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ORIGINAL ARTICLE

Socioeconomic status in relation to incident fracture risk in the Study of Women's Health Across the Nation

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Abstract
Summary We examined baseline and annual follow-up data (through annual follow-up visit 9) from a cohort of 2,234 women aged 42 to 52 years at baseline. Independent of financial status, higher educational level was associated with lower fracture incidence among non-Caucasian women but not among Caucasian women.

Introduction This study was conducted to determine the associations of education and income with fracture incidence among midlife women over 9 years of follow-up.
Methods We examined baseline and annual follow-up data (through annual follow-up visit 9) from 2,234 participants of the Study of Women's Health Across the Nation, a cohort of women aged 42 to 52 years at baseline. We used Cox proportional hazards regression models to examine the associations of socioeconomic predictors (education, family-adjusted poverty-to-income ratio, and difficulty paying for basics) with time to first incident nontraumatic, nondigital, noncraniofacial fracture.
Results Independent of family-adjusted poverty-to-income ratio, higher educational level was associated with decreased time to first incident fracture among non-Caucasian women but not among Caucasian women ($p_{\text{interaction}}$ 0.02). Compared with non-Caucasian women who completed no more than high school education, non-Caucasian women who attained at least some postgraduate education had 87 % lower rates of incident nontraumatic fracture (adjusted hazard ratio 0.13, 95 % confidence interval [CI] 0.03–0.60). Among non-Caucasian women, each additional year of education was associated with a 16 % lower odds of nontraumatic fracture (adjusted odds ratio 0.84, 95 % CI 0.73–0.97). Income, family-adjusted poverty-to-income ratio, and degree of difficulty paying for basic needs were not associated with time to first fracture in Caucasian or non-Caucasian women.
Conclusions Among non-Caucasian midlife women, higher education, but not higher income, was associated with lower fracture incidence. Elucidation of the mechanisms underlying the possible protective effects of higher educational level on nontraumatic fracture incidence may allow us to better target individuals at risk of future fracture.

Keywords Education · Fracture · Income · Osteoporosis · Poverty · Socioeconomic status

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Introduction

Low socioeconomic status (SES) is associated with increased risk of developing chronic health conditions such as cardiovascular disease and diabetes mellitus [1–4] and with the dysregulation of biological systems that are important to health [5, 6]. Many of the physiological systems that are dysregulated among individuals who are socioeconomically disadvantaged, such as the sympathetic nervous system, the hypothalamic-pituitary-adrenal axis, and glucose metabolism [5, 6], are also believed to be important in the regulation of bone health [7–10].

A recently published systematic review concluded that while greater educational attainment is associated with greater bone mineral density (BMD) among women, evidence of income associations with BMD is lacking [11]. We recently showed that higher educational level is (but financial advantage is not) associated with higher lumbar spine BMD, but neither education nor financial advantage is associated with femoral neck BMD in a national sample of U.S. adults [12].

Although a strong predictor, low BMD is not the only factor that influences fracture risk. Because SES has strong links with obesity and chronic diseases, which influence fracture risk via pathways (both protective and deleterious) that are independent of BMD, it is not immediately apparent that fracture risk should be higher in those from low SES. In fact, higher education and higher income have not consistently been associated with fewer osteoporotic fractures [13]. However, most studies of income and education links with incident fracture links in the USA have focused on hip fractures in older individuals [14–16] or have examined neighborhood per-capita income and not individual level income [17]. Whether education and financial advantage are associated with fracture incidence among midlife women is unknown. Younger individuals who experience a fracture are more likely to fracture at sites other than the hip [18], and lumbar spine BMD is a better predictor of fractures at these sites than femoral neck BMD [19]. Low lumbar spine BMD is also a stronger predictor of fractures in younger individuals than femoral neck BMD [20]. Since lumbar BMD is more strongly linked with SES than femoral neck BMD [12, 21, 22], it is possible that SES-fracture associations are stronger in midlife than in older ages.

Therefore, the goal of the present study was to examine associations of individual level education and financial advantage with the incidence of nontraumatic fractures in a cohort of midlife women. Based on the documented links between greater education and higher BMD, we hypothesized that higher educational attainment would be associated with lower fracture incidence and that income level would not be independently associated with fracture incidence.

Methods

Study sample

The Study of Women's Health Across the Nation (SWAN) is a multisite, community-based, longitudinal cohort study of 3,302 women. At cohort baseline, SWAN participants were aged 42 to 52 years, were premenopausal (menstruated in the past 3 months with no change in menstrual regularity in the past year) or early perimenopausal (menstruated in the past 3 months with decreased regularity in the past year), had an intact uterus, had one or two intact ovaries, were not pregnant or lactating, and were not using exogenous reproductive hormones [23]. Each clinical site enrolled Caucasian women as well as women of one other racial/ethnic group: African-American women (Boston, Detroit area, Chicago, and Pittsburgh), Japanese women (Los Angeles), Hispanic women (Newark, NJ), and Chinese women (Oakland, CA). At baseline and annually through follow-up visit 9, participants were asked to fill questionnaires and provide fasting blood samples. Participants gave written informed consent. Sites obtained institutional review board approval.

The SWAN bone substudy occurred at five of the SWAN sites: Boston, Pittsburgh, Detroit, Oakland, and Los Angeles. At baseline, 2,413 participants were enrolled in the SWAN bone substudy. For this analysis, we included data from participants who provided information regarding incident fractures at two or more annual follow-up visits. Thus, we excluded data from 103 participants for whom only baseline data were available. At baseline, no participants were taking osteoporosis medication or aromatase inhibitors and no women were undergoing chemotherapy. However, we excluded data from one participant taking tamoxifen at baseline. Information regarding at least two of the three main SES predictors was available for all of the remaining 2,309 participants. Finally, we excluded data from participants for whom complete information regarding baseline covariates was lacking (n=142). Application of these criteria resulted in a final analytic sample of 2,167 participants.

Incident fracture ascertainment

At each of the five participating SWAN bone substudy sites, fractures were self-reported at baseline and at annual follow-up interviews. At baseline, participants were asked "Since you were age 20 years, has a doctor ever told you that you had a broken bone?" Participants who reported having had a fracture after age 20 years but prior to the SWAN baseline visit were asked to specify the age at which the fracture occurred. At annual follow-up visits, participants were asked "Since your last study visit, how many times did you break or fracture a bone?"

Participants specified the anatomical site of the fracture using the following response choices: hip, spine, wrist (not finger), arm (other than wrist), leg (other than hip, not including toe), or other. Beginning at annual follow-up interview 7, response choices also included the pelvis and rib as fracture locations. Participants were also asked about the mechanism by which the fracture occurred. On that basis, we classified fractures as traumatic or nontraumatic. Specifically, fractures were considered to be nontraumatic unless they occurred after a fall from a height above the ground greater than 6 in.; in a motor vehicle accident; while moving fast like running, bicycling, or skating; while playing sports; or because something heavy fell on or struck them. Beginning at annual follow-up interview 7, fractures were confirmed by medical records. Among women who consented to medical record review, records were available for 88 % of the self-reported nontraumatic fractures. Of these, 100 % were confirmed as accurate.

The outcome for this analysis was incident self-reported, nontraumatic, nondigital, noncraniofacial fractures occurring after the baseline visit. Beginning at follow-up visit 7, participants were asked to provide the exact month and year of fracture. For the purposes of survival analysis, fractures reported at visits prior to visit 7 were assumed to be midway between the reporting visit and the immediately preceding SWAN visit. To test the robustness of findings to this assumption, we carried out secondary analyses using logistic regression models that did not need fracture date information.

Ascertainment of socioeconomic status

At the baseline interview, participants were asked to report their maximum level of education attained from 20 possible response choices, ranging from "did not go to school" to "doctoral degree." For some analyses, responses were collapsed into a four-category variable: high school or less, some college, completed college, and at least some postgraduate education.

Using information regarding baseline income, baseline household size, and US census data (http://www.census.gov/hhes/www/poverty/data/threshld/thresh96.html), we calculated family-adjusted poverty-to-income ratio (FPIR). Baseline income was assessed by the self-assessment questionnaire item "What is your total family income (before taxes) from all sources within your household in the last year? (mark the one that is your best guess)." Response choices were as follows: <$10,000, $10,000–$19,999, $20,000–$34,999, $35,000–$49,999, $50,000–$74,999, $75,000–$99,999, $100,000–$149,999, or≥$150,000. Household size was based on the question "Which of the following relatives or other persons live with you?" Response choices included male partner/husband, female partner, mother, father, mother-in-law, father-in-law, daughter, son, sister, brother, other male, and other female. For example, an FPIR of 3 corresponds to a total household income three times the census bureau-defined poverty level for her family. Primary analyses used FPIR as a continuous predictor.

Finally, we assessed the degree of difficulty paying for basic needs. At the baseline interview, participants were also asked "How hard is it for you to pay for the very basics like food, housing, medical care, and heating? Would you say it is very hard, somewhat hard, or not very hard at all?"

Other questionnaire-based and anthropometric measures

On baseline interviews and self-assessment questionnaires, participants were asked to provide information regarding medical history, prescription medication use, and cigarette smoking. We created a three-category smoking status variable (current smoker, past smoker, never smoker) and categorized pack-years of smoking as ≤10, >10 but ≤20, and >20. Information regarding calcium supplement use, vitamin D supplement use, and usual alcohol intake was taken from a food frequency questionnaire (modified 1995 Block Food Frequency Questionnaire) administered at baseline and annual visit 5 [24–26]. For years in which the food frequency questionnaire was not administered, information was obtained from annual interviews. We collapsed the weekly frequency of calcium and vitamin D supplement use into any versus none. We classified self-reported weekly alcohol intake as follows: abstainer (none), infrequent (≤1 drink/week), light (1<drinks/week< 7), and heavy (≥7 drinks/week).

We used an adaptation of the Kaiser Physical Activity Survey to assess physical activity at baseline [27]. The questionnaire asked about the following three domains of physical activity, each scored using Likert scale responses ranging from 1 to 5: household/caregiving, sports/exercise, and active living (walking or biking for transportation, hours of television viewing reverse-scored). The physical activity score was the sum of the active living, sports, and household caregiving scores (range 4 to 20). At baseline and annually, participants underwent body weight and height measurements. Body mass index (BMI) was calculated as body weight in kilograms divided by the square of the height in meters.

Statistical analysis

We used Cox proportional hazards regression to examine the associations of each of the three socioeconomic predictors with time to first incident fracture. For participants who died without experiencing a fracture, we censored follow-up at the time of the last SWAN visit before death; for participants who were lost to follow-up, we censored follow-up at the time of the last visit; for participants who came to annual follow-up visit 9, we censored follow-up at annual follow-up visit 9. The three socioeconomic predictors were as follows: education (as an ordinal variable ranging from 1 to 20 and as a categorical variable [high school or less, some college, completed college,

at least some postgraduate]), baseline family-adjusted poverty-to-income ratio (continuous), and baseline difficulty paying for basics (categorical: very hard, somewhat hard, not very hard at all). Each socioeconomic predictor served as the main predictor in a separate model. The proportional hazards assumption was satisfied for all primary predictors except education expressed as an ordinal variable (p value 0.02 for education × time interaction term). Thus, we report only the results of Cox proportional hazards models in which education was treated as a categorical variable.

In the secondary analyses (designed to address robustness of findings to the lack of precise fracture date information before SWAN visit 7), we used multivariable logistic regression to model the log odds of fracture incidence over the 10-year follow-up as a function of each of the three socioeconomic predictors.

All models were adjusted for clinical site, baseline age (continuous), baseline menopausal status (premenopausal vs. early perimenopausal), baseline BMI (continuous), baseline BMI-squared, baseline smoking status (current, past, or never), total pack-years of smoking (≤10, >10 but ≤20, >20), baseline alcohol intake (abstainer, infrequent, light, heavy), prevalent fracture (before baseline visit), calcium supplement use at baseline (any vs. none) and annual follow-up (at any follow-up visit vs. never), baseline total physical activity score, and vitamin D supplement use at baseline (any vs. none) and annual follow-up (at any follow-up visit vs. never).

We adjusted regression models for prior ever-use (before baseline: yes vs. no) and use any time during follow-up (one or more follow-up visits vs. never) of exogenous sex steroids (oral or transdermal) or gonadotropin-releasing hormone agonists; use at one or more follow-up visits of osteoporosis medications (risedronate, alendronate, calcitonin, raloxifene, teriparatide); and use of any other bone-active medications (tamoxifen, oral corticosteroids, aromatase inhibitors, gonadotropin-releasing hormone agents, anti-epileptics) (yes vs. no) at follow-up (at any annual follow-up visit vs. never).

Separate parallel analyses were conducted in Caucasians and non-Caucasians because the association of education with fracture odds was significantly different in the two groups: p= 0.02 for test of interaction between education (ordinal) and race/ethnicity (Caucasian vs. non-Caucasian) in logistic regression on the complete sample. In the non-Caucasians, we included adjustment for race/ethnicity. In addition, because there were large BMI differences among the three race/ethnicity groups in the non-Caucasian stratum, we included a BMI × race/ethnicity term in the non-Caucasian analyses to allow for possible different effects of BMI by race/ethnicity. We also conducted a sensitivity analysis in which Asian women were excluded from the non-Caucasian group, leaving only African-American women.

To account for the possibility that early mortality may be more or less common in low versus high SES groups, thus confounding observed SES associations with incident fracture, we performed a second sensitivity analysis using Cox proportional hazards regression of time to any event, fracture, or death.

We considered two possible mechanistic explanations for SES associations with incident fracture: (1) larger changes in BMI over time in women from low SES and (2) faster transition to menopause in women from low SES. To test the first, we added change in BMI over the follow-up period to the model as an explanatory covariate. Change in BMI was calculated as the change from baseline to the last available SWAN visit before fracture or censoring (i.e., $BMI_{\text{last visit}} - BMI_{\text{baseline}}$). To test the second mechanism, we conducted an exploratory analysis in the subset of women who had a known date for their final menstrual period (FMP). In these women, we added age at the FMP as an explanatory covariate to the model.

All statistical tests were two sided. p values≤0.05 were considered statistically significant. Statistical analyses were performed using SAS version 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

Participant characteristics

Selected characteristics of the study participants are summarized in Table 1. The analytic sample was similar to the complete SWAN Bone Study cohort with respect to baseline age, body mass index, alcohol intake, race/ethnicity, menopausal stage, smoking, and frequency of calcium and vitamin D supplement use. The maximum educational level attained, degree of difficulty paying for basic needs, household income, and FPIR of the analytic sample participants were also similar to those of the overall SWAN Bone Study cohort. Over the follow-up period, 29 participants died without experiencing a nontraumatic fracture.

Median (interquartile range) duration of follow-up until first fracture (or last SWAN visit, if no fracture) was 8.97 (0.32) years. During the follow-up period, 42 (1.9 %) of Caucasian and 52 (2.3 %) of non-Caucasian participants reported experiencing nontraumatic fractures. During follow-up, 39.2 % of analytic sample participants reported using sex steroid medications, 9.9 % of participants used osteoporosis medications, and 25.9 % of participants used other bone-active medications (oral corticosteroids, chemotherapy, aromatase inhibitors, anti-epileptics).

SES associations with fracture incidence

Adjusted for race/ethnicity, age, menopausal stage, body mass index, smoking, alcohol intake, prevalent fracture, physical

Table 1 Selected baseline characteristics of the analytic sample: number (percent) or mean (standard deviation)

	Study sample (n=2,167)	SWAN Bone Cohort (n=2,413)
Age, years	45.8 (2.7)	45.8 (2.7)
Body mass index, kg/m^2	27.9 (7.5)	28.0 (7.5)
Alcohol intake, weekly		
None	1,118 (51.6)	1,244 (51.8)
≤1 drink/week	202 (9.3)	220 (9.2)
1<drinks/week<7	553 (25.5)	607 (25.3)
≥7 drinks/week	294 (13.6)	332 (13.8)
Race/ethnicity[a]		
African-American	592 (27.3 %)	686 (28.4 %)
Caucasian	1,093 (50.4 %)	1,196 (49.6 %)
Chinese	223 (10.3 %)	250 (10.4 %)
Japanese	259 (11.9 %)	281 (11.6 %)
Menopausal stage		
Premenopausal	1,181 (54.5 %)	1,288 (54.1 %)
Early perimenopausal	986 (45.5 %)	1,094 (45.9 %)
Smoking status[a]		
Never	1259 (58.1 %)	1,383 (57.8 %)
Past	575 (26.5 %)	619 (25.8 %)
Current	333 (15.4 %)	393 (16.4 %)
Smoking pack-years		
≤10	1,726 (79.6 %)	1,903 (78.9 %)
>10 but ≤20	197 (9.1 %)	229 (9.5 %)
≥20	244 (11.3 %)	281 (11.7 %)
Routine use of vitamin D supplement[a]	843 (38.9 %)	917 (38.2 %)
Routine use of calcium supplement[a]	980 (44.2 %)	1,066 (44.4 %)
Prevalent fracture (before baseline)	415 (19.1 %)	457 (18.9 %)
Total physical activity score without work	7.8 (1.8)	7.8 (1.8)
Maximum educational level attained[b]		
High school or less	459 (21.3 %)	524 (21.9 %)
Some college	728 (33.8 %)	815 (34.0 %)
Completed college	464 (21.5 %)	509 (21.2 %)
At least some postgraduate	503 (23.4 %)	548 (22.9 %)
Difficulty paying for basics[a,c]		
Very hard	162 (7.5 %)	197 (8.2 %)
Somewhat hard	587 (27.2 %)	660 (27.5 %)
Not very hard at all	1,410 (65.3 %)	1,547 (64.3 %)
Total household income in the past year[a]		
<$10,000	96 (4.5 %)	117 (5.0 %)
$10,000 to $19,999	144 (76.8 %)	178 (7.6 %)
$20,000 to $34,999	340 (16.1 %)	379 (16.1 %)
$35,000 to $49,999	404 (19.1 %)	449 (19.1 %)
$50,000 to $74,999	511 (24.2 %)	556 (23.7 %)
$75,000 to $99,999	285 (13.5 %)	310 (13.2 %)
$100,000 to $149,999	240 (11.4 %)	256 (10.9 %)
$150,000 or more	93 (4.4 %)	103 (4.4 %)
Family-adjusted poverty-to-income ratio[a,d]	3.1 (2.9)	3.1 (2.9)

[a] Statistically significant difference between the analytic sample participants and the excluded participants

[b] Information was available for 2,154 participants

[c] Information was available for 2,159 participants

[d] Information was available for 2,112 participants. Information is presented as median (interquartile range)

activity, and medication use in Cox proportional hazards regression, higher educational level was associated with lower fracture rate (hazard) in non-Caucasians women but not in Caucasian women (Table 2). Among non-Caucasians, compared to women who completed no more than high school education, those who attained at least some postgraduate education had 87 % lower rates of incident nontraumatic fracture (adjusted hazard ratio 0.13, 95 % confidence interval [CI] 0.03–0.60). FPIR was not significantly associated with fracture rate (time to first fracture) among non-Caucasian or Caucasian participants. The association between higher education and lower fracture hazard in non-Caucasian women was not substantially different when adjusted for FPIR.

Higher educational level in non-Caucasians was equally strongly associated with lower incident fracture odds in logistic regression (Table 3). Among non-Caucasian women, those who reported completing at least some postgraduate education had 88 % lower odds of incident nontraumatic fracture than those who only obtained high school or less education (adjusted odds ratio 0.12, 95 % CI 0.03–0.53). Among non-Caucasian women, each additional year of education was associated with a 16 % lower odds of incident fracture (adjusted odds ratio 0.84, 95 % CI 0.73–0.97) (data not shown). Further adjustment for FPIR had a negligible effect on the magnitude of this education-fracture association in non-Caucasians (Table 3). Among Caucasian women, educational level was not associated with incident fracture odds. Also, FPIR was not significantly associated with fracture odds in either non-Caucasian or Caucasian women. There were no significant associations of (a) difficulty paying for basic needs, (b) categorical FPIR, or (3) unadjusted household income (treated as a continuous variable) with fracture odds or time to first fracture among Caucasian or non-Caucasian women (data not shown).

Sensitivity analyses

In a sensitivity analysis that excluded Asian women from the non-Caucasian sample (so that the group is limited to African-

Table 2 Adjusted associations of education and family-adjusted poverty-to-income ratio with incident nontraumatic fracture: Cox proportional hazards regression models

	Model 1: education			Model 2: family-adjusted poverty-to-income ratio			Model 3: education and family-adjusted poverty-to-income ratio		
	Hazard ratio	95 % confidence interval	*p* value	Hazard ratio	95 % confidence interval	*p* value	Hazard ratio	95 % confidence interval	*p* value
Non-Caucasians									
At least some postgraduate vs. ≤high school (*n*=169)	0.13	0.03–0.57	0.007	–	–	–	0.14	0.03–0.67	0.01
Completed college vs. ≤high school (*n*=238)	0.46	0.20–1.07	0.07	–	–	–	0.55	0.22–1.41	0.20
Some college vs. ≤high school (*n*=398)	0.56	0.29–1.06	0.08	–	–	–	0.71	0.36–1.41	0.33
Family-adjusted poverty-to-income ratio	–	–	–	0.95	0.82–1.11	0.52	1.04	0.89–1.22	0.58
Caucasians									
At least some postgraduate vs. ≤high school (*n*=347)	1.25	0.41–3.83	0.70	–	–	–	1.10	0.35–3.45	0.87
Completed college vs. ≤high school (*n*=239)	0.71	0.20–2.52	0.59	–	–	–	0.65	0.18–2.33	0.51
Some college vs. ≤high school (*n*=352)	1.14	0.39–3.33	0.81	–	–	–	1.09	0.37–3.20	0.88
Family-adjusted poverty-to-income ratio	–	–	–	1.10	0.97–1.22	0.14	1.09	0.97–1.23	0.16

Regression models are adjusted for race, clinical site, baseline age, baseline menopausal stage (pre- vs. early perimenopausal), baseline body mass index, smoking, baseline alcohol intake, presence of prevalent fracture, calcium and vitamin D supplement use, physical activity, and use of medications known to influence bone density. High school education or less than high school education was reported by 293 non-Caucasian women and 166 Caucasian women. Information regarding educational level was missing for nine non-Caucasian women and for four Caucasian women

Table 3 Adjusted associations of education and family-adjusted poverty-to-income ratio with incident nontraumatic fracture: logistic regression models

	Model 1: education			Model 2: family-adjusted poverty-to-income ratio			Model 3: education and family-adjusted poverty-to-income ratio		
	Odds ratio for fracture	95 % confidence interval	*p* value	Odds ratio for fracture	95 % confidence interval	*p* value	Odds ratio for fracture	95 % confidence interval	*p* value
Non-Caucasians									
At least some postgraduate vs. ≤high school (*n*=169)	0.12	0.03–0.53	0.005	–	–	–	0.13	0.03–0.65	0.01
Completed college vs. ≤high school (*n*=238)	0.44	0.18–1.10	0.08	–	–	–	0.55	0.21–1.43	0.22
Some college vs. ≤high school (*n*=398)	0.57	0.29–1.13	0.11	–	–	–	0.73	0.35–1.51	0.40
Family-adjusted poverty-to-income ratio	–	–	–	0.95	0.81–1.11	0.52	1.04	0.88–1.21	0.66
Caucasians									
At least some postgraduate vs. ≤high school (*n*=347)	1.27	0.40–3.99	0.68	–	–	–	1.11	0.34–3.57	0.86
Completed college vs. ≤high school (*n*=239)	0.90	0.19–2.59	0.60	–	–	–	0.64	0.18–2.38	0.51
Some college vs. ≤high school (*n*=352)	1.23	0.39–3.55	0.76	–	–	–	1.16	0.38–3.51	0.83
Family-adjusted poverty-to-income ratio	–	–	–	1.09	0.97–1.23	0.15	1.09	0.96–1.23	0.17

Regression models are adjusted for race, clinical site, baseline age, baseline menopausal stage (pre- vs. early perimenopausal), baseline body mass index, smoking, baseline alcohol intake, presence of prevalent fracture, calcium and vitamin D supplement use, physical activity, and use of medications known to influence bone density. High school education or less than high school education was reported by 293 non-Caucasian women and 166 Caucasian women. Information regarding educational level was missing for nine non-Caucasian women and for four Caucasian women

American women), the associations of greater education with lower incident fracture risk and lower incident fracture rate persisted (data not shown). In the analysis of time to fracture or death in proportional hazards regression, we found a strong association between greater education and lower event rate (incident fracture or death) in non-Caucasians: adjusted hazard ratio for "some postgraduate education" compared with "no more than high school education" was 0.31, 95 % CI 0.10–0.98.

Exploratory analyses

Associations between greater education and lower incident fracture rate in non-Caucasians did not change substantially after additional adjustment for change in BMI from baseline (adjusted hazard ratio for "at least some postgraduate education" compared with "no more than high school education" increased from 0.14 before the additional adjustment to 0.20 [95 % CI 0.04–0.99] after adjustment for change in BMI).

In an exploratory analysis among the 662 non-Caucasian women in the study sample who had a known date for their FMP, we added age at their FMP as a covariate to the Cox models examining associations between education and fracture incidence. The point estimate for the adjusted hazards ratio for "some postgraduate education" compared with "no more than high school education" changed from 0.14 to 0.21 after adjustment for age at FMP and became statistically nonsignificant—95 % CI 0.02–1.81.

Discussion

In this longitudinal study of midlife women going through the menopausal transition, we found strong associations between high educational level and lower risk of incident nontraumatic fractures in non-Caucasians. In Caucasian women, however, educational level was not associated with fracture risk. In contrast to educational level, income level and self-reported financial hardship were not associated with fracture risk in either Caucasians or non-Caucasians.

These findings are consistent with the current body of evidence regarding SES-BMD associations [11] and with at least one SES-fracture study in older adults [15]. A recent systematic review concluded that there is consistent, albeit limited, evidence for a positive association between educational attainment and BMD in women, but found no evidence for an association between an individual's income and his/her BMD [11]. In our own more recent study of adult U.S. men and women, we found higher educational level to be associated with BMD at the lumbar spine, but we found no association between current financial status and BMD in either the lumbar spine or femoral neck [12].

These findings mirror those from a 2-year study of community-dwelling older adults aged 70 years and older that found 60 % lower risk of fracture in college graduates compared to those who had not completed high school, but found no association between household income and hip fracture risk [15]. The consistency of education associations with bone health and the lack of income associations with bone outcomes are likely a reflection of the ability of educational attainment to index SES over the life course, especially in the younger years, when peak bone mass is being acquired. Income and financial status, although related to educational attainment, vary substantially over the life course, and current levels may not be reflective of economic circumstances at other times.

However, not all previous studies have found lower fracture risk with higher educational attainment. At least two studies in older adults found no link between educational level and hip fracture risk [16, 28], and one study of women aged 50–79 years found higher educational attainment to be associated with higher 8-year risk of nonspine fractures in some race/ethnicity groups [14]. Universal access to health care after age 65 in the USA and the use of bisphosphonates may all weaken education-fracture associations in older ages.

Also, dramatic declines in bone strength during and after the menopausal transition [29–43] may weaken education-fracture associations in studies of older women. Both lumbar spine and femoral neck BMD begin declining rapidly 1 year before the final menstrual period [44]. Indices of femoral neck strength relative to load also decline significantly during the menopausal transition, beginning 1 to 2 years before the final menstrual period [45].

In our study of women, which followed women going through the menopausal transition, associations between higher educational level and lower incident fracture risk were seen only in non-Caucasian women, and not in Caucasians, despite there being similar numbers of Caucasian and non-Caucasian women in the lowest education group and more Caucasian women than non-Caucasian women in the highest education group. Risk factors for low bone accrual, such as smoking, depression, and inadequate vitamin D in the younger years [46–48], are more prevalent in low SES than in high SES women [49–52] and in minority racial/ethnic communities than in Caucasians [49, 53]; the combination of low SES and minority race/ethnicity status might be especially deleterious to peak bone accrual. In fact, SES gradients in the prevalence of adolescent smoking are stronger in minority communities than in whites [54]; thus, differences in adolescent smoking behavior might represent one pathway by which SES influences fracture incidence in minority communities but not in whites. Low SES and minority race/ethnicity status are also independently associated with greater perceived stress in adolescents [55], which can leave its biological signature in changes in the hypothalamic-pituitary-adrenal

axis, sympathetic nervous system, inflammation, and glucose regulation [5]. In turn, the dysregulation of these systems has been related to low BMD [56–60].

One mechanistic explanation for the higher fracture incidence in less educated non-Caucasian women may be accelerated transition through the menopause and the resulting earlier declines in bone strength. Lower educational level has, in fact, been associated with younger age at the final menstrual period in SWAN and other cohorts [61–67]. In exploratory analyses in the subsample of non-Caucasian women with known date of FMP, controlling for age at FMP only slightly diminished the magnitude of the education-fracture association, although it became statistically nonsignificant because of the much smaller sample size.

Our study has some limitations. Fractures that occurred prior to visit 7 were not confirmed by medical record review. Conversely, under-reporting of nontraumatic fractures by participants may have occurred. However, 100 % of self-reported nontraumatic fractures reported after that time were confirmed as accurate by medical record review, and the accuracy of self-report of fractures by women is generally felt to be acceptably high [68]. Because there were only 11 incident nontraumatic fractures in the Asian participants, we could not further stratify our analyses within the non-Caucasian group. The strengths of our study include its large sample size, its longitudinal design, information about fracture type (nontraumatic vs. traumatic), the detailed data collection regarding osteoporosis risk factors and medication use, and its novel focus on midlife women instead of older individuals.

In conclusion, among non-Caucasian midlife women going through the menopausal transition, higher education was associated with lower fracture incidence. The lack of information regarding risk factors for osteoporosis among minority groups in the USA is noted by the US Surgeon General to be an important problem [69]. Our results highlight the need to elucidate the biological and behavioral mechanisms underlying the possible protective effects of higher educational level on osteoporotic fracture incidence so that we can better target individuals at risk of future fracture and design appropriate preventive strategies.

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Conflicts of interest None.

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