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ORIGINAL ARTICLE

Carbonated Beverages, Dietary Calcium, the Dietary Calcium/Phosphorus Ratio, and Bone Fractures in Girls and Boys

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Purpose: **The aim of this study was to explore the association between carbonated beverage consumption, as well as other nutritional intake, and the occurrence of bone fractures in girls (mean ± SD) 14.3 yr ± 1.8 and boys 14.6 yr ± 1.6.**

Methods: **Food-frequency questionnaires and medical histories were obtained from 76 girls and 51 boys. Subjects were recruited from a swimming club and physicians' offices; their physical characteristics are representative of the normal adolescent population.**

Results: **The data show a strong association between cola beverage consumption and bone fractures in girls [the adjusted odds ratio (*OR*) = 3.59; 95% confidence interval (*CI*) 1.21, 10.75; $p = 0.022$]. High intake of dietary calcium was protective (adjusted *OR* = 0.284; 95% *CI* 0.087, 0.920; $p = 0.036$). No association between the non-cola drinks and bone fractures was found. In boys, only total caloric intake was associated with the risk of bone fractures; the association was inverse.**

Conclusion: **The high consumption of carbonated beverages and the declining consumption of milk are of great public health significance for girls and women because of their proneness to osteoporosis in later life.**

KEY WORDS:
Cola beverages
Calcium
Calcium/phosphorus ratio
Bone fractures

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Calcium intake and the calcium/phosphorus ratio in relation to bone fractures and osteoporosis are of great current interest (1). In earlier work, we reported a statistically significant association between the consumption of non-alcoholic carbonated beverages and bone fractures, which occurred among women former college athletes, 21–80 years of age (2). It was hypothesized that the association was attributable to cola drinks that contain phosphoric acid. Using a detailed food-frequency questionnaire and self-reported medical histories, we report here on the association between carbonated beverage consumption and other nutrient intake and the prevalence of bone fractures in girls and boys 8–16 yr of age.

Subjects and Methods

Subjects were white and middle class: 76 girls, ranging in age from 8 to 16 years (mean 14.3, SD 1.77 years) and 51 boys (mean, 14.65; SD, 1.62 years). Twenty-six girls and 24 boys were recruited from a university sponsored swimming club. Another 46 girls and 27 boys were recruited while outpatients of or accompanying patients to orthopedists (four girls). Orthopedists' offices were selected as a source of patients with fractures. The major interest of the study was not related to weight-bearing versus non–weight-bearing activity. Informed consent was obtained by a research assistant. The study was approved by the Research on Human Subjects Committee of the Harvard School of Public Health.

Participants completed a self-administered medical history questionnaire which sought information

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on current physical and athletic activity, smoking and medical history. Activity level was measured on a five-point scale: (a) inactive: no regular physical activity; (b) light activity: no organized physical activity during leisure time; (c) moderate activity: occasionally involved in activities such as golf, tennis, jogging, swimming, or cycling; (d) heavy activity: regular participation in jogging, swimming, cycling or active sports at least three times per week; and (e) vigorous activity: participation in extensive physical exercise for at least 60 min per session, four times per week.

Girls were asked age at menarche to the nearest year and month, regularity of periods, and problems with periods. Participants also completed a standardized food-frequency questionnaire, "Diet Assessment" (3,4); a 116-item food-frequency questionnaire that yields daily dietary intake of a variety of nutrients. This instrument provides "useful estimates of nutrient intake . . . can be obtained by a relatively inexpensive, . . . self-administered questionnaire" (4). The two questionnaires took 30–45 min to complete. For children under 12 years, mothers or other adults may have helped in providing data.

The "Diet Assessment" sought information on frequency of average use during the last year; the range of response was on a nine-point scale, from never to more than six units (servings) per day. The completed "Diet Assessment" questionnaire is optically scanned and the composition of nutritional intake computed by standardized algorithms. Information from the medical histories was edited and entered into a computer. Data from the "Diet Assessment" and from the medical history were merged for the purposes of this study.

Dietary intake measures used in this analysis consisted of (a) units of nutrient intake, e.g., total calories, calcium (mg/day), and phosphorus (mg/day); and (b) frequency of use in last year. Six questions on carbonated beverage consumption are included in the "Diet Assessment;" three for low-calorie/no-sugar drinks: (a) low-calorie colas, (b) low calorie caffeine-free colas, (c) other low-calorie carbonated drinks—Fresca®, ginger ale, 7-Up®; and three for regular/sugar containing drinks: (a) colas—Coke®, Pepsi®, (b) caffeine-free Coke®, (c) other carbonated drinks with sugar. A scale of daily consumption was constructed based on the food-frequency questionnaire for all carbonated drinks, for only cola drinks, for non-cola drinks, and for milk consumption (whole and skim milk). The calcium/phosphorus ratio was formulated as the total amount of calcium intake divided by the total amount of phosphorus intake; this ratio in effect controls for total caloric intake.

From the medical questionnaire, data on the lifetime occurrence of bone fractures were obtained. Subjects reported the site, cause, treatment, and age of occurrence of each fracture. No measurements of bone density were made.

Statistical Methods

Statistical analyses were done using the Statistical Analysis System (SAS) on both a main frame and a personal computer (5). Statistical procedures included simple univariate statistics, student's t test, χ^2, Pearson product–moment correlation; odds ratios using the Mantel–Haenszel method; and multiple logistic regression. (The Mantel–Haenszel method is used to assess the association between two dichotomous variables after controlling for one or more confounding variables. The Mantel–Haenszel method also provides an estimate of the common odds ratio (*OR*) for stratified data.) Two-tailed p values and 95% confidence limits (*CL*) are reported. For the computing of odds ratios and logistic regression, variables relating to nutritional intake were dichotomized at or near the median of the respective distributions.

Results

Tables 1 and 2 presents basic personal and dietary data for boys and girls. The proportion of smokers among girls is 16% (12/76), compared with 4% (2/51) for boys. Activity level was measured on a five-point scale, ranging from little to strenuous physical activity. The mean activity level was more than 4 for both boys and girls. Ninety-five percent of the girls and 98% of the boys engaged in the highest three categories—moderate to vigorous activity; 61% of the girls and 74% of the boys in category 5, the most strenuous activity. For the calculation of odds ratios, activity level was dichotomized—1–4, versus 5. Total caloric intake is significantly higher among boys. Girls consume slightly, but not significantly, more carbonated beverages than boys, and less milk; the calcium/phosphorus ratio (Ca/P; calcium mg/day/phosphorus mg/day) is higher among boys than girls; but this difference in Ca/P ratio is not statistically significant (see Table 1). The medians for daily consumption of beverages are: all carbonated beverages, 1 can for girls and 0.7 for boys; colas, 0.7 can for girls and 0.5

Table 1. Personal Characteristics and Nutritional Intake by Gender

Variable	Girls (n = 76) Mean	Girls (n = 76) SD	Boys (n = 51) Mean	Boys (n = 51) SD
Age (years)	14.34	1.77	14.65	1.62
Age of menarche[a] (years)	12.60	1.66	—	—
Height*** (m)	1.60	0.08	1.72	0.12
Weight*** (kg)	52.16	8.60	64.59	12.41
Calories***	2329.09	1149.69	3515.62	1877.15
Activity (1–5)	4.33	0.97	4.60	0.76
Smoke* (y/n)	0.16	0.37	0.04	0.20
All carbonated[b]	2.16	2.94	1.83	3.16
Colas[b]	1.52	1.92	1.21	2.00
Milk[c]***	1.86	1.53	3.22	2.04
Ca/P × 100	76.69	23.39	80.71	18.84

SD, standard deviation.
[a]By Probit Analysis.
[b]Servings per day—bottles or cans.
[c]Servings per day—8 oz glass.
*Means for girls and boys are significantly different, $p < 0.05$.
**Means for girls and boys are significantly different, $p < 0.02$.
***Means for girls and boys are significantly different, $p = 0.0001$.

for boys; and milk, 1.1 servings (8 oz) for girls and 2.5 for boys.

The proportion of lifetime occurrence of bone fractures in this sample does not differ by gender; 39% of the girls (30/76) and 41% of the boys (21/51) reported at least one fracture. Types or sites of fractures did not differ by activity level nor by gender. For girls and boys, respectively, 44% and 47% were of the hand, wrist, or arm; 44% and 37% leg, ankle, or foot; 8% and 11% back, and 4% and 5% collarbone. The mean number of fractures was 0.63 for girls and 0.78 for boys; mean differences by activity level were not significant. Among those with at least one, the mean was 1.6 for girls and 1.9 for boys.

Table 2. Dietary Intake of Selected Nutrients

Dietary intake		Girls (n = 76) Mean	Girls (n = 76) SD	Boys (n = 51) Mean	Boys (n = 51) SD
Calories		2329.09	1149.69	3515.62	1877.15
Protein	(g)	86.92	34.87	127.66	58.46
Animal fat	(g)	49.08	26.09	75.08	38.02
Vegetable fat	(g)	34.40	25.34	51.37	38.67
Carbohydrates	(g)	320.21	175.77	485.96	292.99
Crude fiber	(g)	5.32	2.50	7.39	5.64
Diet fiber	(g)	21.23	10.02	30.38	23.54
Calcium	(mg)	1196.85	558.71	1869.91	885.01
Iron	(mg)	24.56	22.65	22.93	13.06
Magnesium	(mg)	323.08	146.94	472.33	271.93
Phosphorous	(mg)	1575.07	652.15	2330.14	1114.84
Caffeine	(mg)	65.00	91.77	64.14	105.36

Nutrient intake per day. All differences are significant *except iron and caffeine.*

Table 3. Odds Ratios for the Association of Various Behavioral or Nutritional Factors and Bone Fractures in Girls Under 17 Years of Age

Factor	Odds Ratio	95% CI	p Value
Total caloric intake			
<2000, ≥2000 per day	0.552	(0.215, 1.417)	0.216
Activity level			
High/low	0.216	(0.081, 0.573)	0.002
Smoke			
Yes/no	2.374	(0.684, 8.235)	0.173
Cola beverages			
>0.7 Serving/≤0.7 serving per day	3.193	(1.211, 8.421)	0.019
Controlling for activity and calories	3.592	(1.207, 10.750)	0.022
All carbonated beverages			
>1 Serving/≤1 serving per day	2.286	(0.878, 5.952)	0.090
Controlling for activity and calories	3.151	(1.027, 9.672)	0.045
Calcium intake per day			
<1200, ≥1200 mg	0.291	(0.108, 0.780)	0.014
Controlling for activity and calories	0.284	(0.087, 0.920)	0.036
Milk			
>1 Serving/≤1 serving per day	0.633	(0.244, 1.644)	0.348
CONTROLLING FOR ACTIVITY*			
High/low	0.742	(0.298, 1.849)	0.522
STRATIFYING BY ACTIVITY			
High	0.179	(0.042, 0.761)	0.020
Low	3.810	(0.744, 19.499)	0.108
CONTROLLING FOR ACTIVITY AND CALORIES	0.822	(0.304, 2.223)	0.669
CA/P RATIO			
≤0.75/>0.75)	0.365	(0.140, 0.951)	0.039
Controlling for activity and calories	0.386	(0.139, 1.068)	0.067

*p Value for heterogeneity of odds ratio = 0.005.

The proportion of girls who had attained menarche by time of reporting are as follows: age 8 years, (0/1); age 11 years, (2/4); age 12 years, (1/9); age 13 years, (6/9); age 14 years, (8/10), age 15 years, (13/15); and age 16 years, (28/28). By probit analysis, the mean age of menarche is 12.598 ± 1.566 ($\mu \pm \sigma$).

Table 3 presents the odds ratios for the association of nutritional and other behavioral factors with bone fractures *among girls*. Total caloric intake alone is not significantly related to bone fractures, though high intake is somewhat protective (*OR* is 0.552; 95% *CI* 0.215, 1.417); $p = 0.216$).

A higher activity level was inversely associated

with risk of fractures (*OR* is 0.216; 95% *CI* 0.081, 0.573; $p = 0.002$). (Using a three-point scale of physical activity, a dose–response inverse relationship between activity and fractures was observed. Percent of fractures by activity category were categories 1,2, or 3, 60%; category 4, 50%; and category 5—most active, 27%). The percentage of smokers in this sample is 16% (12/76), and in this sample the relation between smoking and bone fractures is not significant (*OR* is 2.374; 95% *CI* 0.684, 8.235; $p = 0.173$).

The consumption of cola beverages is associated with bone fractures (unadjusted *OR* is 3.19; 95% *CI* 1.21, 8.42; $p = 0.019$). The consumption of all carbonated beverages is marginally associated with bone fractures (*OR* is 2.29; 95% *CI* 0.89, 5.95; $p = 0.090$); the association is statistically significant when activity level and caloric intake are controlled for (Table 3).

High calcium intake is significantly protective (unadjusted *OR* = 0.291; 95% *CI* 0.108, 0.780; $p = 0.014$). Milk consumption is also protective, but an interaction between activity level and milk consumption is observed. The test for the homogeneity of the odds ratio is significant. For relatively inactive girls, there is no significant association between milk consumption and fractures; among active girls, milk is highly protective (*OR* is 0.179; 95% *CI* 0.042, 0.761; $p = 0.020$). When adjusted for caloric intake, however, the association between milk and bone fractures is not significant. The correlation between daily dietary calcium intake and the frequency of milk consumption is 0.830, $p = 0.0001$.

The calcium/phosphorus ratio (formulated from the computed calcium intake and the computed phosphorus intake, both based on all nutritional intake; the median of the distribution is 0.75 for girls, 0.8 for boys) is a significant risk factor for bone fractures; a higher calcium/phosphorus ratio is protective (unadjusted *OR* is 0.365; 95% *CI* 0.140, 0.951; $p = 0.039$). The effect of the Ca/P ratio is modified slightly by caloric intake and activity level; the *OR* is marginally significant (Table 2).

The observed associations between consumption of colas, all carbonated beverages, dietary calcium intake, and the calcium/phosphorus ratio and bone fractures persist when activity level and total caloric intake are adjusted for the Mantel–Haenszel method (Table 2), and by a multiple logistic regression model that also included age, weight, and height.

No association between non-cola drinks—Fresca®, diet 7-Up®, diet ginger ale, or ginger ale with sugar, or 7-Up® with sugar—and bone fractures was found, whether the data were adjusted for activity level, total caloric intake, smoking, consumption of cola drinks or not. The frequency of consumption of the various types of carbonated beverages, including the colas, are highly correlated. There is no difference in the type of fracture in the cola-consuming girls and non–cola-consuming girls. Results from analyses of caffeinated/non-caffeinated, sugar/no sugar did not show patterns differing from those based on all carbonated beverages and on the colas, but the odds ratios were lower and not statistically significant.

For boys, among the variables examined, total caloric intake is negatively associated with bone fractures. When caloric intake is taken into account, other intake such as calcium, milk, or carbonated beverages are not associated with the risk of fractures. The tables for boys are not shown.

Discussion

The results from this study of adolescent girls confirm our earlier findings of an association between bone fractures and carbonated beverage consumption in older women former college athletes (whose ages ranged from 21 to 80 years) (2). They also support our hypothesis that the association is due to the cola drinks, which contain phosphoric acid. High calcium intake from all sources is protective, but the association of milk consumption alone and bone fractures is not significant. Cola drinks, all carbonated beverages combined, and dietary calcium intake are significant risk factors for bone fractures after adjusting for age, weight, height, activity level and total caloric intake. A lower calcium/phosphorus ratio is marginally significant. The non-cola drinks, caffeine-free drinks, and low-calorie drinks showed no significant association with bone fractures. We also considered the relation between total caffeine intake and the risk of fractures. The results showed no significant association. Heaney et al. (6) have reported that among normal middle-aged women caffeine intake appears to contribute to a worsening of calcium balance. The levels of caffeine intake in our adolescents averaged about 65 mg/day, and are considerably less than the 0.35 gm/day for Heaney's subjects.

The great majority of the subjects in this study engaged in moderate-to-vigorous physical activity. The inverse relation between activity and fractures may be due to the fact that subjects reduced their physical activity following fractures. Many of the subjects were recruited from among patients' of

orthopedists. The proportion of fractures in subjects of orthopedists was somewhat but not significantly higher than in subjects who were not orthopedists' patients.

It is also possible, but unlikely, that subjects would be told to alter their diet after fractures. Subjects did not differ in their dietary intake by place of recruitment—swimming club or orthopedists' office. Menarcheal age did not differ by activity level or between girls according to whether they reported a fracture or not. The age of menarche, 12.6 ± 1.7 yr, by probit analysis is similar to that in the general U.S. population (7). Despite their possible limitations, dietary questionnaires can provide reasonable measurements of dietary intake (4); imprecise data on the exact amounts of nutrient intake are not likely to affect our findings.

The odds ratio for the cola drinks, adjusted for activity level and caloric intake, is 3.6, although the sample in this study is relatively small. In addition, the association between cola beverages and bone fractures was significant, controlling for whether subjects were orthopedists' patients or not. The protective effect of calcium is consistent and biologically plausible.

As noted, high dietary calcium intake (from all food sources) was significantly protective, even when caloric intake is taken into account. The observed interaction between activity level and milk consumption and the relation to bone fractures could be due to chance, or due to the fact that only 5% of the girls reported themselves as sedentary and 74% engaged in strenuous physical activity. Nevertheless, this interaction may be consistent with conclusions, based on laboratory studies, that retention of calcium is related to activity; viz, that an active person consuming 60 g of protein will retain more calcium than her sedentary counterpart consuming 100 g of protein (8).

For boys (mean age, 14 years), the only factor we found to be associated with bone fractures is total caloric intake; higher intake is associated with a lower risk of fractures. Controlling for total caloric intake, calcium and the calcium/phosphorus ratio were not associated with the risk of bone fractures. Calvo et al. (9,10), who studied parathyroid hormone level alterations in relation to calcium and phosphorus intake, also observed greater effects in young women than in young men.

Our results are consistent with our previous work (2), that the consumption of carbonated beverages increases the risk of bone fractures among more active women (former college athletes). That study suggested that the effect is due to the cola (phosphoric acid containing) drinks. A possible explanation for the effect on active young women is that highly trained athletes have lower levels of endogenous estrogen and less potent estrogens, associated with physical activity (11) and increased leanness (12). Consistent with this are the findings of a lower prevalence of breast cancer, cancers of the reproductive system, and benign tumors of the breast and reproductive system among former college athletes, when compared with non-athletes (13,14).

Peak bone mass is now recognized as a key determinant of osteoporosis in later life (1). It has been suggested that osteoporotic fractures may be delayed by modifications of diet and activity among young women (15); and that adolescence could be a critical period for bone mass formation (16,17). Matkovic et al. report that by age 16 yr, daughters had accumulated 90%–97% of the bone mass of their pre-menopausal mothers (18). The adverse effect of carbonated beverage consumption (especially colas) on the risk of bone fractures and the protective effect of calcium has been shown in active girls under 17 years. These findings are of considerable public health significance, particularly because of (a) the high consumption of carbonated beverages (estimated as more than 40 gallons per person per year), and the declining consumption of milk (19–23); and (b) the proneness of women to osteoporosis in the peri- and post-menopausal years.

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