the only significant predictor variable determined by our analysis.

Emerging work consistently demonstrates that sedentary behavior is independently associated with mortality risk [47]. For example, Biswas et al. [47] recently reviewed the literature via a meta-analysis evaluating outcomes for cardiovascular disease and diabetes (14 studies), cancer (14 studies), and all-cause mortality (13 studies). Higher levels of sedentary behavior were independently associated with increased all-cause mortality (HR, 1.24), cardiovascular disease mortality (HR, 1.18), cardiovascular disease incidence (HR, 1.14), cancer mortality (HR, 1.17), cancer incidence (HR, 1.13) and type 2 diabetes incidence (HR, 1.91). Based on these findings, coupled with the present study's observation, minimizing prolonged sedentary behavior among older adults is of critical importance. Strategies to accomplish this have recently been discussed in the SOS-framework (Systems of Sedentary behaviors) [48].

Health promotion professionals should support physical activity initiatives aiming to increase opportunities for light physical activity in office environments [45]. Substituting prolonged seated behavior with brief movement breaks is suggested to combat adverse health risks linked with multimorbidity and mortality [49,50]. Such breaks are not expected to interfere with office productivity [51], and may even limit employee stress, anxiety, and depression [52], which arguably, would elevate workplace performance.

In conclusion, and while considering physical activity, sedentary behavior, daily protein frequency consumption, lean mass and muscular strength, only sedentary behavior was independently associated with mortality risk among older adults. However, there was some evidence that those with more of these health characteristics had a lower mortality risk. Despite the notable strengths of this study, which include the evaluation of a comprehensive mortality risk model, employing a national sample with a reasonable follow-up duration, and utilizing several objective measures, a limitation of the present study is the utilization of a subjective assessment of sedentary behavior. As such, future confirmatory work, particularly utilizing an objective measure of sedentary behavior, is warranted.

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