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Adult height, dietary patterns, and healthy aging

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ABSTRACT

Background: Adult height has shown directionally diverse associations with several age-related disorders, including cardiovascular disease, cancer, decline in cognitive function, and mortality.

Objectives: We investigated the associations of adult height with healthy aging measured by a full spectrum of health outcomes, including incidence of chronic diseases, memory, physical functioning, and mental health, among populations who have survived to older age, and whether lifestyle factors modified such relations.

Design: We included 52,135 women (mean age: 44.2 y) from the Nurses' Health Study without chronic diseases in 1980 and whose health status was available in 2012. Healthy aging was defined as being free of 11 major chronic diseases and having no reported impairment of subjective memory, physical impairment, or mental health limitations.

Results: Of all eligible study participants, 6877 (13.2%) were classified as healthy agers. After adjustment for demographic and lifestyle factors, we observed an 8% (95% CI: 6%, 11%) decrease in the odds of healthy aging per SD (0.062 m) increase in height. Compared with the lowest category of height (≤1.57 m), the OR of achieving healthy aging in the highest category (≥1.70 m) was 0.80 (95% CI: 0.73, 0.87; *P*-trend < 0.001). In addition, we found a significant interaction of height with a prudent dietary pattern in relation to healthy aging (*P*-interaction = 0.005), and among the individual dietary factors characterizing the prudent dietary pattern, fruit and vegetable intake showed the strongest effect modification (*P*-interaction = 0.01). The association of greater height with reduced odds of healthy aging appeared to be more evident among women with higher adherence to the prudent dietary pattern rich in vegetable and fruit intake.

Conclusions: Greater height was associated with a modest decrease in the likelihood of healthy aging. A prudent diet rich in fruit and vegetables might modify the relation. *Am J Clin Nutr* doi: https://doi.org/10.3945/ajcn.116.147256.

Keywords: adult height, healthy aging, lifestyle, dietary pattern, fruit and vegetables

INTRODUCTION

It is projected that, by 2030, 1 in every 5 Americans will be aged ≥65 y (1). The subsequent increase in age-related diseases and functional disabilities will cause enormous medical and societal burdens. Although evidence is accumulating, the impact of early-life exposures on the health conditions of older adults remains largely unknown (2).

Adult height reflects the interplay of genetic endowment and various early-life exposures, such as fetal, nutritional, socioeconomic, and psychological circumstances (3, 4). Current studies found that height was differentially related to various age-related diseases. For example, greater adulthood height was related to an increased risk of pancreatic, ovary, breast, and prostate cancers (5, 6) but a reduced risk of morbidity and mortality from coronary artery disease (5, 7). In addition, independent of educational attainment, greater height was related to better cognitive functioning as well as better physical and mental health in later life (8, 9). To the best of our knowledge, however, no study has assessed how and why height might affect overall health and well-being among populations who have survived to older age.

Therefore, we investigated the associations of height with healthy aging measured by a full spectrum of health outcomes, including incidence of chronic diseases, memory, physical functioning, and mental status, as well as these separate domains of healthy aging in a cohort of US women in the Nurses' Health Study. Because lifestyle factors, including dietary behaviors at midlife, are among the most important modifiable determinants of the aging process (10–15), we specifically assessed whether lifestyle factors in adulthood modified the relation of height with healthy aging.

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Supplemental Figure 1 and Supplemental Tables 1 and 2 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://ajcn.nutrition.org.

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METHODS

Study population

The Nurses' Health Study is a prospective study in a cohort of 121,700 female registered nurses aged 30–55 y from 11 states who were enrolled in 1976. Participants were followed with the use of validated questionnaires every 2 y with detailed reporting of medical history, lifestyle, and health practices (16–20). A follow-up rate of ≥90% has been achieved throughout. The study protocol was approved by the Institutional Review Board of the Brigham and Women's Hospital. Return of the questionnaires was considered to imply informed consent.

In the current analysis, we used 1980 as the study baseline, when information on major covariates, such as physical activity and multivitamin and aspirin use, and diet was first assessed. Of 68,590 nurses who returned the 2012 questionnaire, we excluded 4 participants aged >55 y in 1976, 49 participants with missing information on height, and 3130 participants who were diagnosed with any of 11 chronic diseases (e.g., cancer and myocardial infarction, as addressed below) before baseline. We also excluded 480 participants who skipped >5 items on the physical function scale and 12,792 participants who skipped any item on the subjective memory or 15-item Geriatric Depression Scale (GDS-15) score, as we previously documented (21, 22), which left 52,135 participants available for the present analyses (**Supplemental Figure 1**). The participants aged 33.5–60.6 y in 1980 and 65.5–93.3 y in 2012. We compared baseline characteristics of the participants who did not return the 2012 questionnaire with that of our study population (**Supplemental Table 1**). Women who did not return the 2012 questionnaire were older and more likely to be smokers and hypertensive.

Assessment of height, lifestyle, and covariates

Participants were requested to report current height at the time of enrollment. Self-reported height as an estimate of true height has been validated against measured height with a correlation of 0.94 (23). Data on demographic characteristics, lifestyle, and health practices, such as age, education, marriage status, smoking status, body weight, menopausal status and postmenopausal hormone use, family history of myocardial infarction, diabetes, cancer, multivitamin and aspirin use, and history of hypertension and hypercholesterolemia, were obtained from biennial questionnaires. BMI was calculated as weight in kilograms divided by height squared in meters. Physical activity was assessed every 2–4 y by using validated Nurses' Health Study Physical Activity Questionnaire (17). Dietary intake was assessed by means of a validated semiquantitative Willett food-frequency questionnaire administered every 4 y, which inquired about usual consumption of foods, beverages, and supplements during the past year (20). The derivation of dietary patterns was previously described in detail (24, 25). Briefly, the items on the food-frequency questionnaire were first aggregated into 37–39 food groups on the basis of similarities in nutrient profile and culinary preference. Second, factor analysis (principal components analysis) was applied with the orthogonal rotation procedure varimax to the predefined food groups. Two major dietary patterns were identified (24–26): a high prudent dietary pattern score was characterized by high intakes of vegetables, fruit, legumes, fish, poultry, and whole grains, whereas a high Western pattern score represented high intakes of red and processed meats, refined grains, French fries, and sweets and desserts. Lifestyle factors and covariates assessed in 1980 were used in the analyses.

Ascertainment of healthy aging

We updated the definition of healthy aging from what was described previously (13, 14). Healthy aging was considered as being free of 11 major chronic diseases with no impairment of memory, no impairment of physical function, and good mental health; otherwise, aging was considered as usual aging. Healthy aging was separated from usual aging on the basis of the 4 health domains as of 2012 when the information on mental, physical, and memory was available for participants. A description of each of the 4 domains is listed below.

Assessment of chronic diseases

From biennial questionnaires, the medical history of 11 major chronic diseases was determined, including cancer (except for nonmelanoma skin cancer), type 2 diabetes, myocardial infarction, coronary artery bypass graft surgery or percutaneous transluminal coronary angioplasty, congestive heart failure, stroke, kidney failure, chronic obstructive pulmonary disease, Parkinson disease, multiple sclerosis, and amyotrophic lateral sclerosis. Self-reported health information has been shown to have a high validity in this cohort of nurses (16).

Assessment of memory

Subjective memory was assessed on the basis of 7 questions with regard to memory complaints about change in ability to remember things and trouble in remembering recent events, short lists, one second to the next, spoken instructions, following conversations or plot, and finding the way on familiar streets. Subjective memory complaints have been associated with performance on objective cognitive tests (21, 22). No more than 1 memory complaint was considered as the absence of impairment of memory.

Assessment of physical function

Physical function was assessed on the basis of 10 questions according to the Medical Outcomes Study Short-Form Health Survey (SF-36), which is a 36-item questionnaire that evaluates 8 health concepts including physical function and mental health (27). The 10 questions inquired about physical limitations in performing the following activities: moderate activities (e.g., moving a table, pushing a vacuum cleaner, bowling, playing golf); bathing and dressing yourself; walking 1 block; walking several blocks; walking >1 mile; vigorous activities (e.g., running, lifting heavy objects, strenuous sports); bending, kneeling, or stooping; climbing 1 flight of stairs; climbing several flights of stairs; and lifting or carrying groceries. Each question had the same 3 response choices: "Yes, limited a lot," "Yes, limited a little," or "No, not limited at all." No impairment of physical function was identified as having no limitations on moderate activities and no more than moderate limitations on vigorous activities.

Assessment of mental status

Mental status was assessed by using the GDS-15 (28). Good mental health status was defined as a GDS-15 score ≤1 (the median value in the analytic cohort).

Statistical analysis

We modeled height both in categories and continuously as height per SD. The participants were divided into categories according to height in meters, including ≤1.57, 1.58–1.62, 1.63–1.65, 1.66–1.69, and ≥1.70 m. Multivariable-adjusted logistic regression was used to model the association between height and the odds of healthy aging as well as each of the 4 domains, including being free of 11 major chronic diseases, no impairment of subjective memory, no impairment of physical function, and good mental health. A linear trend across height categories was quantified with a Wald test by assigning the median value to each category and modeling this value as continuous. We adjusted for potential confounding variables, including age, ethnicity, marriage status, education, menopausal status and postmenopausal hormone use, smoking status, alcohol intake, physical activity, BMI, family history of myocardial infarction, cancer, diabetes, baseline history of hypertension and hypercholesterolemia, aspirin use, multivitamin use, total energy intake, and dietary quality as assessed by the Alternate Healthy Eating Index score. We also adjusted for several socioeconomic variables such as husband's education and father's and mother's occupations, which did not influence the primary relations of height to healthy aging in multivariable-adjusted models, so these covariates were not controlled for in the results presented in this article. An OR >1 in these models indicates that height is associated with increased (i.e., better) odds of healthy aging, whereas an OR <1 indicates reduced (i.e., worse) odds of healthy aging.

We explicitly assessed potential effect modification by lifestyle factors at baseline, including BMI (in kg/m^2; ≥25 compared with <25), smoking status (current smoker compared with current nonsmoker), alcohol intake (drinkers compared with nondrinkers), levels of physical activity (median), prudent dietary pattern score (median), and Western dietary pattern score (median). We constructed cross-product terms between height and these factors, with the significance of multiplicative interaction determined by using Wald's test. For any significant interaction, we further assessed the joint associations of height and the lifestyle factor with healthy aging by classifying participants according to combined categories of height and lifestyle factors. Statistical analyses were conducted by using SAS software version 9.3 (SAS Institute, Inc.). All *P* values were 2-sided, and $P < 0.05$ was considered significant.

RESULTS

Of the total of 52,135 participants in our study, 27,430 (52.6%) women had none of the 11 chronic diseases included in the definition of healthy aging, 37,614 (72.2%) reported no impairments in subjective memory, 13,398 (25.7%) had no impairment of physical function, and 31,722 (60.9%) had good mental health. Overall, 6877 women (13.2%) met the criteria of healthy agers, whereas the remaining 45,258 women (86.8%) were considered to be usual agers. **Table 1** shows the characteristics of the participants in 1980 by categories of height. The mean height was 1.64 m, with a SD of 0.062 m. The mean height and categories of height were similar to the reported values for white women in the United States (29). Compared with persons in the lowest category of height (≤1.57 m), taller individuals were leaner, had a higher alcohol consumption and total energy intake, and were less likely to have hypertension and hypercholesterolemia.

Table 2 presents the association between adult height and the odds of healthy aging. In age-adjusted analyses, height was associated with decreased odds of healthy aging. Compared with the lowest category of height, the OR in the highest category was 0.84 (95% CI: 0.78, 0.91; *P*-trend < 0.001). After adjustment for demographic, lifestyle, and dietary factors, we observed an 8% (95% CI: 6%, 11%) decrease in the odds of healthy aging per SD of greater height. The OR in the highest category was 0.80 (95% CI: 0.73, 0.87; *P*-trend < 0.001) in comparison to the lowest category.

The associations of height with each domain of healthy aging are shown in **Supplemental Table 2**. Greater height was significantly associated with increased odds of having any of 11 major chronic diseases, having impairment of physical function, and having mental health limitations. Compared with the lowest category of height, the multivariable-adjusted ORs in the highest category were 0.92 (95% CI: 0.87, 0.97; *P*-trend < 0.001) for being free of chronic diseases, 0.72 (95% CI: 0.68, 0.77; *P*-trend < 0.001) for having no impairment of physical function, and 0.83 (95% CI: 0.79, 0.88; *P*-trend < 0.001) for having good mental health. When height was evaluated continuously, per-SD greater height was associated with a 3% (95% CI: 1%, 5%) decreased odds of being free of chronic diseases, an 11% (95% CI: 9%, 13%) decreased odds of having no impairment of physical function, and a 6% (95% CI: 4%, 8%) decreased odds of having good mental health. In contrast, height was not significantly associated with the odds of having no impairment of subjective memory (extreme-category OR: 1.06; 95% CI: 1.00, 1.12; *P*-trend = 0.17).

In stratified analyses of height and healthy aging by baseline lifestyle characteristics, including BMI, smoking status, alcohol intake, physical activity, prudent dietary pattern score, and Western dietary pattern score (**Table 3**), a significant interaction was observed between height and prudent dietary pattern score on healthy aging (*P*-interaction = 0.005). The association of greater height with a reduced odds of healthy aging was more evident among participants with a higher prudent pattern score (extreme-category OR: 0.69; 95% CI: 0.61, 0.79) compared with those with a lower prudent pattern score (extreme-category OR: 0.92; 95% CI: 0.81, 1.05). We did not observe a significant effect modification by any of the other factors. Greater height was consistently associated with decreased odds of healthy aging in each subgroup.

We found that among individual dietary factors characterizing the prudent dietary pattern, fruit and vegetable intake showed the strongest interaction with height (*P*-interaction = 0.01), so we further classified participants according to combined categories of height and prudent dietary pattern score (**Figure 1**) as well as fruit and vegetable intake (**Figure 2**) with the group who had the shortest stature and the highest prudent dietary pattern score and fruit and vegetable intake as the reference. The benefits of higher adherence to a prudent dietary pattern rich in vegetable and fruit intake appeared to be more evident among women with

TABLE 1
Baseline age-adjusted characteristics of participants by categories of height in the Nurses' Health Study[1]

	Categories of adult height				
	1 (n = 11,439)	2 (n = 6161)	3 (n = 16,362)	4 (n = 7365)	5 (n = 10,808)
Height range, m	≤1.57	1.58–1.62	1.63–1.65	1.66–1.69	≥1.70
Age,[2] y	44.5 ± 6.6	44.6 ± 6.6	44.3 ± 6.5	44.1 ± 6.3	43.7 ± 6.2
White, %	95.8	97.9	98.0	98.1	98.3
Education, %					
Registered nurse	70.0	69.0	67.6	66.2	64.3
Bachelor	19.8	20.2	21.2	22.1	23.6
Master's or higher	10.2	10.8	11.3	11.7	12.1
Marriage status, %					
Married	92.8	92.3	92.8	92.9	92.8
Widowed	2.1	2.1	1.9	1.7	1.9
Separated/divorced	5.2	5.6	5.3	5.3	5.3
BMI, kg/m^2	24.2 ± 4.2	24.0 ± 4.1	23.9 ± 4.0	23.7 ± 4.0	23.6 ± 3.9
Physical activity, h/wk	4.0 ± 2.9	4.1 ± 2.9	4.2 ± 2.9	4.2 ± 2.9	4.1 ± 2.9
Alcohol intake, g/d	5.3 ± 9.1	5.8 ± 9.5	6.1 ± 9.6	6.2 ± 9.7	6.7 ± 10.2
Menopausal status and postmenopausal hormone use, %					
Premenopausal	68.5	68.4	69.1	69.5	68.9
Postmenopausal, never used hormones	18.6	18.4	18.5	18.0	17.8
Postmenopausal, current hormone user	6.2	6.3	6.3	6.3	6.8
Postmenopausal, past hormone user	6.6	6.9	6.1	6.2	6.6
Smoking status, %					
Never smoked	49.1	48.7	47.8	45.1	44.3
Past smoker	26.7	27.3	27.6	29.5	30.2
Current smoker	22.1	22.0	22.5	23.5	23.4
Aspirin use, %	40.1	40.1	40.5	39.8	41.2
Multivitamin use, %	27.1	29.1	29.7	30.1	30.2
Family history of myocardial infarction, %	20.2	18.0	17.9	18.1	18.0
Family history of diabetes, %	28.9	28.1	26.9	27.3	26.3
Family history of cancer, %	11.8	12.1	11.8	13.1	13.3
Hypertension, %	11.0	10.7	10.9	10.5	10.5
Hypercholesterolemia, %	4.3	3.9	3.8	3.3	2.7
Total energy intake, kcal/d	1533.2 ± 494.1	1531.6 ± 482.0	1559.1 ± 487.1	1582.8 ± 486.9	1595.5 ± 492.7
Fruit and vegetable intake, servings/d	3.3 ± 1.9	3.3 ± 1.8	3.3 ± 1.9	3.4 ± 1.9	3.4 ± 1.9
Alternate Healthy Eating Index score	33.8 ± 8.7	33.8 ± 8.7	33.6 ± 8.7	33.5 ± 8.7	33.6 ± 8.9
Prudent dietary pattern score[3]	0.1 ± 0.7	0.0 ± 0.7	0.0 ± 0.7	0.1 ± 0.7	0.1 ± 0.7
Western dietary pattern score[3]	0.2 ± 0.9	0.2 ± 0.9	0.2 ± 0.9	0.2 ± 0.9	0.2 ± 0.9

[1] n = 52,135. Values are means ± SDs unless otherwise indicated and are standardized to the age distribution of the study population.
[2] Values are not age adjusted.
[3] The factor score for each pattern was calculated by summing intakes of food groups weighted by their factor loadings. Factor scores were standardized with a mean of 0 and an SD of 1. Factor loadings represent correlation coefficients between the food groups and the particular pattern, with positive loadings representing positive correlations and negative loadings representing inverse correlations. Each woman received a factor score for each identified pattern.

shorter height. Compared with the reference, the multivariable-adjusted OR was 0.68 (95% CI: 0.57, 0.80) for women in the highest tertile of height and the lowest category of prudent dietary pattern score and 0.61 (95% CI: 0.52, 0.72) for women in the highest tertile of height and the lowest category of fruit and vegetable intake.

DISCUSSION

In this large prospective cohort of US women, we documented a linear, inverse relation between adult height and overall healthy aging in later life. In addition, we found that the association between height and healthy aging was significantly modified by a prudent dietary pattern rich in fruit and vegetables.

Our findings are in line with the previous notion that shorter stature may offer particular advantages in health and promote longevity (30). The inverse relation of height with longevity has been described in different populations (31). In Japanese, greater height was positively associated with all-cause mortality and inversely associated with the longevity-associated genetic variants (32). Longevity describes life span, whereas healthy aging indicates health span. Although not identical, these 2 outcomes are intimately related, and individuals who live exceptionally long would also be healthy for much of their lives (33). The biological mechanisms that link attained adult height and aging are intricate and far from being fully understood. Extended longevity was well documented in mouse models with defects in growth hormone and insulin-like growth factor I (IGF-I) signaling (34–36). Genetic variations that cause reduced insulin and IGF-I activation were significantly associated with shorter stature and improved old age survival in women (37, 38). Therefore, the IGF-I signaling pathway regulated by growth hormone or insulin may play a crucial role in linking adult height and the human aging process.

TABLE 2
ORs (95% CIs) of healthy aging according to categories of height[1]

	Categories of height						
	1	2	3	4	5	Per SD[2]	*P*-trend[3]
Median height, m	1.57	1.60	1.63	1.68	1.73		
Healthy ager, *n* (%)	1532 (13)	832 (14)	2224 (14)	960 (13)	1329 (12)		
Age-adjusted	1.00 (ref)	1.02 (0.93, 1.12)	1.00 (0.93, 1.07)	0.94 (0.86, 1.02)	0.84 (0.78, 0.91)	0.94 (0.91, 0.96)	<0.001
Multivariable-adjusted[4]	1.00 (ref)	1.00 (0.90, 1.10)	0.96 (0.89, 1.04)	0.88 (0.81, 0.97)	0.80 (0.73, 0.87)	0.92 (0.89, 0.94)	<0.001

[1] An OR <1 denotes reduced odds of healthy aging. These analyses included 6877 healthy agers and 45,258 usual agers. ref, reference.
[2] The SD for height was 0.062 m.
[3] *P*-trend was assessed by assigning the median value in each category to participants and evaluating this as a continuous variable.
[4] Logistic regression models were adjusted for the following: age (years); ethnicity (white: yes or no); education (registered nurse, bachelor, or graduate); marriage status (married, widowed, or separated/divorced); menopausal status (pre- or postmenopausal; never, past, or current menopausal hormone use); smoking status (never smoked; pack-years: 1.0–9.9, 10.0–24.9, 25.0–44.9, or ≥45.0); alcohol intake (0, 0.1–4.9, 5.0–14.9, 15.0–19.9, 20.0–29.9, or ≥30.0 g/d); physical activity (0, 0.01–0.9, 1.0–3.5, 3.6–6.0, or ≥6 h/wk); BMI (kg/m^2; <23.0, 23.0–24.9, 25.0–26.9, 27.0–28.9, 29.0–30.9, 31.0–32.9, 33.0–34.9, 35.0–36.9, 37.0–38.9, 39.0–40.9, 41.0–42.9, 43.0–44.9, or ≥45.0); family history of myocardial infarction, cancer, or diabetes (yes or no); baseline history of hypertension or hypercholesterolemia (yes or no); aspirin use (yes or no); multivitamin use (yes or no); total energy intake (quintiles); and Alternate Healthy Eating Index score (quintiles).

The relation between height and healthy aging was not modified by lifestyle factors such as BMI, smoking, alcohol intake, or physical activity. Intriguingly, we found significant interactions between height and a prudent dietary pattern high in fruit and vegetables. Diet is one of the most important modifiable determinants of the "healthy aging phenotype" (10, 11), and compelling

TABLE 3
ORs (95% CIs) of healthy aging, stratified by lifestyle factors[1]

	Categories of height						
	1	2	3	4	5	Per SD[2]	*P*-interaction
BMI							0.09
≥25 kg/m^2	1.00 (ref)	0.93 (0.71, 1.22)	0.92 (0.75, 1.13)	0.76 (0.58, 0.99)	0.66 (0.52, 0.84)	0.84 (0.78, 0.91)	
<25 kg/m^2	1.00 (ref)	0.99 (0.89, 1.10)	0.96 (0.89, 1.04)	0.92 (0.84, 1.02)	0.84 (0.77, 0.92)	0.94 (0.91, 0.97)	
Smoking status							0.60
Current smokers	1.00 (ref)	0.97 (0.78, 1.22)	0.83 (0.69, 0.99)	0.88 (0.71, 1.09)	0.82 (0.68, 1.00)	0.93 (0.87, 0.99)	
Non–current smokers	1.00 (ref)	1.00 (0.90, 1.11)	0.99 (0.91, 1.07)	0.88 (0.79, 0.97)	0.78 (0.71, 0.86)	0.91 (0.88, 0.94)	
Alcohol intake							0.34
Drinkers	1.00 (ref)	1.04 (0.93, 1.16)	0.95 (0.87, 1.03)	0.86 (0.77, 0.96)	0.80 (0.72, 0.88)	0.91 (0.89, 0.94)	
Nondrinkers	1.00 (ref)	0.87 (0.71, 1.07)	1.01 (0.87, 1.17)	0.96 (0.80, 1.16)	0.80 (0.68, 0.96)	0.93 (0.87, 0.98)	
Physical activity							0.24
≥3 h/wk	1.00 (ref)	1.02 (0.87, 1.19)	0.97 (0.87, 1.10)	0.85 (0.74, 0.98)	0.77 (0.67, 0.88)	0.89 (0.85, 0.93)	
<3 h/wk	1.00 (ref)	0.96 (0.82, 1.13)	1.01 (0.89, 1.14)	0.94 (0.81, 1.09)	0.81 (0.71, 0.93)	0.93 (0.89, 0.97)	
Prudent dietary pattern score							0.005
≥−0.07	1.00 (ref)	0.88 (0.76, 1.02)	0.92 (0.82, 1.03)	0.84 (0.73, 0.96)	0.69 (0.61, 0.79)	0.88 (0.84, 0.91)	
<−0.07	1.00 (ref)	1.12 (0.97, 1.30)	1.05 (0.93, 1.18)	0.90 (0.78, 1.04)	0.92 (0.81, 1.05)	0.95 (0.91, 0.99)	
Western dietary pattern score							0.05
≥0.10	1.00 (ref)	0.99 (0.86, 1.15)	0.95 (0.85, 1.07)	0.84 (0.73, 0.98)	0.82 (0.72, 0.93)	0.92 (0.88, 0.96)	
<0.10	1.00 (ref)	0.99 (0.85, 1.15)	0.99 (0.88, 1.11)	0.88 (0.76, 1.01)	0.77 (0.67, 0.87)	0.90 (0.86, 0.94)	

[1] An OR <1 denotes reduced odds of healthy aging. For BMI, the analysis included 719 healthy agers and 12,633 usual agers among women with a BMI (in kg/m^2) ≥25 and 6158 healthy agers and 32,625 usual agers among women with a BMI <25. For smoking status, the analysis included 1180 healthy agers and 10,646 usual agers among current smokers and 5697 healthy agers and 34,612 usual agers among current nonsmokers. For alcohol intake, the analysis included 5289 healthy agers and 33,607 usual agers among drinkers and 1588 healthy agers and 11,651 usual agers among nondrinkers. For physical activity, the analysis included 2957 healthy agers and 14,780 usual agers among women with a physical activity level ≥3 h/wk and 2480 healthy agers and 20,489 usual agers among women with a physical activity level <3 h/wk. For the prudent dietary pattern score, the analysis included 2969 healthy agers and 18,992 usual agers among women with a prudent dietary pattern score ≥−0.07 and 2875 healthy agers and 19,289 usual agers among women with a prudent dietary pattern score <−0.07. For the Western dietary pattern score, the analysis included 2819 healthy agers and 19,298 usual agers among women with a Western dietary pattern score ≥0.10 and 3025 healthy agers and 18,983 usual agers among women with a Western dietary pattern score <0.10. Logistic regression models were adjusted for the following: age (years); ethnicity (white: yes or no); education (registered nurse, bachelor, or graduate); marriage status (married, widowed, or separated/divorced); menopausal status (pre- or postmenopausal; never, past, or current menopausal hormone use); smoking status (never smoked; pack-years: 1.0–9.9, 10.0–24.9, 25.0–44.9, or ≥45.0); alcohol intake (0, 0.1–4.9, 5.0–14.9, 15.0–19.9, 20.0–29.9, or ≥30.0 g/d); physical activity (0, 0.01–1.0, 1.0–3.5, 3.6–6.0, or ≥6.0 h/wk); BMI (kg/m^2; <23.0, 23.0–24.9, 25.0–26.9, 27.0–28.9, 29.0–30.9, 31.0–32.9, 33.0–34.9, 35.0–36.9, 37.0–38.9, 39.0–40.9, 41.0–42.9, 43.0–44.9, or ≥45.0); family history of myocardial infarction, cancer, or diabetes (yes or no); baseline history of hypertension or hypercholesterolemia (yes or no); aspirin use (yes or no); multivitamin use (yes or no); total energy intake (quintiles); and Alternate Healthy Eating Index score (quintiles). ref, reference.
[2] The SD for height was 0.062 m.

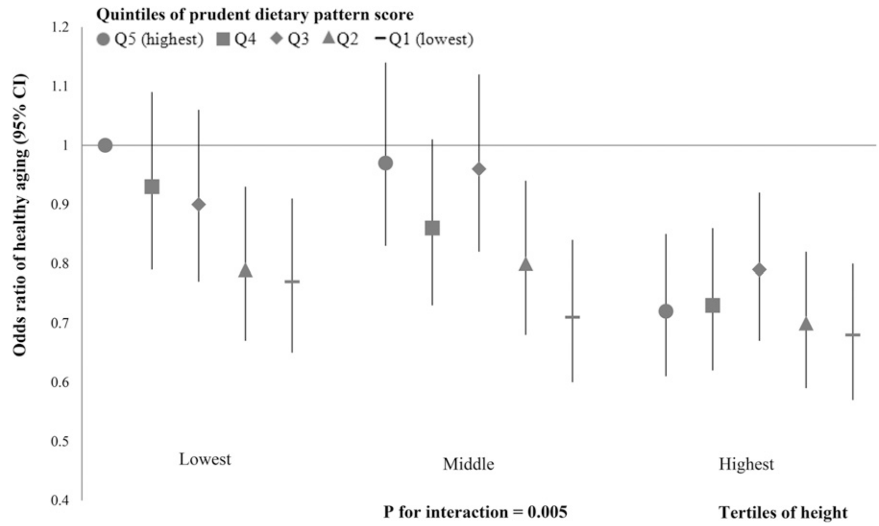

FIGURE 1 ORs (95% CIs) of healthy aging according to joint categories of height and prudent dietary pattern score. The analysis included 5844 healthy agers and 38,281 usual agers. The logistic regression model was adjusted for the following: age (years); ethnicity (white: yes or no); education (registered nurse, bachelor, or graduate); marriage status (married, widowed, or separated/divorced); menopausal status (pre- or postmenopausal; never, past, or current menopausal hormone use); smoking status (never smoked; pack-years: 1.0–9.9, 10.0–24.9, 25.0–44.9, or ≥45.0); alcohol intake (0, 0.1–4.9, 5.0–14.9, 15.0–19.9, 20.0–29.9, or ≥30.0 g/d); physical activity (0, 0.01–0.9, 1.0–3.5, 3.6–5.9, or ≥6.0 h/wk); BMI (kg/m^2: <23.0, 23.0–24.9, 25.0–26.9, 27.0–28.9, 29.0–30.9, 31.0–32.9, 33.0–34.9, 35.0–36.9, 37.0–38.9, 39.0–40.9, 41.0–42.9, 43.0–44.9, or ≥45.0); family history of myocardial infarction, cancer, or diabetes (yes or no); baseline history of hypertension or hypercholesterolemia (yes or no); aspirin use (yes or no); multivitamin use (yes or no); and total energy intake (quintiles). Q, quintile.

evidence has suggested that a dietary pattern rich in fruit, vegetables, fish, whole grains, and starchy low-fat staple foods are likely to play key roles in promoting healthy aging (11, 39, 40). In addition to being genetically determined, attained adult height is a marker of early-life exposures affecting childhood and adolescent growth (e.g., maternal diet during pregnancy, childhood diet, infection, and psychological stress) (4, 41), which are thought to affect health during adulthood. The health effects of aging start early in life and are modulated by the accumulation of both early- and late-life exposures throughout the life course. Our results suggest that individuals of different stature may carry distinct burdens of risk factors accumulated during early life and therefore exhibit divergent susceptibilities to the effects of late-life lifestyle factors on healthy aging. The beneficial effect of an increased

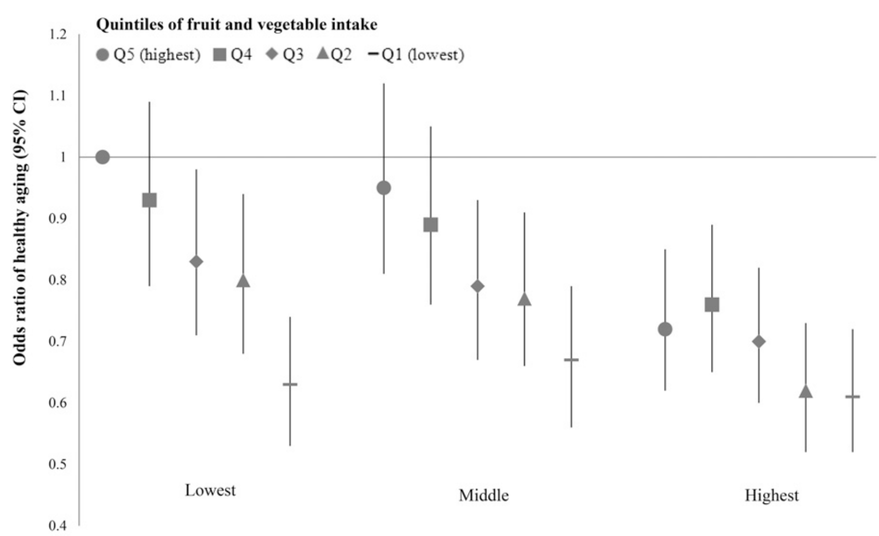

FIGURE 2 ORs (95% CIs) of healthy aging according to joint categories of height and dietary intake of fruit and vegetables. The analysis included 5844 healthy agers and 38,281 usual agers. The logistic regression model was adjusted for the following: age (years); ethnicity (white: yes or no); education (registered nurse, bachelor, or graduate); marriage status (married, widowed, or separated/divorced); menopausal status (pre- or postmenopausal; never, past, or current menopausal hormone use); smoking status (never smoked; pack-years: 1.0–9.9, 10.0–24.9, 25.0–44.9, or ≥45.0); alcohol intake (0, 0.1–4.9, 5.0–14.9, 15.0–19.9, 20.0–29.9, or ≥30.0 g/d); physical activity (0, 0.01–0.9, 1.0–3.5, 3.6–6.0, or ≥6.0 h/wk); BMI (kg/m^2: <23.0, 23.0–24.9, 25.0–26.9, 27.0–28.9, 29.0–30.9, 31.0–32.9, 33.0–34.9, 35.0–36.9, 37.0–38.9, 39.0–40.9, 41.0–42.9, 43.0–44.9, or ≥45.0); family history of myocardial infarction, cancer, or diabetes (yes or no); baseline history of hypertension or hypercholesterolemia (yes or no); aspirin use (yes or no); multivitamin use (yes or no); total energy intake (quintiles); and modified Alternate Healthy Eating Index score (excluding fruit and vegetables; quintiles). Q, quintile.

prudent dietary pattern score and fruit and vegetable intake was more evident in the lowest and middle tertiles of height than in the highest tertile. This interaction between height and diet provides supportive evidence for the development of precision dietary interventions based on individual differences in height, which may be more effective in preventing age-related dysfunction.

Of the individual component of aging, the strongest association was observed between greater height and decreased odds of no impairment of physical function. Intuitively, taller individuals may have more difficulty in bending, twisting, and running, whereas shorter stature confers substantial nimbleness and flexibility in daily activities. Our results indicated that such height-related differences in physical function might become even more marked in old age. Despite the divergent associations of height with various age-related diseases (5–7), our data indicated that greater height was associated with a modest decrease in the odds of being free of major chronic diseases, which might be partly due to the disease spectrum in our study cohort. In addition, we found that greater height was associated with decreased odds of having good mental health status but not with subjective memory. Because taller stature is proposed as a proxy for higher socioeconomic status and superior nutrition as well as other conditions during early childhood, one might expect taller persons to have better physical functioning, mental health status, and memory in later life, as seen in the limited previous studies (8). In our study, however, additional adjustment for several indicators, such as husband's education and father's and mother's occupations, did not materially alter the associations, and the relative homogeneity of the cohort in educational attainment and profession also helped control for the potential influence of socioeconomic status.

Our study has important strengths. To the best of our knowledge, this study is the first to investigate the association between adult height and overall health status in women who have survived to older ages and also the first to investigate how height, an indicator of genetics and early-life exposures, and adulthood dietary behaviors are jointly related to healthy aging. Other strengths include a comprehensive assessment of overall health, a high follow-up rate, accurate self-reported incidence of chronic diseases, and validated methods to quantify physical and mental status. A large sample size provided the statistical power to detect relevant associations. Comprehensive information on demographic characteristics, lifestyle, and diet minimized the potential for residual confounding. We also tried to reduce possible bias due to reverse causation by excluding participants with chronic diseases at baseline, because these individuals might have changed their diet and lifestyle habits after being diagnosed with a major health condition.

Several potential limitations of our study should also be considered. First, our cohort included mostly registered nurses of European ancestry and who were largely healthy at midlife, so the results may not be readily generalizable to other populations. However, as mentioned above, the relative homogeneity of the study population in educational attainment and socioeconomic status enhanced the internal validity. Second, we could not exclude participants with impaired physical function, mental health, and subjective memory in midlife because those data were not available at baseline. Third, some known or unknown demographic, lifestyle, socioeconomic, or behavioral factors may affect both attained adult height and healthy aging, and thus contribute to the observed association between them. Although we adjusted for multiple potential confounders, residual confounding might exist because of unmeasured (e.g., income) or imprecisely measured (e.g., self-reported physical activity) confounders. However, taller persons were generally healthier in lifestyle, which resulted in an even stronger association in the multivariate model, which indicated an underestimation of the effect size with an inadequate control for confounding. Fourth, we acknowledge that the results might depend on the distribution of height and variability in the number of participants in each category. However, the inverse relation between height and healthy aging remained robust when modeling height as continuous. Finally, we acknowledge that adult height might not be a causal risk factor for overall health status but rather an indicator of genetic background and various early-life exposures.

In summary, we found that greater adult height was associated with decreased overall health status among women who had survived to older ages, and this relation was modified by a prudent diet rich in fruit and vegetables. Future investigations are warranted to verify our findings in other populations and to elucidate the height-associated biological mechanisms underlying healthy aging.

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The authors' responsibilities were as follows—WM and LQ: conceived the study and designed and drafted the manuscript; WM: performed the statistical analysis; KAH and LQ: provided statistical advice; LQ: had full access to all of the data in the study and took responsibility for the integrity of the data and the accuracy of the data analysis; and all authors: interpreted the data and critically revised the manuscript for important intellectual content, and read and approved the final manuscript. None of the authors reported a conflict of interest related to the study.

REFERENCES

1. Ortman JM, Velkoff VA, Hogan H. An aging nation: the older population in the United States. Washington (DC): US Census Bureau; 2014.
2. McEniry M. Early-life conditions and older adult health in low- and middle-income countries: a review. J Dev Orig Health Dis 2013;4:10–29.
3. Wood AR, Esko T, Yang J, Vedantam S, Pers TH, Gustafsson S, Chu AY, Estrada K, Luan J, Kutalik Z, et al. Defining the role of common variation in the genomic and biological architecture of adult human height. Nat Genet 2014;46:1173–86.
4. Silventoinen K. Determinants of variation in adult body height. J Biosoc Sci 2003;35:263–85.
5. Emerging Risk Factors Collaboration. Adult height and the risk of cause-specific death and vascular morbidity in 1 million people: individual participant meta-analysis. Int J Epidemiol 2012;41:1419–33.
6. Green J, Cairns BJ, Casabonne D, Wright FL, Reeves G, Beral V; Million Women Study Collaborators. Height and cancer incidence in the Million Women Study: prospective cohort, and meta-analysis of prospective studies of height and total cancer risk. Lancet Oncol 2011; 12:785–94.
7. Paajanen TA, Oksala NK, Kuukasjarvi P, Karhunen PJ. Short stature is associated with coronary heart disease: a systematic review of the literature and a meta-analysis. Eur Heart J 2010;31:1802–9.
8. Case A, Paxson C. Height, health, and cognitive function at older ages. Am Econ Rev 2008;98:463–7.
9. Guven C, Lee WS. Height and cognitive function at older ages: is height a useful summary measure of early childhood experiences? Health Econ 2013;22:224–33.

10. Mathers JC. Nutrition and ageing: knowledge, gaps and research priorities. Proc Nutr Soc 2013;72:246–50.
11. Kiefte-de Jong JC, Mathers JC, Franco OH. Nutrition and healthy ageing: the key ingredients. Proc Nutr Soc 2014;73:249–59.
12. Haveman-Nies A, de Groot LC, van Staveren WA. Dietary quality, lifestyle factors and healthy ageing in Europe: the SENECA study. Age Ageing 2003;32:427–34.
13. Sun Q, Townsend MK, Okereke OI, Franco OH, Hu FB, Grodstein F. Physical activity at midlife in relation to successful survival in women at age 70 years or older. Arch Intern Med 2010;170:194–201.
14. Sun Q, Townsend MK, Okereke OI, Rimm EB, Hu FB, Stampfer MJ, Grodstein F. Alcohol consumption at midlife and successful ageing in women: a prospective cohort analysis in the Nurses' Health Study. PLoS Med 2011;8:e1001090.
15. Chakravarty EF, Hubert HB, Krishnan E, Bruce BB, Lingala VB, Fries JF. Lifestyle risk factors predict disability and death in healthy aging adults. Am J Med 2012;125:190–7.
16. Colditz GA, Martin P, Stampfer MJ, Willett WC, Sampson L, Rosner B, Hennekens CH, Speizer FE. Validation of questionnaire information on risk factors and disease outcomes in a prospective cohort study of women. Am J Epidemiol 1986;123:894–900.
17. Wolf AM, Hunter DJ, Colditz GA, Manson JE, Stampfer MJ, Corsano KA, Rosner B, Kriska A, Willett WC. Reproducibility and validity of a self-administered physical activity questionnaire. Int J Epidemiol 1994;23:991–9.
18. Rimm EB, Stampfer MJ, Colditz GA, Chute CG, Litin LB, Willett WC. Validity of self-reported waist and hip circumferences in men and women. Epidemiology 1990;1:466–73.
19. Colditz GA, Stampfer MJ, Willett WC, Stason WB, Rosner B, Hennekens CH, Speizer FE. Reproducibility and validity of self-reported menopausal status in a prospective cohort study. Am J Epidemiol 1987;126:319–25.
20. Willett WC, Sampson L, Stampfer MJ, Rosner B, Bain C, Witschi J, Hennekens CH, Speizer FE. Reproducibility and validity of a semi-quantitative food frequency questionnaire. Am J Epidemiol 1985;122:51–65.
21. Amariglio RE, Townsend MK, Grodstein F, Sperling RA, Rentz DM. Specific subjective memory complaints in older persons may indicate poor cognitive function. J Am Geriatr Soc 2011;59:1612–7.
22. Samieri C, Proust-Lima C, Glymour MM, Okereke OI, Amariglio RE, Sperling RA, Rentz DM, Grodstein F. Subjective cognitive concerns, episodic memory, and the APOE epsilon4 allele. Alzheimers Dement 2014;10:752–9, e1.
23. Troy LM, Hunter DJ, Manson JE, Colditz GA, Stampfer MJ, Willett WC. The validity of recalled weight among younger women. Int J Obes Relat Metab Disord 1995;19:570–2.
24. Fung TT, Schulze M, Manson JE, Willett WC, Hu FB. Dietary patterns, meat intake, and the risk of type 2 diabetes in women. Arch Intern Med 2004;164:2235–40.
25. Heidemann C, Schulze MB, Franco OH, van Dam RM, Mantzoros CS, Hu FB. Dietary patterns and risk of mortality from cardiovascular disease, cancer, and all causes in a prospective cohort of women. Circulation 2008;118:230–7.
26. Fung TT, Hu FB, Holmes MD, Rosner BA, Hunter DJ, Colditz GA, Willett WC. Dietary patterns and the risk of postmenopausal breast cancer. Int J Cancer 2005;116:116–21.
27. McHorney CA, Ware JE Jr., Raczek AE. The MOS 36-Item Short-Form Health Survey (SF-36): II. Psychometric and clinical tests of validity in measuring physical and mental health constructs. Med Care 1993;31:247–63.
28. de Craen AJ, Heeren TJ, Gussekloo J. Accuracy of the 15-item Geriatric Depression Scale (GDS-15) in a community sample of the oldest old. Int J Geriatr Psychiatry 2003;18:63–6.
29. Fryar CD, Gu Q, Ogden CL, Flegal KM. Anthropometric reference data for children and adults: United States, 2011–2014. Vital Health Stat 3 2016;3:1–46.
30. Bartke A. Healthy aging: is smaller better? A mini-review. Gerontology 2012;58:337–43.
31. Samaras TT. How height is related to our health and longevity: a review. Nutr Health 2012;21:247–61.
32. He Q, Morris BJ, Grove JS, Petrovitch H, Ross W, Masaki KH, Rodriguez B, Chen R, Donlon TA, Willcox DC, et al. Shorter men live longer: association of height with longevity and FOXO3 genotype in American men of Japanese ancestry. PLoS One 2014;9:e94385.
33. Brooks-Wilson AR. Genetics of healthy aging and longevity. Hum Genet 2013;132:1323–38.
34. Brown-Borg HM, Borg KE, Meliska CJ, Bartke A. Dwarf mice and the ageing process. Nature 1996;384:33.
35. Coschigano KT, Holland AN, Riders ME, List EO, Flyvbjerg A, Kopchick JJ. Deletion, but not antagonism, of the mouse growth hormone receptor results in severely decreased body weights, insulin, and insulin-like growth factor I levels and increased life span. Endocrinology 2003;144:3799–810.
36. Russell SJ, Kahn CR. Endocrine regulation of ageing. Nat Rev Mol Cell Biol 2007;8:681–91.
37. van Heemst D, Beekman M, Mooijaart SP, Heijmans BT, Brandt BW, Zwaan BJ, Slagboom PE, Westendorp RG. Reduced insulin/IGF-1 signalling and human longevity. Aging Cell 2005;4:79–85.
38. Suh Y, Atzmon G, Cho MO, Hwang D, Liu B, Leahy DJ, Barzilai N, Cohen P. Functionally significant insulin-like growth factor I receptor mutations in centenarians. Proc Natl Acad Sci USA 2008;105:3438–42.
39. Samieri C, Sun Q, Townsend MK, Chiuve SE, Okereke OI, Willett WC, Stampfer M, Grodstein F. The association between dietary patterns at midlife and health in aging: an observational study. Ann Intern Med 2013;159:584–91.
40. Shakersain B, Santoni G, Larsson SC, Faxen-Irving G, Fastbom J, Fratiglioni L, Xu W. Prudent diet may attenuate the adverse effects of Western diet on cognitive decline. Alzheimers Dement 2016;12:100–9.
41. Batty GD, Shipley MJ, Gunnell D, Huxley R, Kivimaki M, Woodward M, Lee CM, Smith GD. Height, wealth, and health: an overview with new data from three longitudinal studies. Econ Hum Biol 2009;7:137–52.