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ORIGINAL ARTICLE

Milk consumption throughout life and bone mineral content and density in elderly men and women

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Abstract
Summary Association between bone mineral density and bone mineral content in old age and milk consumption in adolescence, midlife, and old age was assessed. The association was strongest for milk consumption in midlife: those drinking milk daily or more often had higher bone mineral density and content in old age than those drinking milk seldom or never.
Introduction The role of lifelong milk consumption for bone mineral density (BMD) and bone mineral content (BMC) in old age is not clear. Here we assess the association between hip BMD and BMC in old age and milk consumption in adolescence, midlife, and current old age.
Methods Participants of the Age, Gene/Environment Susceptibility-Reykjavik Study, aged 66–96 years (N=4,797), reported retrospective milk intake during adolescence and midlife as well as in current old age, using a validated food frequency questionnaire. BMC of femoral neck and trochanteric area was measured by volumetric quantitative computed tomography and BMD obtained. Association was assessed using linear regression models. Differences in BMC, bone volume, and BMD in relation to milk intake were portrayed as gender-specific Z-scores.
Results Men consuming milk≥once/day during midlife had 0.21 higher Z-scores for BMD and 0.18 for BMC in femoral neck (95 % confidence interval 0.05–0.39 and 0.01–0.35, respectively) compared with<once/week. Results were comparable for trochanter. For women the results were similar, with slightly lower differences according to midlife milk consumption. For current and adolescent milk consumption, differences in Z-scores were smaller and only reached statistical significance in the case of BMD for current consumption in men, while this association was less pronounced for BMC.

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Conclusions Our data suggest that regular milk consumption throughout life, from adolescence to old age, is associated with higher BMC and BMD in old age, with no differences seen in bone volume. The strongest associations are seen for midlife milk consumption in both genders.

Keywords AGES-Reykjavik Study · Bone mineral content · Bone mineral density · Elderly · Milk intake

Introduction

Daily consumption of milk and dairy products is widely recommended for people of all ages [1–3], not the least for their high calcium content and importance for obtaining and maintaining bone health. Other important nutrients and other factors in milk, including proteins, phosphates, and growth factors, may also affect bone mineral density [4–6]. Still the evidence is inconclusive when it comes to the significance of lifelong consumption of milk and dairy products for bone health in old age, the time when serious and debilitating osteoporotic fractures are most likely to occur [7].

While intervention studies have reported a positive effect of milk consumption in childhood and adolescence on bone mineral content (BMC) and bone mineral density (BMD) [8, 9], most long-term studies of calcium supplementation find the increase to be transient [10, 11]. Conversely, cross-sectional and cohort studies have reported a positive association between milk intake in early life, both before and after puberty, and bone health in adulthood [12–15], as well as between midlife intake and bone health in old age [13, 14]. Few studies are available on whole life exposure, from adolescence to old age, and long-term association between milk consumption and late life BMD or BMC, and results from epidemiological studies are still inconclusive on this point [13, 14, 16–18]. Furthermore, studies on the role of milk/dairy consumption on bone health of elderly men are lacking. More information is needed to better understand and assess the strength of this relationship and to identify the time periods most critical when it comes to bone health in old age.

The Age, Gene/Environment Susceptibility-Reykjavik (AGES-Reykjavik) Study is a study with 5,764 elderly participants (42 % men). Extensive data on multiple lifestyle, health, and biological factors have been gathered, including data on BMC, BMD, and bone volume at different skeletal sites, by quantitative computed tomography (QCT) scanning, and dietary intake at different periods of life (14–19 years, 40–50 years, current) using a validated food frequency questionnaire [19–21].

In this study our aims were to investigate whether, and to what extent, retrospective self-reports of milk and dairy intake in adolescence and midlife, as well as current old age, were associated with hip BMC, bone volume, and BMD in old age in participants of the AGES-Reykjavik Study. Our hypothesis was that inadequate calcium consumption during midlife and old age might lead to secondary rise in parathyroid hormone for maintaining normal serum calcium concentration. This might, in the long run, lead to lower BMC and BMD in old age due to increased bone resorption. In adolescence inadequate calcium consumption might however be reflected in lower bone volume acquired during bone growth. The hip was chosen over other skeletal sites due to the great impact hip fractures have on the elderly, their quality of life and life expectancy, as well as their substantial cost for the health care systems.

Methods/subjects

Subjects and design

The AGES-Reykjavik Study originates from the Reykjavik Study, a large population-based cohort study that started in 1967. All men and women born in 1907–1935 (n=30,795) and residing in Reykjavik and nearby communities in 1967 were selected; 27,281 were invited to participate and 19,381 attended [19, 22]. Of the 11,549 previously examined Reykjavik Study cohort members still alive when AGES-Reykjavik examinations began in 2002, 8,030 individuals were randomly chosen and invited to participate. From these, 5,764 individuals (42 % male) had participated in the AGES-Reykjavik Study by its conclusion in 2006. Participants were 66–96 years old at the time of examinations, average age being 76 years.

The AGES-Reykjavik examination was completed in three clinic visits within a 4- to 6-week time window. Extensive data were collected during clinical examinations, e.g., on physical and cognitive function, anthropometry, health history, and food history during adolescence, midlife, and late life, i.e., current diet. Participants also underwent QCT scanning and were asked to bring to the clinic all medications and supplements used in the previous 2 weeks, representing current usage [19].

Of the 5,764 participants of AGES-Reykjavik, 933 did not undergo the QCT scanning and additional 34 individuals did not give information on milk or dairy consumption in the AGES-food frequency questionnaire (FFQ); therefore, data from 4,797 individuals (44 % male) were used in the present study.

The AGES-Reykjavik Study was approved by the Icelandic National Bioethics Committee (VSN: 00–063) and the MedStar IRB for the Intramural Research Program, Baltimore, MD, USA.

Bone measurements

QCT measurements, providing true volumetric density, were performed on the left hip using a four-detector CT system (Sensation, Siemens Medical Systems, Erlangen Germany). Scans were acquired using a standardized protocol and encompassed the proximal femur from a level 1 cm above the acetabulum to a level 5 mm inferior to the lesser trochanter with 1-mm slice thickness. Further procedures and quality assessments have been described in detail elsewhere [19, 23].

The variables used in the present study are BMC (g), volume (cm^3), and volumetric integral BMD (g/cm^3), reflecting both trabecular and cortical bone mass, of the femoral neck and trochanteric area, encompassing both trochanters. Reasons for exclusion from the QCT were inability to lie supine or weight over 150 kg. Furthermore, hip scans were not performed on individuals that had undergone hip replacement surgery.

Dietary information

Dietary data were collected using a short food frequency questionnaire designed for participants of the AGES-Reykjavik Study (AGES-FFQ). The questionnaire is divided into three parts, asking about intake at different periods of life: 16 questions on adolescent diet (14–19 years), 17 questions on midlife diet (40–50 years), and 30 questions on current diet. Foods and food groups were selected for the questionnaire on the basis of their contribution to the absolute intake of elderly Icelanders according to a National Nutrition Survey [24] as well as their unique nutritional qualities and possible connection to the development of various diseases in later life. The questionnaire has been described previously [20, 21].

Frequency of consumption of both milk and dairy products, excluding cheese (hereafter referred to as milk), was measured in each of the three parts of the AGES-FFQ. The response categories were as follows: (1) never, (2) less than once a week, (3) 1–2 times a week, (4) 3–4 times a week, (5) 5–6 times a week, (6) daily, or (7) more than once a day.

Validity of questions on midlife diet and current diet has been assessed in previous studies, and milk was among the foods that showed the highest validity [20, 21]. Midlife milk intake of 56–72-year-old individuals was estimated retrospectively using the questions on midlife diet in the AGES-FFQ and results compared with detailed dietary data, gathered from the same individuals 18–19 years previously, i.e., in midlife, as a part of a national dietary survey [24]. Correlation using Spearman's rho was $r=0.43$, $p<0.001$ and $r=0.29$, $p=0.003$ for men and women, respectively [20]. The validity of current milk intake was assessed among elderly individuals (average age 74 years) by comparing answers of the AGES-FFQ to 3-day weighed food records completed by the same individuals. Correlation using Spearman's rho was $r=0.49$, $p<0.001$ and $r=0.45$, $p<0.001$ for men and women, respectively [21].

Covariates

For examining the association between milk consumption through different periods of life and hip BMC, BMD, and volume, we selected a priori the following set of covariates: age, physical activity during different periods of life, current alcohol intake, cod liver oil intake (main dietary source of vitamin D in the population studied) in the same time period as milk intake, and body mass index (BMI). Midlife BMI was chosen as a covariate for the retrospective data and current BMI for the current data.

To obtain history of physical activity, participants were asked how much time (hours/week) they spent on moderate to vigorous activities in four different periods of life: young adulthood (20–34 years), early middle age (35–49 years), late middle age (50–64 years), and current physical activity. Both weight-bearing and non-weight-bearing exercises were included. Current consumption of alcohol was converted into grams per week using 14 g of alcohol as a standard drink and then divided into <25, 25–50, and >50 g/week. Information on cod liver oil intake was gathered using the AGES-FFQ [19, 20]. Midlife data on BMI had been collected in the Reykjavik Study [22].

For early life, most of these covariates can only be considered surrogate measures of corresponding early life characteristics. For midlife and current old age, the selected covariates are potential predictors of both bone health and dietary habits.

Data analysis and statistical analysis

Characteristics of study participants were described using mean and standard deviation (SD) for normal variables, median and interquartile range for skewed variables, and percentages for dichotomous variables. As our source BMC and BMD variables were approximately normally distributed, we were able to transform them into sex-specific Z-scores, reflecting the number of SD from the mean in our subject group of 66–96 year-old individuals.

Univariate and multivariate linear regression was used for examining the association between milk intake and BMD. Milk consumption was categorized a priori into three groups: ≤once/week, 1–6 times/week, and≥once/day. The lowest intake group (≤once/week) was, in all cases, used as referent, and results are represented as difference (Δ) in Z-score with increased frequency of consumption compared to the referent. Student's *t* test was used to test whether BMD was linearly related to milk consumption (ordinal values). Visual inspection of model residual suggested that the use of Z-scores was justifiable.

Data are presented unadjusted and adjusted for age, midlife or current BMI, past and present physical activity, alcohol consumption, and cod liver oil consumption.

For stability analyses, individuals taking medications known to affect bone health at the time of AGES examinations, 435 men (21 %) and 992 women (37 %), were excluded. The list of medications that resulted in exclusion for this secondary analysis includes antiepileptic medication, calcium supplements, oral estrogens, glucocorticoids, osteoporosis drugs, prostate disease drugs, proton pump inhibitors, oral steroids, and thyroid agonists. Statistical analyses were conducted in SAS (version 9.2; SAS Institute Inc., Cary, NC, USA).

Results

Possible confounders, in relation to the category of milk consumption in adolescence, midlife, and current old age, are shown in Table 1. Consumption of milk was common at

Table 1 Possible confounding factors in relation to milk consumption in adolescence (14–19 years), midlife (40–50 years), and current consumption. Data shown as mean (SD), median (IQR), or proportion (%)

	Men			Women		
	<once/week	1–6/week	≥once/day	<once/week	1–6/week	≥once/day
Adolescence						
No. (%)	40 (2)	399 (19)	1,659 (79)	111 (4)	542 (20)	2,036 (75.7)
Age (years)	77.5 (6.2)	76.5 (5.2)	76.4 (5.4)	76.4 (6.2)	75.7 (5.3)	76.2 (5.6)
Midlife BMI (kg/m^2)	26.1 (3.0)	25.6 (3.0)	25.5 (3.2)	24.8 (6.1)[a]	24.4 (4.7)[a]	24.2 (4.4)[a]
Current BMI (kg/m^2)	26.8 (3.9)	26.8 (3.7)	26.8 (3.8)	28.2 (6.9)[a]	27.1 (6.0)[a]	26.7 (5.9)[a]
Alcohol (g/week)	3.2 (30.8)[a]	6.4 (26.4)[a]	6.4 (26.4)[a]	1.6 (6.4)[a]	1.6 (9.7)[a]	1.6 (8.0)[a]
PA present (h/week)	0.03 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.0 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
PA 50–65 years (h/week)	0.0 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
PA 35–49 years (h/week)	0.0 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
PA 20–34 years (h/week)	0.05 (0.5)[a]	0.05 (1.5)[a]	0.05 (5.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
Daily intake of cod liver oil (%)	30.0	21.7	32.9	20.0	23.8	38.8
Medications[b] (%)	22.5	21.8	20.4	43.2	36.7	36.4
Midlife						
No. (%)	140 (7)	649 (31)	1,302 (62)	238 (9)	933 (35)	1,511 (56)
Age (years)	76.6 (5.6)	76.1 (5.2)	76.6 (5.4)	76.5 (5.8)	75.6 (5.2)	76.4 (5.6)
Midlife BMI (kg/m^2)	25.8 (3.2)	25.6 (3.2)	25.4 (3.1)	24.5 (4.9)[a]	24.3 (4.4)[a]	24.2 (4.5)[a]
Current BMI (kg/m^2)	27.2 (4.1)	27.0 (3.7)	26.6 (3.8)	27.5 (6.3)[a]	27.0 (5.9)[a]	26.6 (5.9)[a]
Alcohol (g/week)	6.4 (33.0)[a]	8.0 (24.8)[a]	4.8 (26.4)[a]	1.6 (16.1)[a]	1.6 (9.7)[a]	1.6 (8.0)[a]
PA present (h/week)	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.0 (0.05)[a]	0.05 (1.5)[a]	0.0 (1.5)[a]
PA 50–65 years (h/week)	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
PA 35–49 years (h/week)	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
PA 20–34 years (h/week)	0.05 (1.5)[a]	0.05 (5.5)[a]	0.05 (5.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
Daily intake of cod liver oil (%)	42.1	34.4	48.9	37.8	39.6	46.2
Medications[b] (%)	23.6	19.6	20.9	35.3	36.9	37.0
Current						
No. (%)	484 (23)	511 (24)	1,098 (52)	711 (26)	714 (27)	1,262 (47)
Age (years)	76.3 (5.4)	75.9 (5.1)	76.8 (5.4)	76.0 (5.6)	75.9 (5.3)	76.3 (5.6)
Midlife BMI (kg/m^2)	25.4 (3.4)	25.6 (3.0)	25.5 (3.1)	24.2 (4.4)[a]	24.3 (4.4)[a]	24.4 (4.5)[a]
Current BMI (kg/m^2)	26.5 (3.9)	27.0 (3.6)	26.8 (3.8)	26.6 (6.0)[a]	26.8 (6.1)[a]	26.9 (5.8)[a]
Alcohol (g/week)	8.0 (32.8)[a]	8.0 (24.8)[a]	4.8 (24.1)[a]	3.2 (13.2)[a]	1.6 (8.0)[a]	1.6 (6.4)[a]
PA present (h/week)	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.0 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
PA 50–65 years (h/week)	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
PA 35–49 years (h/week)	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
PA 20–34 years (h/week)	0.05 (5.5)[a]	0.05 (4.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]	0.05 (1.5)[a]
Daily intake of cod liver oil (%)	59.8	55.6	63.6	54.2	57.5	65.7
Medications[b] (%)	19.8	17.0	22.7	35.9	36.1	37.7

PA physical activity, *SD* standard deviation, *IQR* interquartile range

[a] Interquartile range

[b] Reported intake of medications known to affect bone density

all periods of life, though the proportion of participants reporting any intake decreased with age. Daily consumption decreased from 77 % in adolescence to 59 % in midlife and 49 % in current old age. Only 1.5 % of our participants reported no intake in adolescence, 3.5 % in midlife, and 14 % in current old age.

The relationship between different levels of milk consumption during different periods of life and adjusted differences in Z-scores calculated from femoral neck BMD, BMC, and bone volume in old age is shown in Table 2 and that for the trochanteric area in Table 3. Data are shown separately for men and women, adjusted for confounders. Individuals with the highest frequency of milk consumption in adolescence (≥once/day) had, on the average, higher BMD Z-scores by 0.08–0.15 compared to those in the lowest intake group (<once/week). The difference was insignificant for both men and women and for both femoral neck and trochanter. Men and women with the highest frequency of milk consumption during midlife had significantly higher BMC and BMD Z-scores for femoral neck and trochanter, compared to those with the lowest frequency of consumption. For men the differences in femoral neck Z-scores were 0.18 in BMC and 0.21 in BMD, while for women the corresponding differences were 0.15 and 0.20. Values for the trochanteric area were 0.15 and 0.16 for BMC and 0.22 and 0.18 for BMD in men and women, respectively. Women with midlife milk consumption of 1–6 times/week also had significantly higher Z-scores for BMD in femoral neck compared to women in the lowest intake group.

Table 2 Adjusted differences in Z-scores derived from femoral neck BMD, BMC, and bone volume according to self-reported milk consumption during different periods of life. Results are presented separately for males and females

	Bone mineral density		Bone mineral content		Bone volume	
	ΔZ	95 % CI	ΔZ	95 % CI	ΔZ	95 % CI
Males						
Adolescence						
<once/week	Referent	–	Referent	–	Referent	–
1–6/week	0.09	−0.23 to 0.41	0.03	−0.28 to 0.34	−0.10	−0.43 to 0.22
≥once/day	0.13	−0.17 to 0.44	0.10	−0.21 to 0.40	−0.06	−0.37 to 0.25
p for trend		0.28		0.18		0.65
Midlife						
<once/week	Referent	–	Referent	–	Referent	–
1–6/week	0.16	−0.02 to 0.34	0.12	−0.06 to 0.29	−0.07	−0.25 to 0.12
≥once/day	0.21	0.05 to 0.39	0.18	0.01 to 0.35	−0.05	−0.23 to 0.12
p for trend		0.02		0.03		0.79
Current						
<once/week	Referent	–	Referent	–	Referent	–
1–6/week	−0.02	−0.14 to 0.10	0.00	−0.12 to 0.12	0.02	−0.15 to 0.10
≥once/day	0.09	−0.01 to 0.20	0.07	−0.04 to 0.17	−0.04	−0.15 to 0.07
p for trend		0.04		0.15		0.47
Females						
Adolescence						
<once/week	Referent	–	Referent	–	Referent	
1–6/week	0.11	−0.08 to 0.30	0.04	−0.15 to 0.23	−0.08	−0.28 to 0.13
≥once/day	0.12	−0.06 to 0.30	0.10	−0.08 to 0.28	−0.01	−0.20 to 0.18
p for trend		0.29		0.11		0.36
Midlife						
< once/week	Referent	–	Referent	–	Referent	
1–6/week	0.14	0.00 to 0.27	0.12	−0.01 to 0.25	−0.01	−0.15 to 0.14
≥ once/day	0.20	0.07 to 0.33	0.15	0.02 to 0.28	−0.03	−0.17 to 0.11
p for trend		0.002		0.04		0.54
Current						
< once/week	Referent	–	Referent	–	Referent	
1–6/week	0.06	−0.03 to 0.16	0.10	0.01 to 0.21	0.08	−0.03 to 0.18
≥ once/day	0.07	−0.01 to 0.16	0.03	−0.05 to 0.12	−0.02	−0.11 to 0.07
p for trend		0.12		0.69		0.45

Adjusted for age, past and present physical activity, alcohol consumption, cod liver oil intake, midlife BMI for adolescent and midlife consumption, and current BMI for current consumption

ΔZ mean difference in Z-score, *CI* confidence interval

Table 3 Adjusted differences in Z-scores derived from trochanteric area for BMD, BMC, and bone volume according to self-reported milk consumption at different periods of life. Results are presented separately for males and females

	Bone mineral density		Bone mineral content		Bone volume	
	ΔZ	95 % CI	ΔZ	95 % CI	ΔZ	95 % CI
Males						
Adolescence						
< once/week	Referent	–	Referent	–	Referent	–
1–6 week	−0.001	−0.32 to 0.31	−0.06	−0.37 to 0.26	−0.15	−0.47 to 0.18
≥ once/day	0.07	−0.23 to 0.37	0.02	−0.28 to 0.32	−0.10	−0.41 to 0.21
p for trend		0.19		0.25		0.72
Midlife						
< once/week	Referent	–	Referent	–	Referent	–
1–6/week	0.14	−0.03 to 0.32	0.10	−0.08 to 0.27	−0.06	−0.24 to 0.13
≥ once/day	0.22	0.05 to 0.39	0.15	−0.02 to 0.32	−0.06	−0.23 to 0.12
p for trend		0.007		0.06		0.67
Current						
< once/week	Referent	–	Referent	–	Referent	–
1–6/week	0.02	−0.10 to 0.14	0.04	−0.07 to 0.16	0.01	−0.12 to 0.13
≥ once/day	0.10	−0.007 to 0.20	0.08	−0.02 to 0.18	−0.01	−0.11 to 0.10
p for trend		0.049		0.13		0.84
Females						
Adolescence						
< once/week	Referent	–	Referent	–		
1–6/week	0.11	−0.08 to 0.29	−0.06	−0.25 to 0.14	−0.25	−0.46 to −0.04
≥ once/day	0.13	−0.04 to 0.31	0.03	−0.16 to 0.21	−0.15	−0.34 to 0.05
p for trend		0.15		0.17		0.69
Midlife						
< once/week	Referent	–				
1–6/week	0.13	−0.001 to 0.26	0.12	−0.02 to 0.26	0.01	−0.13 to 0.15
≥ once/day	0.18	0.05 to 0.30	0.16	0.03 to 0.29	0.01	−0.13 to 0.15
p for trend		0.006		0.03		0.93
Current						
< once/week	referent	–				
1–6/week	0.09	−0.003 to 0.18	0.13	0.04 to 0.23	0.08	−0.03 to 0.18
≥ once/day	0.09	0.01 to 0.17	0.06	−0.02 to 0.15	−0.02	−0.11 to 0.08
p for trend		0.047		0.29		0.54

Adjusted for age, past and present physical activity, alcohol consumption, cod liver oil intake, midlife BMI for adolescent and midlife consumption, and current BMI for current consumption

ΔZ mean difference in Z-score, *CI* confidence interval

For current consumption, individuals with the highest frequency of consumption had BMD Z-scores approximately 0.09 higher than those in the lowest intake group; the differences were similar for femoral neck and trochanter.

There was a dose response between milk consumption at each period of time and Z-scores calculated from hip BMC and BMD in old age. When comparing individuals constantly with the highest versus the lowest frequency of intake in the three different periods of life included in the study, the differences in BMC and BMD for both femoral neck and trochanter were similar to the differences seen for midlife consumption (data not shown).

There were no differences in bone volume Z-scores according to milk consumption at any time during the life span assessed here, neither in femoral neck nor in trochanter.

Almost one third of the participants were taking medications known to be able to affect bone health. Proton pump inhibitors were most common (13 %), followed by thyroid agonists, osteoporosis-related drugs, oral estrogens for women, and prostate disease drugs for men. We therefore also performed analysis without these individuals reaching the same conclusions as in our primary analysis where these subjects were included.

Discussion

This study assessed the association between milk consumption at different periods of life and hip BMC and BMD in old age. Our findings suggest that regular milk consumption throughout life, from adolescence to old age, is associated with higher BMD and BMC in old age but no change in bone volume. The strongest association was seen for midlife milk consumption, slightly stronger for men than women.

The midlife period in our study (40–50 years) probably includes early menopause for most women in our study, and those years are characterized by rapid bone loss, largely due to decreased estrogen production [25–28]. While some studies have found calcium interventions to be more effective in late postmenopausal women compared to perimenopausal women [29], we found the strongest association between frequent milk consumption during midlife and BMC and BMD in old age. A comparable relationship for BMD has also been found in another cross-sectional study by Soroko et al. [14].

Men lose bone minerals from all skeletal sites after approximately 50 years of age, even though their bone loss is more gradual than that of women [30, 31]. The stronger association observed between midlife milk consumption and BMD and BMC in old age among men compared to women was therefore somewhat surprising. Possibly, the stronger association seen for men might be related to the validity of the AGES-FFQ, as men's answers to questions on milk consumption were found to be of greater validity than those of women [20, 21]. The association seen for men may therefore reflect an even more accurate relationship than that for women.

Studies on areal BMD have concluded that a 1 SD decrease in hip BMD can be associated with approximately 2.5-fold increased risk of hip fracture [32, 33]. A comparable relationship has been found between volumetric BMD (vBMD) and hip fractures in prospective studies [34, 35]. Yang et al. [35] found that QCT measurements of the proximal femur were significantly associated with hip fracture risk, hazard ratios for 1 SD decrease ranging from 2.28 (95 % confidence interval (CI), 1.44–3.63) to 6.91 (95 % CI, 3.11–15.53). Additionally, Black et al. [34] found that for femoral neck integral volumetric density, the 5-year risk of hip fracture in the lowest quartile was >15 times that in the highest quartile (3.6 versus 0.2 %). Similarly, we have also found in our own material from the AGES-Reykjavik Study that vBMD predicts hip fractures in elderly men and women [36, 37]. The difference of 0.2 Z-scores (equal to 0.2 SD in vBMD) seen in the present study between individuals with high versus low frequency of milk intake in midlife is therefore likely to be of clinical relevance.

The interest in milk consumption and its association to BMD is primarily due to the relationship between BMD and osteoporosis and fracture risk. Osteoporosis is an important health problem for men as well as women [38], while studies on bone health among the elderly have generally focused on women. Intervention studies have shown that calcium supplementation in elderly women can have a small benefit on age-related bone loss [39, 40], and milk supplementation may diminish bone turnover among postmenopausal women [41]. As milk consumption is just as strongly related to BMD and BMC for men as for women in the present study, it is plausible that calcium supplementation and/or increased milk consumption among men would have a comparable effect to that among women.

Similar to findings of other cross-sectional and cohort studies on milk intake in childhood and/or adolescence and bone health in adult women [11–15], we also found a positive association between milk consumption in adolescence and BMD in old age, though insignificant. One should however bear in mind that retrospective assessment of milk intake with more than 60 years of temporal separation is always going to provide less precise estimates and is likely to mask or weaken any potential association.

While BMD is a commonly used indicator for bone health in adult life, volumetric BMC may be the preferred indicator, particularly during growth, as it reflects bone size and bone mass [42]. In this study we report on BMC and bone volume, as well as volumetric BMD. Associations between BMD and milk intake during different periods of life were found mostly comparable, but slightly stronger, than those using BMC. The slightly higher associations seen for BMD might suggest lower bone volume in those consuming more milk, i.e., a lower value in the denominator of the equation BMC / volume. However, no significant differences in bone volume were observed between milk consumption categories. Particularly, milk intake in adolescence, a period of bone growth, was not significantly related to BMC in old age, neither in men nor in women, in either femoral neck or trochanter. The difference observed between BMC and BMD in relation to milk consumption may therefore most likely be explained by the slight fluctuation in bone volume in our data.

Consumption of milk and dairy products is a good indicator of calcium intake in Iceland, both during present and earlier times. Traditionally, consumption of milk and dairy products has been high, while other calcium sources have been limited, including a calcium-depleted water supply (4.8 mg/l) and minimal consumption of green vegetable or calcium-rich small fish [24, 43, 44]. Furthermore, calcium fortification has not been common and was virtually non-existent during the participants' adolescence and midlife, and according to Icelandic National Dietary Surveys (INDSs), approximately 70 % of dietary calcium has been obtained from milk and dairy products, including cheese. The consumption of cheese was relatively low in earlier times, or 3.6 kg/person/year in 1956–1960 according to food supply statistics. Since then, the supply has gradually increased and is now 16.9 kg/person/year [45]. Average consumption over the past two decades has been rather stable, at approximately 35–40 g/day [24, 43, 44]. It can therefore be assumed that those participants consuming little or no milk or dairy products most likely had low calcium intakes, especially in earlier times.

It should be mentioned that milk is generally not fortified with vitamin D in Iceland, except for one low-fat milk product that came on the market in the 1980s, containing 0.36 μg/100 ml and another one introduced in 2012 containing 1 μg/100 ml. The milk consumed in adolescence or midlife by our study participants therefore did not contain vitamin D of any consequence. Dietary sources of vitamin D are few, and according to the 2010–2011 INDS [44], average intake of vitamin D among 61–80-year-old individuals, not counting supplements, was 5.3 μg/day. Due to the lay of the land, dermal production of vitamin D is also limited or non-existent from approximately October to April [46]. There is a tradition of using cod liver oil as a vitamin D supplement in Iceland, and we adjusted for intake in our analysis. However, leaving it out of adjustments only resulted in minor changes in the association seen between milk intake and hip BMD.

The AGES-Reykjavik Study, with its large number of participants and relatively high proportion of men, provided a unique opportunity to assess the association between milk consumption of different periods of life and bone health in old age of both sexes. Also, extensive data gathered in the AGES Study, and midlife data received from the Reykjavik Study, allowed for adjustments of various confounding factors. Finally, the ability to measure both bone volume and bone mineral content, in addition to density, gave the study an added value.

The retrospective assessment of milk consumption is the main limitation of the study. The validity of the AGES-FFQ on midlife and current intake has been assessed, and milk and dairy products were among the food items with the highest correlation to the reference methods in both instances [20, 21]. Nevertheless, the AGES-FFQ only partly captures the variance of the actually recorded intake. As associations tend to bias towards the null, our results may underestimate the true extent of the relationship.

The part of the AGES-FFQ asking about adolescent intake (14–19 years) has not and will not be assessed for validity, as it is extremely difficult to do. However, studies have shown that there is not necessarily a clear decline in the accuracy of reports with increased time lag, and recalled diet from childhood, with 50 years of temporal separation, may be fairly accurate [47]. Furthermore, data from the AGES-FFQ on milk intake have been used in cancer risk studies, where frequent intake during adolescence was associated with a threefold increased risk of advanced prostate cancer in old age, while no significant risk differences were associated with milk intake during later periods of life [48]. This further supports our conclusion that milk intake in adolescence is reported with sufficient accuracy to rank individuals according to level of consumption and identify high and low consumers for studying diet-related disease risk.

The inability to accurately assess the amount consumed is another limitation of the study since the AGES-FFQ includes only questions on the frequency of intake. As a result, we are only able to rank individuals into higher and lower intake groups, without defining the specific amounts of milk or dairy. Still, the comparisons being made between the lowest (<once/week) and the highest (≥once/day) milk intake can be of practical relevance, and ranking individuals according to intake is a common practice in epidemiologic research [48].

Milk and dairy products are nutrient-dense foods, also supplying other nutrients and factors besides calcium that may promote bone growth and calcium accretion, such as proteins, peptides, phosphates, potassium, and magnesium, as well as growth factors and other hormones [4–6]. Possibly, milk also contains other components yet to be identified that affect bone density and bone mass. Thus, the observed association between milk consumption and BMD and BMC may possibly be explained by other factors besides calcium intake. While the significance of milk intake at various ages for bone health in old age warrants further study, we believe that the differences seen here in bone mass and bone density between elderly people according to their milk intake throughout life, and especially during midlife, may have practical relevance for public health.

Conclusion

Our findings suggest that regular milk consumption throughout life, from adolescence to old age, is associated with higher BMD and BMC in old age. The strongest association was seen for midlife milk consumption, and the association was slightly stronger for men than for women. As BMD and bone mass have been shown to be predictors of fracture risk, we consider the differences seen between individuals with more versus less frequent milk consumption to be of clinical relevance for both men and women.

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Conflicts of interest None.

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