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ORIGINAL ARTICLE

Adult bone strength of children from single-parent families: the Midlife in the United States Study

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Abstract
Summary Bone health may be negatively impacted by childhood socio-environmental circumstances. We examined the independent associations of single-parent childhood and parental death or divorce in childhood with adult bone strength indices. Longer exposure to a single-parent household in childhood was associated with lower bone strength in adulthood.
Introduction Because peak bone mass is acquired during childhood, bone health may be negatively impacted by childhood socio-environmental disadvantage. The goal of this study was to determine whether being raised in a single-parent household is associated with lower bone strength in adulthood.
Methods Using dual-energy X-ray absorptiometry data from 708 participants (mean age 57 years) in the Midlife in the United States Biomarker Project, we examined the independent associations of composite indices of femoral neck bone strength relative to load (in three failure modes: compression, bending, and impact) in adulthood with the experience of single-parent childhood and parental death or divorce in childhood.
Results After adjustment for gender, race, menopause transition stage, age, and body mass index, each additional year of single-parent childhood was associated with 0.02 to 0.03 SD lower indices of adult femoral neck strength. In those with 9–16 years of single-parent childhood, the compression strength index was 0.41 SD lower, bending strength index was 0.31 SD lower, and impact strength index was 0.25 SD lower (all p values <0.05). In contrast, parental death or divorce during childhood was not by itself independently associated with adult bone strength indices. The magnitudes of these associations were unaltered by additional adjustment for lifestyle factors and socioeconomic status in childhood and adulthood.
Conclusions Independent of parental death or divorce, growing up in a single-parent household is associated with lower femoral neck bone strength in adulthood, and this association is not entirely explained by childhood or adult socioeconomic conditions or lifestyle choices.

Keywords Bone strength · Composite strength indices · Parental death · Parental divorce · Single-parent childhood · Strength relative to load

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Introduction

Bone strength in older ages is critically dependent on bone acquisition in the growing years—the higher the peak bone

mass achieved, the lower the likelihood of developing osteoporosis later in life [1–3]. Many environmental factors influence bone accrual during childhood and adolescence [4]. Infancy and childhood are also critical periods that are characterized by increased vulnerability to stressors [5–7]. Exposure to early life stressors has been linked both with poor health and with problematic health behaviors, such as smoking [8, 9], greater alcohol consumption [8, 10], and lower levels of physical activity [8], that are deleterious to bone mass.

However, little is known about how exposure to childhood stress affects adult bone health. We recently reported that childhood socioeconomic disadvantage is associated with lower adult hip strength relative to load in men [11] and with lower adult lumbar spine bone mineral density (BMD) in both men and women [12]. To explore further the potential link between childhood stressors and bone health, we postulated that being raised by a single parent and experiencing parental death or divorce would also be associated with lower adult bone strength. Indeed, the experience of a parental death or divorce during childhood has been linked with poor mental and physical health (e.g., stroke, smoking- and alcohol-related cancers, obesity, disabling conditions) and decreased survival in adulthood [9, 13–32]. Parental separation during childhood is also associated with several deleterious health behaviors, including smoking [9, 33, 34] and problem drinking [21, 33, 35–37].

However, it is not clear whether links between parental death or divorce and adult health are related to not having two parents for most of one's childhood or to the experience of parental separation itself. Indeed, the absence of a father figure is associated with earlier menarche in girls [38, 39], and children in single-parent families have poorer physical and psychological health than do children in two-parent families [40–43], a difference that persists into midlife and early old age [44] and that may even decrease life expectancy [45]. Especially germane to the research question posed here is that children in single-parent families have lower bone age [46].

Childhood stressors can also affect body size [47–51] and therefore bone size. Larger bones are stronger, but bone strength has to be commensurate with the load to which it is exposed in a fall (which also increases with body size) [52]. Composite indices of femoral neck bone strength relative to load integrate femoral neck size and BMD with body size to capture their combined influence on fracture risk, and are inversely associated with incident hip fracture risk [53, 54]. These indices are robust indicators of resistance to fracture and, unlike BMD, correctly stratify risk across ethnic groups [55, 56] and between adults with and without diabetes [57].

We hypothesized that being raised by a single parent for most of one's childhood and experiencing parental divorce or death during childhood would each be independently associated with lower adult femoral neck strength relative to load. To test this hypothesis, we analyzed data from the Midlife in the United States (MIDUS) National Study of Health and Well-Being [58–60].

Methods

Participants: the Midlife in the United States National Study of Health and Well-Being

We used data from MIDUS [58–60]. The MIDUS study recruited a national sample of adults between ages 25 and 75 residing in the coterminous USA in 1995–1996 and re-interviewed them 9–10 years later (MIDUS II). Details regarding study design, recruitment, and retention are available at http://www.icpsr.umich.edu/icpsrweb/NACDA/. Of 3191 MIDUS II participants who were medically able to travel to the research sites, 1255 consented to participate in the MIDUS II Biomarker Project. The MIDUS II Biomarker Project (data collection occurred between July 2004 and May 2009) entailed travel to one of the three clinical research centers: University of California at Los Angeles, Georgetown University, and University of Wisconsin. Reasons given for nonparticipation were travel burden, family obligations, and being too busy. Via self-administered questionnaires and interviews, we obtained medical history information. Using standardized protocols, body weight and height were measured for calculation of body mass index (BMI, body weight in kilograms divided by the square of body height in meters). Informed consent was provided by each participant. Each MIDUS center obtained institutional review board approval.

The characteristics of the MIDUS II participants were similar to those of the MIDUS I participants [60], and the MIDUS Biomarker Project participants (e.g., subjective health status, chronic health conditions, exercise, alcohol use) were similar to those of the MIDUS II participants as a whole [59].

Of the 1255 participants in the MIDUS II Biomarker Project, we excluded data from 348 participants without BMD measurement (which was added to the Biomarker Project partway into data collection), 94 participants who reported the use of medications known to influence BMD (oral corticosteroids, alendronate, anastrozole, calcitonin, ibandronate, leuprolide, letrozole, raloxifene, risedronate, tamoxifen, zoledronic acid, testosterone, finasteride, dutasteride), 88 female participants whose menopause transition stage was unclassifiable, 11 participants for whom we lacked complete information regarding education and/or childhood socioeconomic status, 2 participants with BMI values >60 kg/m^2, and 3 participants for whom we lacked information regarding parental death and divorce. One additional participant reported experiencing parental divorce and being raised by a single parent but did not report the age at which the parental divorce occurred, resulting in an analytic sample of 708 participants.

Outcomes: bone strength

According to standardized protocols, trained technologists performed DXA scans using GE Healthcare Lunar Prodigy (U. Wisconsin—Madison) or Hologic 4500 (UCLA and Georgetown U.) densitometers. Phantoms were scanned on all densitometers three times per week and on all days on which scans were obtained. No densitometer shift or drift occurred during the course of this study. BMD and bone size measurements from all DXA scans were adjudicated centrally at the University of Wisconsin DXA center using manufacturer-provided software (GE Lunar, Inc. and Hologic, Inc.).

On the DXA scans, we measured the two-dimensional (2D) projected areal BMD in the femoral neck; the femoral neck axis length (FNAL)—the distance on the 2D projected plane along the femoral neck axis from the lateral margin of the base of the greater trochanter to the apex of the femoral head; and the femoral neck width (FNW)—the smallest thickness of the femoral neck on the 2D projected plane along a line perpendicular to the femoral neck axis. Using those DXA-based measurements, and measured body height and body weight, we calculated composite indices of femoral neck strength that index bone strength relative to the load during a fall using the following formulas [11, 53], which have been validated against three-dimensional (3D) methods based on quantitative computed tomography [61]:

$$\text{Compression Strength Index} = \frac{\text{BMD}^{*}\text{FNW}}{\text{Weight}}$$

$$\text{Bending Strength Index} = \frac{\text{BMD}^{*}\text{FNW}^{2}}{\text{FNAL}^{*}\text{Weight}}$$

$$\text{Impact Strength Index} = \frac{\text{BMD}^{*}\text{FNW}^{*}\text{FNAL}}{\text{Height}^{*}\text{ Weight}}$$

The compression strength index reflects the ability of the femoral neck to withstand axial compressive loading, the bending strength index reflects its ability to withstand bending, and the impact strength index reflects its ability to absorb the energy of impact in a fall from standing height.

Predictors: childhood family environment

Information regarding childhood family structure and stability was self-reported in MIDUS I (1995–1996). Participants were asked whether they had lived with both biological parents for most of their childhood until the age of 16. If the response was negative, they were asked the reason (mother died, father died, parents separated/divorced, parents never lived together, adopted). If the reason provided was death or divorce/separation of biological parents or adoption, they were further asked their age when this occurred.

Participants were then asked who was the female head of household for most of their childhood until the age of 16 (biological mother, adoptive mother, stepmother, other female, no female in household) and who was the male head of household for most of their childhood until the age of 16 (biological father, adoptive father, stepfather, other male, no male in household). Participants who reported having either no male head of household or no female head of household for most of their childhood were identified as having a single-parent childhood. For each participant, we calculated the number of years in a single-parent household before reaching age 16 years by subtracting the age (in years) at which parental death or divorce occurred from 16. We assigned a value of 0 to participants who did not have a single-parent childhood and a value of 16 to those who reported living in a single-parent household without having experienced a parental death or divorce.

Race/ethnicity

Race/ethnicity was self-identified as white, black/African American, other, or multiracial. For this analysis, we classified race as black vs. not black; the latter group was mostly white but included a small number (n=31, 4.4 %) of participants who reported being neither white nor black/African American. This latter group included participants who reported being Asian, Native American/Pacific Islander, multiracial, or "other."

Menopausal transition stage and age

Menopausal staging in women was based on self-reported menstrual patterns, self-reported use of sex steroid hormones in the past year, and examination of medication bottles brought to the clinical research center. We defined the following menopause transition stage categories: premenopausal (no change in regularity of menses), early perimenopausal (menses in last 3 months with change in regularity of menses), late perimenopausal (last menses 3–12 months previously with change in regularity of menses), postmenopausal (no menses in prior 12 months) not taking menopausal hormone therapy, and postmenopausal taking menopausal hormone therapy. For analytic purposes, because there were few late perimenopausal women, we combined them with the postmenopausal women not taking menopausal hormone therapy.

Men were categorized by age. The choice of age categories in men was based on previous observations that significant

age-related bone loss in men does not start until age 50 years [62], and to age-match the oldest group to the postmenopausal women because only 0.3 % of occurrences of spontaneous menopause take place at or after 59 years of age [63].

In addition to these categories, in order to control for declines in bone strength with aging in later years, age was also included as a continuous variable (in whole years) only in men 60 years and older and in late peri/postmenopausal women not taking menopausal hormone therapy.

Socioeconomic status

Socioeconomic status measures included childhood socioeconomic advantage, education, and adult financial advantage. These classifications were based on the categories used in our recent study examining BMD and socioeconomic advantage [12]. Childhood socioeconomic advantage score was calculated by summing three components (possible range 0–6): being on welfare during childhood (0: yes, 2: no), childhood financial level relative to others (0: worse off, 1: same, 2: better), and highest parental education level (0: < high school, 1: high school/general educational development [GED] certificate, 2: some college or more). Scores were calculated only for participants who supplied data regarding at least two of the three components; the missing component was imputed as the rounded mean of the other two components for 47 participants. The participant's reported educational level was collapsed to a three-category variable: (1) no college, (2) some college or associate's degree, or (3) bachelor's degree or more.

To calculate the adult financial advantage score, we first determined the family-adjusted poverty-to-income ratio (FPIR) for each participant as the ratio of the participant's total household income (sum of self-reported earnings, pension, social security, and government assistance for all household members) to the US Census Bureau poverty threshold specific to the participant's age, presence of a spouse or partner in the household, the number of children under age 18 living in the household, and year of data collection. An FPIR of 3 would correspond to a total household income three times the Census Bureau-defined poverty level for his/her family. Adult financial advantage score was calculated by summing four components (possible range 0–8): FPIR (0 for FPIR <3, 1 for FPIR ≥3 but <6, 2 for FPIR ≥6, reflecting approximate tertiles of its distribution), self-rated current financial situation (0: worst, 1: average, 2: best), sufficient money to meet needs (0: not enough, 1: just enough, 2: more than enough), and degree of difficulty paying bills (0: very, 1: not very, 2: not at all). Scores were calculated only for participants who supplied data regarding at least three of the four components; the missing component was imputed as the rounded mean of the other three components for 20 participants.

Lifestyle measures

On self-administered questionnaires, participants were asked to report their alcohol intake levels during the period of life at which their alcohol consumption was highest as well as their alcohol intake within the last month.

Smoking was quantified as the total pack-years of cigarette smoking (years smoked regularly multiplied by the number of cigarettes per day divided by 20) and also as a binary variable of current smoker vs. not current smoker. Participants were also asked at what age they started smoking, and we created a dichotomous variable indicating smoking regularly before age 18 years.

Recalled self-reported physical activity during three life stages was recorded: the number of years of participation in competitive sports and recreational sports (separately) during high school (ages 14–18 years); the number of years of light, moderate, and vigorous exercise (self-categorized) during young adulthood (ages 20–35 years), and the average number of minutes per week currently spent doing light, moderate, and vigorous exercise. For each participant's young adulthood and current levels of physical activity, we created summary scores as weighted sums of reported times for light (weight of 1), moderate (weight of 2), and vigorous (weight of 3) activity. Construct validity of summary scores based on recalled self-reports of physical activity has been previously reported [64, 65].

Statistical analysis

LOESS plots of each of the three indices of femoral neck strength relative to load as a function of the number of childhood years in a single parent household showed that bone strength stayed relatively stable up to about 8 years of exposure to a single parent household, and then trended down steeply (Fig. 1). Therefore, we modeled years of single-parent childhood both as a continuous predictor and as a categorical predictor (0, 1–8, and 9–16 years). We also included a binary indicator for parental death or divorce before age 16 as a second exposure to test whether the experience of parental death or divorce had effects that were independent of subsequently being raised by a single parent. The reference group for this exposure was stable (i.e., continuous), two-parent childhoods, which included those who had either lived with both biological parents until age 16 or were adopted at birth.

The three composite indices of adult femoral neck strength relative to load (bending, compression, and impact) were the dependent variables in three separate linear regression models that included adjustment for gender, race (black vs. nonblack), study site, menopausal transition stage (in women), BMI (continuous linear plus quadratic terms), gender by BMI interaction (to model gender-specific effects of BMI on bone

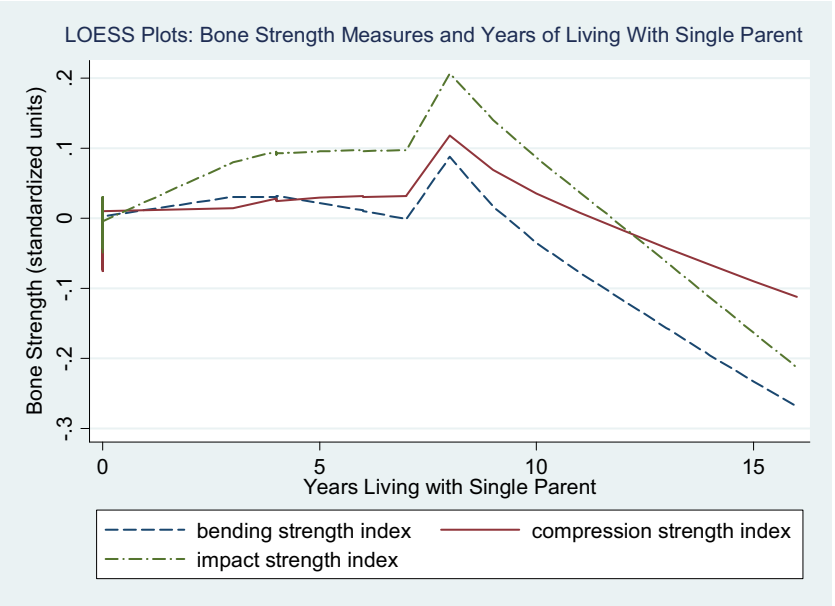

Fig. 1 LOESS plots of numbers of years of living with a single parent vs. bone strength indices, where bone strength indices are in standardized units

strength), and age. Age was operationalized with two continuous variables to capture age-related declines in older adults (one that tracked age in men 60 years and older and one that tracked age in late perimenopausal and postmenopausal women not taking menopausal hormones), and a three-category age variable (<50, 50–59, and ≥60 years) in men only, to capture age/cohort differences in younger men. In younger women, age was highly collinear with menopausal transition stage and was therefore not included separately.

To test whether socioeconomic disadvantage and unhealthy lifestyles accounted for the associations of single parenting and parental death or divorce in childhood with adult bone strength, we added the following potential explanatory variables to the regression models in a second step: childhood socioeconomic advantage score, number of years in recreational sports during ages 14–18 years, number of years in competitive sports during ages 14–18 years, physical activity summary score for ages 20–35 years, smoking initiation at age ≤18 years, heavy alcohol intake at time of peak alcohol consumption, participant education level, adult financial advantage score, current physical activity score, current smoking, pack-years of smoking, and heavy alcohol intake in the past month. Women reporting any of the following alcohol intake patterns were classified as heavy drinkers: ≥8 drinks per week, >3 drinks per day on average, or >4 drinks on a single occasion. Men reporting any of the following alcohol intake patterns were classified as heavy drinkers: ≥ 15 drinks per week, >4 drinks per day on average, or >4 drinks on a single occasion. These thresholds were taken from the National Institute on Alcohol Abuse and Alcoholism [66].

To test whether associations varied by gender or menopausal transition stage, we added an interaction term between the primary predictors (years of single-parent childhood-continuous and parental death or divorce experienced before age 16—yes/no) and gender/menopause status (pre/early perimenopausal women, late peri/postmenopausal women, men [reference]) to the regression models.

Results

The characteristics of the analytic sample were similar to those of the overall MIDUS II Biomarker Project (Table 1). The Madison, WI study site, which had a larger proportion of black participants by design, began DXA scanning prior to the other study sites; thus, the current study sample had a larger proportion of blacks compared with the Biomarker Project sample. On average, participants were aged 56.7 years; 49 % of the analytic sample participants were male, and 24 % were black. The majority (72.5 %) of participants had a stable two-parent family until age 16 (i.e., they either lived with biological parents until age 16 or were adopted at birth), but 22.7 % experienced a parental death or divorce before they were 16 years old. Only 8.1 % reported having a single parent for most of their childhood, 2.0 % for 1–8 years, and 6.1 % for 9–16 years.

Adjusted associations between childhood family environment and adult bone strength indices

In linear regression models adjusted for race, site, menopausal stage, age, gender, BMI, and duration of single-parent childhood as a continuous predictor, a longer duration of single-parent childhood was associated with lower indices of femoral neck strength relative to load (Table 2, model 1). For each

Table 1 Descriptive statistics for the study sample and the Midlife in the United States (MIDUS) II Biomarker sample

	Study sample (N=708)[a] % (n) or median [interquartile range]	MIDUS II Biomarker sample (n=1255)[b] % (n) or median [interquartile range]
Age (years)	56.0 [48.0–64.0]	57.0 [48.0–65.0]
Gender		
Male	48.9 (346)	43.2
Female	51.1 (362)	56.8 (713)
Race		
Black	23.9 (169)	17.7 (222)
White	72.0 (539)	77.2 (1031)
Body mass index (kg/m^2)	29.0 [25.3–33.6]	28.6 [25.2–33.0]
Males		
Age <50 years	32.4 (112)	28.8 (156)
Age 50–59 years	30.1 (104)	28.2 (153)
Age ≥60 years	37.6 (130)	43.0 (233)
Females		
Premenopausal	17.4 (63)	12.7 (72)
Early perimenopausal	14.4 (52)	9.9 (56)
Late peri/postmenopausal, no menopausal hormone therapy	58.8 (213)	65.9 (374)
Postmenopausal, taking menopausal hormone therapy	9.4 (34)	11.6 (66)
Smoking (pack-years)	0 [0–11.3]	0 [0–11.3]
Smoking currently	16.7 (118)	14.9 (187)
Started smoking <age 18	26.8 (190)	25.1 (314)
Heavy drinker at peak alcohol consumption	33.1 (232)	29.6 (368)
Heavy drinker in the past month	18.2 (128)	15.4 (192)
Physical activity scores		
Number of years doing recreational sports for ages 14–18 years	0 [0–4.0]	0 [0–4.0]
Number of years doing competitive sports for ages 14–18 years	1.0 [0–4.0]	1 [0–4.0]
Summary score for ages 20–35 years[c]	30.0 [15.0–45.0]	30.0 [15.0–45.0]
Summary score for current (at the time of MIDUS Biomarker Project visit)[d]	312.5 [67.5–780.0]	320.0 [70.0–720.0]
Education		
≤High school	29.8 (211)	27.7 (344)
Some college	28.8 (204)	29.9 (371)
≥College	41.4 (293)	42.4 (527)
Childhood socioeconomic advantage score[e]	4.0 [3.0–5.0]	4.0 [3.0–5.0]
Adult financial advantage score[f]	4.0 [2.0–6.0]	4.0 [2.0–6.0]
Bone strength measures		
Bending strength index (g/kg/m)	1.2 [1.0–1.4]	1.2 [1.0–1.4]
Compression strength index (g/kg/m)	3.5 [3.1–4.1]	3.5 [3.1–4.0]
Impact strength index (g/kg/m)	0.2 [0.17–0.23]	0.2 [0.17–0.23]
Parental death/divorce before age 16 years		
Lived with both biological parents until age 16 years or adopted at birth	72.5	74.8
Parental death/divorce when participant was under age 16 years	22.7	21.1
Other reasons for not living with both biological parents until age 16	3.0	2.6
Number of years living in a single-parent household before age 16 years	0 [0–0]	0 [0–0]
0	92.0* (651)	92.3 (1154)
1–8	2.0 (14)	2.0 (25)
9–16	6.1 (43)	5.7 (71)

[a] Major reason for exclusion was unavailability of bone mineral density measurement. Sample sizes are reduced for some of the measures, including financial advantage (n=706), smoking pack-years (n=642), physical activity ages 14–18 (n=644), physical activity ages 20–35 (n=640), current physical activity (n=706), heavy drinker at peak (n=701), and heavy drinker in the past month (n=703)

[b] Sample sizes are reduced for some of the measures, including race (n=1253), menopause group (n=1110), started smoking <age 18 (n=1253), heavy drinker at peak (n=1245), heavy drinker in the past month (n=1246), education (n=1242), parental death/divorce (n=1251), years in a single-parent household (n=1250), body mass index (n=1254), financial advantage (n=1252), childhood advantage (n=1249), smoking pack-years (n=842), physical activity ages 14–18 (n=845), physical activity ages 20–35 (n=841), physical activity at 4 years (n=1250), and bone strength measures (n=907)

[c] Summary score=(number of years doing light exercise*1)+(number of years doing moderate exercise*2)+(number of years doing vigorous exercise*3)

[d] Summary score=(average number of minutes per week doing light exercise*1)+(average number of minutes doing moderate exercise*2)+(average number of minutes doing vigorous exercise*3)

[e] Childhood socioeconomic advantage score=being on welfare during childhood+childhood financial level relative to others+highest parental education. Possible range of score was 0–6

[f] Adult financial advantage score=family-adjusted poverty-to-income ratio+self-rated current financial situation+sufficient money to meet needs+degree of difficulty paying bills. Possible range of score was 0–8

additional year of single-parent childhood, femoral neck compression strength index was 0.029 SD lower (p<0.05), bending strength index was 0.021 SD lower (p<0.05), and impact strength index was 0.017 SD lower (p value=0.07). The magnitudes of these associations were similar after further

adjustment for childhood and adult socioeconomic status and childhood and adult lifestyle factors (Table 2, model 2).

However, in linear regression with duration of single-parent childhood as a categorical predictor, we found that the associations (adjusted as before for race, site, menopausal stage, age, gender, and BMI) were primarily driven by those who reported nine or more years of single-parent childhood (Table 3, model 1). Compared with not living in a single parent household before age 16, living in a single-parent household for 9–16 years was associated with 0.401 SD lower compression strength index, 0.307 SD lower bending strength index, and −0.254 SD lower impact strength index (all p values <0.05). The magnitudes of these associations were similar after further adjustment for childhood and adult socioeconomic status and childhood and adult lifestyle factors (Table 3, model 2).

In contrast, parental death or divorce itself was not independently associated with adult bone strength, suggesting that the chronic experience of residing in a single-parent family rather than the acute event of parental marital dissolution contributes to decreased adult bone strength.

Interaction testing revealed that associations of bone strength indices with parental death or divorce prior to age 16 and of the number of childhood years in a single parent did not vary by gender or menopausal transition stage (p values 0.11 to 0.93, model 1).

Discussion

Independent of parental divorce or parental death, growing up in a single-parent household was associated with lower bone strength in adulthood. There was a strong inverse association between the number of childhood years in a single-parent household and all three indices of adult femoral neck strength relative to load. These associations were not explained by childhood or adult socioeconomic status or by health behaviors over the life course, and add to the growing list of adverse subclinical and clinical health outcomes that have been linked to childhood psychosocial disadvantage [17, 67–73]. However, the experience of parental death or divorce during

Table 2 Adjusted associations of childhood family environment with indices of femoral neck strength relative to load; number of single parenting years as a continuous exposure

		Model 1 (N=708)[a]	Model 2 (N=619)[b]
		Compression strength index	Compression strength index
		Effect size (95 % CI) in SD units	Effect size (95 % CI) in SD units
Parental death or divorce (ref: stable 2-parent family)[c]	Parental death or divorce until age 16	0.171 (−0.021, 0.362)~	0.190 (−0.030, 0.410)~
	Other reasons for not living with biological parents under age 16[d]	0.381 (−0.234, 0.996)	0.330 (−0.321, 0.982)
Single parent childhood	Per additional year in single parent household	−0.029 (−0.053, −0.006)*	−0.028 (−0.051, −0.004)*
		Bending strength index	Bending strength index
		Effect size (95 % CI) in SD units	Effect size (95 % CI) in SD units
Parental death or divorce (ref: stable 2-parent family)	Parental death or divorce until age 16	0.039 (−0.112, 0.190)	0.044 (-0.128, 0.216)
	Other reasons for not living with biological parents under age 16	0.103 (−0.244, 0.450)	0.017 (−0.309, 0.343)
Single parent childhood	Per additional year in single parent household	−0.021 (−0.039, −0.004)*	−0.021 (−0.041, −0.002)*
		Impact strength index	Impact strength index
		Effect size (95 % CI) in SD units	Effect size (95 % CI) in SD units
Parental death or divorce (ref: stable 2-parent family)[e]	Parental death or divorce until age 16	0.105 (−0.037, 0.247)	0.096 (−0.068, 0.260)
	Other reasons for not living with biological parents under age 16	−0.006 (−0.330, 0.318)	−0.070 (−0.398, 0.258)
Single parent childhood	Per additional year in single parent household	−0.017 (−0.034, 0.001)~	−0.018 (−0.037, 0.001)~

SD standard deviation, *95 % CI* 95 % confidence interval

[a] Model 1: Adjusted for race, site, menopausal stage, age, gender, body mass index (BMI), and BMI-gender interaction

[b] Model 2: Adjusted for all covariates in model 1+education, adult financial advantage, childhood socioeconomic advantage, smoking pack-years, recreational physical activity at ages 14–18, competitive sports at ages 14–18, physical activity at ages 20–35, current physical activity, smoking initiation before age 18, current smoking, heavy peak alcohol use, and heavy alcohol use in the past month

[c] Lived with both biological parents until age 16 or adopted at birth

[d] Lived in a single-parent household without death or divorce, or gave other reasons for not living with biological parents until age 16

[e] Lived with both biological parents until age 16 or adopted at birth

*p value 0.05–0.01; ~0.05–0.1

Table 3 Adjusted associations of childhood family environment with indices of femoral neck strength relative to load; years of single parenting as a categorical exposure

		Model 1 (N=708)[a] Compression strength index Effect size (95 % CI) in SD units	Model 2 (N=619)[b] Compression strength index Effect size (95 % CI) in SD units
Parental death or divorce (ref: stable 2-parent family)[c]	Parental death or divorce under age 16	0.168 (−0.032, 0.367)~	0.179 (−0.051, 0.410)
	Other reasons for not living with biological parents until age 16[d]	0.356 (−0.231, 0.944)	0.308 (−0.315, 0.932)
Single parent childhood (ref: did not have single parent for most of childhood)	Single parent household for 1–8 years	−0.067 (−0.568, 0.435)	0.012 (−0.524, 0.548)
	Single parent household for 9–16 years	−0.401 (−0.701, −0.100)*	−0.376 (−0.675, −0.077)*
		Bending strength index Effect size (95 % CI) in SD units	Bending strength index Effect size (95 % CI) in SD units
Parental death or divorce (ref: stable 2-parent family)	Parental death or divorce under age 16	0.027 (−0.124, 0.178)	0.024 (−0.151, 0.198)
	Other reasons for not living with biological parents until age 16	0.090 (−0.247, 0.427)	0.008 (−0.310, 0.325)
Single parent childhood (ref: did not have single parent for most of childhood)	Single parent household for 1–8 years	0.089 (−0.469, 0.647)	0.177 (−0.425, 0.780)
	Single parent household for 9–16 years	−0.307 (−0.537, −0.076)*	−0.307 (−0.558, −0.057)*
		Impact strength index Effect size (95 % CI) in SD units	Impact strength index Effect size (95 % CI) in SD units
Parental death or divorce (ref: stable 2-parent family)	Parental death or divorce under age 16	0.091 (−0.050, 0.232)	0.076 (−0.091, 0.243)
	Other reasons for not living with biological parents under age 16	−0.010 (−0.321, 0.301)	−0.073 (−0.385, 0.240)
Single parent childhood (ref: did not have single parent for most of childhood)	Single parent household for 1–8 years	0.155 (−0.463, 0.772)	0.213 (−0.456, 0.883)
	Single parent household for 9–16 years	−0.254 (−0.484, −0.023)*	−0.271 (−0.521, −0.020)*

SD standard deviation, *95 % CI* 95 % confidence interval

[a] Model 1: Adjusted for race, site, menopausal stage, age, gender, body mass index (BMI), and BMI-gender interaction

[b] Model 2: Adjusted for all covariates in model 1+education, adult financial advantage, childhood socioeconomic advantage, smoking pack-years, recreational physical activity at ages 14–18, competitive sports at ages 14–18, physical activity at ages 20–35, current physical activity, smoking initiation before age 18, current smoking, heavy peak alcohol use, and heavy alcohol use in the past month

[c] Lived with both biological parents until age 16 or adopted at birth

[d] Lived in a single-parent household without death or divorce, or gave other reasons for not living with biological parents until age 16

*p value 0.05–0.01; ~0.05–0.1

childhood was not independently associated with adult bone strength once we accounted for the number of years spent living in a single-parent household, suggesting that the event of parental death or divorce during childhood does not by itself have direct effects on bone health independent of the subsequent chronic exposure to single parenting.

Although previous studies have documented links between childhood socioeconomic exposures and adult bone health [12, 74–76], as far as we are aware, this is the first investigation of the effect of childhood family stability and structure on adult bone strength. Previous studies have shown that each SD increment in the femoral neck composite strength indices was associated with 34–41 % relative decrement in the rate (hazard) of fracture at any site in women going through the menopausal transition [56], and 57–66 % relative decrement in the risk of hip fracture over 10 years in postmenopausal women [53]. If the differences in the composite strength indices seen in this study between single-parent and two-parent childhoods lead to similar fracture risk differences, women who experienced nine or more years of single parenting in childhood would be at 14–19 % relative increase (relative to women who did not have a single parent for most of childhood) in fracture hazard when going through the menopausal transition, and 31–41 % relative increase in 10-year hip fracture risk in the postmenopause. These findings carry important implications for the bone health of future cohorts of adults. In 2012, only 64 % of American children resided with both parents [77]. Thus, large and growing numbers of children who spend much of their first 16 years in a single-parent household may be at elevated risk for poor bone health as adults.

We considered several possible reasons for our findings. First, the physical absence of a father or mother figure could influence adult bone health via the adoption of maladaptive health behaviors such as smoking and underage or heavy alcohol intake. Single-parent childhood is associated with

increased smoking [34, 78–81] and alcohol intake [79, 81–84] by adolescents; in turn, smoking and alcohol intake have known adverse effects on bone health [85–88]. Second, decreased physical activity is more common in children in single-parent families [89–92], and skeletal growth is negatively influenced by childhood, especially adolescent, physical inactivity [4, 93–97]. Finally, many children living with single parents are economically disadvantaged [40, 98–106], which also has been linked to poor bone health [11, 12, 107, 108]. However, in our study, the associations between the single-parent childhood and lower adult bone strength were not explained by childhood or adult socioeconomic status or health behaviors over the life course.

Independent of socioeconomic and behavioral pathways, the environmental and psychological stresses of growing up with a single parent could directly affect the hormonal milieu in the child, thereby affecting bone accrual. This is supported by the following observations: (1) children living with single parents face more emotional and environmental stressors than children from two-parent families [40, 98]; (2) basal cortisol levels in children vary by the magnitude of environmental stress, and these gradients are stronger in younger (below age 10) than in older children [109]; (3) early-life adversity has been linked to dysregulation of the sympathetic nervous system, as well to chronic inflammation [110–113]; and (4) the activation of sympathetic nervous signaling by stress and increased levels of inflammatory markers are both associated with low BMD [114–123].

Our study has several strengths, including the focus on the independent effects of family disruption and single parenting, careful attention to the duration for which a child resided in a single-parent household, the national sample recruited from across the US coterminous states, availability of socioeconomic and lifestyle data over the life course, and the focus on hip strength relative to load, which is better at fracture risk stratification in a diverse population than is BMD on its own.

Limitations of our study include its observational design, which does not allow attribution of causality, and the lack of information on childhood diet and nutrition. Further, our ability to examine possible racial and gender differences in associations between childhood family environment and adult bone strength was limited by the small number of nonwhite MIDUS participants and the small number of participants with the primary exposures. The number of participants who were raised by a single parent from birth was also very small; this meant that we could not disentangle the effect of long exposure to single parenting from that of experiencing parental separation at a young age, and the findings from this study may not be applicable to the children of mothers who choose to be single parents from the start. Finally, the phrasing of the MIDUS questions about male and female heads of household "for most of their childhood" could have failed to capture short, time-limited exposure to single parenting; such underreporting and the resulting misclassification would have weakened our power to find an effect for 1–8 years of single-parent childhood.

Conclusions

In conclusion, independent of childhood and adult socioeconomic status, being raised in a single-parent household for most of one's childhood was associated with lower levels of femoral neck strength in adulthood, whereas the event of parental death or divorce experienced during childhood was not independently associated with bone strength. Further research is needed to elucidate the mechanisms underlying these associations and, ultimately, to develop targeted strategies aimed at decreasing the fracture burden and other adverse health effects of childhood stresses.

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