

[Primary Care]

A Systematic Review of Bone Health in Cyclists

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Context: Low bone mineral density (BMD) is a serious public health problem. Osteoporotic fractures are associated with low bone mass, occurring frequently in the hip and spine. Previous studies have demonstrated a positive relationship between BMD and weightbearing exercise but not a similar positive relationship with nonweightbearing exercise. There is concern that cycling, a weight-supported sport, does not benefit bone health.

Objective: To systematically review the evidence suggesting that cyclists have impaired bone health at the femoral neck and lumbar spine.

Data Sources: Articles in PubMed, Cochrane Library, and CINAHL were identified in December 2009 based on the following terms and combinations: *bicycling, bone density, cyclist*.

Study Selection: Thirteen studies satisfied inclusion criteria: 2 prospective studies (level of evidence 2b) and 11 cross-sectional studies (level of evidence 2c).

Data Extraction: Data included sample size, demographics, description of cycling and control criteria, and BMD (g/cm²) at the lumbar spine, femoral neck, and hip.

Results: Two prospective studies showed a decrease in femoral neck, total hip, or lumbar spine BMD in cyclists over the study period. Four cross-sectional studies compared cyclists with sedentary controls, and 3 found cyclists' lumbar spine and femoral neck BMD similar to that of controls, whereas 1 found cyclists' BMD to be lower than that of controls. Seven cross-sectional studies compared cyclists with active controls: 2 found no differences in femoral neck and lumbar spine BMD between cyclists and controls; 4 found that cyclists had lower lumbar spine BMD than did active controls, including runners; and 1 reported a trend toward lower lumbar spine BMD in cyclists versus controls.

Conclusions: There is concerning but inconsistent, limited-quality disease-oriented evidence—primarily from cross-sectional data—indicating that cyclists may be at risk for low bone mass, particularly at the lumbar spine. Additional longitudinal controlled intervention trials are needed.

Keywords: bicycling; bone health; bone mineral density; cyclists; dual-energy x-ray absorptiometry

Low bone mineral density (BMD), or osteoporosis, is a serious public health problem in the United States and internationally.¹⁶ Osteoporotic fractures are associated with low bone mass, occurring frequently in the hip and spine. Identifying risk factors, such as inactivity or specific types of activity, may be important for developing strategies to reduce or prevent osteoporotic fracture at the femoral neck or lumbar spine. Previous studies have demonstrated a positive relationship between weightbearing exercise and BMD.^{1,3,32} Studies of nonweightbearing exercise have not demonstrated a similar positive relationship with BMD.³⁶ In general, exercise involving gravitational loading or impact activity appears to

provide bone with an effective osteogenic stimulus. Cross-sectional studies of athletes have shown that those who participate in weightbearing activities such as running have a higher bone mass at the lumbar spine and hip than do nonathlete controls.^{2,36,37}

There is concern that nonweightbearing sports such as cycling and swimming do not benefit bone health. It is not known whether muscle strength and shear loading (muscle forces) of the bone from muscle contraction can effectively promote bone formation.^{16,32} The biomechanics of cycling (body weight mostly supported by the bike, repetitive lower intensity motion, and the prone position) may not adequately stimulate bone

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formation, especially at the spine and hip. Numerous studies have evaluated the relationship between the weight-supported sport of cycling and bone health. Our objective was to review these studies and assess the evidence that cyclists may have impaired bone health, specifically at the femoral neck and lumbar spine.

METHODS

Study Identification

PubMed MEDLINE database was searched in December 2009 on the basis of the following terms and Boolean operators: (*"bicycling"*[MeSH Terms] OR *"bicycling"*[All Fields]) AND (*"bone density"*[MeSH Terms] OR (*"bone"*[All Fields] AND *"density"*[All Fields]) OR *"bone density"*[All Fields]); *cyclist*[All Fields] AND (*"bone density"*[MeSH Terms] OR (*"bone"*[All Fields] AND *"density"*[All Fields]) OR *"bone density"*[All Fields]); *cyclists*[All Fields] AND (*"bone density"*[MeSH Terms] OR (*"bone"*[All Fields] AND *"density"*[All Fields]) OR *"bone density"*[All Fields]). Additional articles were identified using the Related Articles search feature on PubMed. In December 2009, the Cochrane Library was searched, including the Cochrane Central Register of Controlled Trials and the Cochrane Database of Systematic Reviews, for clinical trials and systematic reviews by searching for (*bicycling AND bone density*, *cyclist AND bone density*, *cyclists AND bone density*). CINAHL Plus was searched for articles from 1980 to the present using (*bicycling AND bone density*, *cyclist AND bone density*, *cyclists AND bone density*).

Full text was obtained for the articles meriting further review based on title and abstract. The bibliographies of these articles were screened for additional studies to evaluate. The search did not limit study inclusion by the year of publication and did not include articles written in languages other than English. Abstracts of annual meetings or unpublished studies were not searched.

Eligibility Criteria

Articles were identified that met the following eligibility criteria: (1) a target population of males and females of any age who cycled exclusively or extensively (at least 6 hours per week) for exercise but not necessarily at a competitive or an elite level; (2) measured BMD of lumbar spine, femoral neck, or hip with dual-energy x-ray absorptiometry (DXA); (3) and clearly stated inclusion and exclusion criteria and physical activity of cyclists and controls.⁹

Assessment of Study Quality and Data Extraction

Both authors (K.B.N. and M.A.B.) assessed the full text of potentially eligible studies for eligibility criteria, type of study, level of evidence (according to Oxford Centre for Evidence-Based Medicine), demographic information, methodology, and reported outcomes. Disagreements were resolved with discussion and additional review. No attempts were made to contact any of the authors to request additional data. The data

extracted included sample size, demographics, description of cycling and control criteria, and BMD (g/cm²) at the lumbar spine (at least 3 vertebral levels: L1-L4 or L2-L4), femoral neck, and hip. Articles were assessed for quality but not excluded if (1) study participants were not excluded for conditions or medications affecting bone health (eg, thyroid disease, smoking), (2) there were less than 10 cycling participants, and (3) the study controlled for past lifetime physical activity, vitamin D and calcium intake, menstrual status, and body mass. Eligible studies were placed into groups based on study type, active versus sedentary controls, female sex, and professional level.

RESULTS

The search strategy identified 25 studies, 12 of which were excluded. Maimoun et al, and McClanahan et al studied triathletes but not cyclists.^{19,21} Rico et al,³¹ Wilks et al,³⁹ Morel et al,²⁵ Medelli et al,²³ and Duncan et al⁷ did not measure and report BMD for cyclists and control groups at the lumbar spine, femoral neck, or hip. Torstveit and Sundgot-Borgen³⁷ included only 4 cyclists and presented the data in aggregate form with other low-impact sports. Nevill et al,²⁶ Stewart and Hannan,³⁵ Fiore et al,⁸ and Rico et al³¹ did not provide adequate descriptions of the cycling and/or control groups. Thirteen studies satisfied the inclusion and exclusion criteria. Of these eligible studies, 2 were prospective studies (level of evidence 2b). The remaining 11 were cross-sectional studies comparing cyclists with active or sedentary control groups (level of evidence 2c).

Prospective Studies

Two prospective studies showed a decrease in bone mass in cyclists over the study period (Table 1). Barry and Kohrt³ followed 14 amateur competitive male cyclists over 1 year, with measurements of BMD at 4 time points (preseason, midseason, postseason, and off-season).³ The cyclists were randomized to receive high- or low-dose oral supplementation with calcium. Femoral neck BMD decreased significantly over the season ($-0.7\% \pm 2.1\%$), and there was a trend toward decreasing lumbar spine BMD ($-1.0\% \pm 1.2\%$). At the hip, 12-month BMD remained significantly lower ($-1.5\% \pm 2.1\%$) than baseline ($P < 0.01$). There was no difference in BMD at either site between high and low calcium supplementation groups, nor was there a noncycling control group. Beshgetoor et al⁴ measured BMD in 3 groups of middle-aged women (runners, cyclists, sedentary controls) at baseline and 18 months.⁴ There was no group difference in baseline BMD at either site. Femoral neck BMD was maintained in cyclists and runners but decreased in controls over the study period. Lumbar spine BMD decreased in both cyclists and controls but was maintained in runners.

Cross-Sectional Studies With Sedentary Control Groups

Four studies compared femoral neck and lumbar spine BMD in cyclists to a sedentary or inactive control group, defined as individuals averaging less than 2 hours of exercise per week

Table 1. Prospective cohort studies assessing femoral neck and lumbar spine bone mineral density (BMD) in cyclists.^a

Group	Physical Activity	BMD, g/cm ²				P for Time	
		0 mo	4.5 mo	9 mo	12 mo		
Barry and Kohrt, ³ N = 14 men ^b							
High calcium, 1500 mg orally once per day, n = 7, 33.9 ± 3.7 y	Amateur cyclists competing at state and regional levels; mean 460 h/y cycling with 20 h/y weight lifting and 36 h/y running	FN	0.905 ± 0.021	0.908 ± 0.025	0.893 ± 0.025	0.896 ± 0.027	0.036 ^d
		TH	1.063 ± 0.024	1.061 ± 0.029	1.040 ± 0.029	1.048 ± 0.029	0.001 ^{d,e}
		LS	1.082 ± 0.037	1.080 ± 0.041	1.065 ± 0.045	1.066 ± 0.041	0.079
Low calcium, 250 mg once a day, n = 7, 35.1 ± 5.4 y	Amateur cyclists competing at state and regional levels; mean 502 h/y cycling with 45 h/y weight lifting and 15 h/y running	FN	0.873 ± 0.027	0.881 ± 0.027	0.867 ± 0.029	0.871 ± 0.029	0.036 ^d
		TH	1.014 ± 0.038	1.013 ± 0.037	0.999 ± 0.037	0.999 ± 0.039	0.001 ^{d,e}
		LS	1.076 ± 0.043	1.077 ± 0.043	1.080 ± 0.044	1.071 ± 0.043	0.079
Beshgebor et al, ⁴ n = 30 women ^e		Baseline	18 mo			P	
Cyclists, n = 12, 48.2 ± 8.4 y	Year-round training in sport (5 d/wk), competitive in sport for 1 y prior; 9.4 ± 2.2 h/wk	LS	0.993 ± 0.150	0.970 ± 0.155			< 0.007
		FN	0.778 ± 0.122	0.776 ± 0.138			NS
Runners, n = 9, 50.9 ± 7.5 y	7.7 ± 4.5 h/wk	LS ^f	0.974 ± 0.142	0.966 ± 0.138			NS
		FN ^f	0.742 ± 0.076	0.743 ± 0.090			NS
Controls, n = 9, 50.1 ± 8.5 y	1.6 ± 1.1 h/wk	LS ^f	0.993 ± 0.148	0.969 ± 0.153			< 0.03
		FN ^f	0.738 ± 0.154	0.710 ± 0.149			< 0.05

^aFN, femoral neck; TH, total hip; LS, lumbar spine. Values are mean ± sd.^bStudy duration: 1 year, measured at pre-season, mid-season, post-season, and off-season points. Adjusted for changes in lean or fat mass. Summary: FN and TH decreased over the course of cycling season with incomplete recovery during off-season. No significant differences in FN or LS by high- or low-calcium group.^cNine months significantly different from 4.5 months.^dNine months and 12 months significantly different from 0 months.^eStudy duration: 18 months, measured at 0 and 18 months. NS, not statistically significant at P > 0.05. Summary: BMD at femoral neck maintained in runners and cyclists but decreased in controls. BMD of lumbar spine decreased in cyclists and controls but maintained in runners.^fSignificant main effect for time (P < 0.05).^gSignificant group × time interaction (P = 0.04).

Table 2. Cross-sectional studies comparing cyclists with sedentary control groups.^a

Study: Group	Physical Activity	Site	Results
Duncan et al, ⁶ N = 75 females ^b			Adjusted BMD, g/cm ² (95% CI)
Runners, n = 15, 17.6 ± 1.4 y	8.4 ± 1.2 h/wk	LS FN	1.27 (1.2-1.3) 1.20 (1.1-1.3)
Triathletes, n = 15, 17.7 ± 1.1 y	16.2 ± 4.7 h/wk	LS FN	1.15 (1.1-1.2) 1.11 (1.0-1.1)
Cyclists, n = 15, 16.5 ± 1.4 y	15 ± 4.9 h/wk	LS FN	1.20 (1.1-1.3) 1.07 (1.0-1.1)
Swimmers, n = 15, 16.7 ± 1.3 y	15 ± 4.8 h/wk	LS FN	1.18 (1.1-1.3) 0.99 (0.9-1.1)
Controls, n = 15, 16.9 ± 0.9 y	< 2 h/wk and no previous elite competitive sport	LS FN	1.21 (1.1-1.3) 1.05 (0.9-1.1)
Maimoun et al, ²⁰ N = 38 males ^c			BMD, g/cm ² (SD)
Cyclists, n = 11, 27.4 ± 5.8 y	10.6 ± 3.9 h/wk	FN TH LS	0.934 (0.026) 1.073 (0.023) 1.083 (0.027)
Swimmers, n = 13, 25.4 ± 6.5 y	10.7 ± 3.2 h/wk	FN TH LS	0.959 (0.024) 1.045 (0.022) 1.038 (0.026)
Triathletes, n = 14, 25.7 ± 6.6 y	15.2 ± 4.3 h/wk	FN TH LS	0.987 (0.024) 1.103 (0.021) 1.072 (0.026)
Controls, n = 10, 27.5 ± 4.3 y	< 2 h/wk for past 2 y	FN TH LS	0.987 (0.024) 1.032 (0.026) 1.072 (0.026)
Medelli et al, ²⁴ N = 103 males ^d			BMD, g/cm ² (SD)
Professional and elite amateur cyclists, n = 73, divided into 3 groups based on calcium intake, 25.8 ± 4.3 y	Two y racing at respective level: 22,000 km/y for elite, 32,000 km/y for pro. Pro, 22-25 h/wk × 45 wk; all cyclists mainly, if not exclusively, riding bikes; strength training/weight lifting rarely performed.	FN LS L1-L4	0.986 (0.132) 1.104 (0.125)
Controls (n = 30), 28.3 ± 4.5 y	No regular physical activity, excluded if > 1 h/wk cycling and/or > 1 h/wk weightbearing exercise for prior 3 y	FN LS L1-L4	1.09 (0.141) 1.228 (0.151)
Warner et al, ³⁸ N = 45 males ^e			BMD, g/cm ² /kg (SD)
Mountain cyclists, n = 16, 26.2 ± 5.0 y	For at least 3 y previous for ≥ 10 h/wk and for ≥ 10 mo/y and no cross-training or weightbearing/resistance training; expert, elite, pro level	LS FN	0.0183 (0.0019) 0.0161 (0.0021)

(continued)

Table 2. (continued)

Study: Group	Physical Activity	Site	Results
Road cyclists, n = 14, 31.4 ± 5.5 y	For at least 3 y previous for ≥ 10 h/wk and for ≥ 10 mo/y and no cross-training or weightbearing/resistance training. Category 1, 2 and 3	LS FN	0.0160 (0.0016) 0.0134 (0.0016)
Controls, n = 15, 30.4 ± 5.8 y	No regular physical activity schedule; < 2 h/wk cycling, < 1 h/wk weightbearing/resistance training for the 3 y prior	LS FN	0.0154 (0.0019) 0.0135 (0.0019)

^aAverage less than 2 h exercise per week. BMD, bone mineral density; LS, lumbar spine; FN, femoral neck; TH, total hip; CI, confidence interval. Values are mean ± sd unless otherwise noted.

^bAt least 8 h/wk plus competition at state/national level. Adjusted for lean tissue mass, years since menarche, years prior sport-specific training. Summary: Runners LS greater than triathletes ($P < 0.05$). Runners FN greater than controls, swimmers, cyclists, triathletes ($P < 0.05$). No difference at LS or FN between cyclists and controls.

^cAdjusted for age, body mass, fat-free soft tissue. Summary: No difference between cyclists and controls. No significant differences between groups for LS BMD. Triathletes had higher femoral neck and total hip BMD compared with controls ($P < 0.05$). Swimmers had lower total hip BMD than triathletes ($P < 0.05$).

^dCyclists had lower BMD than controls at both sites (LS, $P < 0.0001$; FN, $P = 0.0005$). Cyclists had higher calcium intake than controls ($P = 0.008$).

^eAdjusted for body mass, age. Summary: Unadjusted BMD at all sites similar for all 3 groups. When adjusted for body weight and age, no significant difference between road cyclists and controls. Mountain cyclists had higher FN and LS than road cyclists and controls ($P < 0.05$).

(Table 2). Three studies found that lumbar spine and femoral neck BMD in cyclists was similar to sedentary controls.^{6,20,38} One study found cyclists had lower BMD at the spine and femoral neck than sedentary controls.²⁴

In a study of adolescent females, similar femoral neck and lumbar spine BMD was found in cyclists and sedentary controls; runners had higher femoral neck BMD than that of cyclists.⁶ Maimoun et al²⁰ also found that cyclists had femoral neck and lumbar spine BMD similar to that of sedentary controls. In contrast, triathletes had higher femoral neck and hip BMD than did controls but no difference in lumbar spine BMD. BMD unadjusted for body mass (in kilograms) was similar at femoral neck and lumbar spine for studied mountain bikers, road cyclists, and sedentary controls.³⁸ Adjusted BMD ($\text{g}/\text{cm}^2/\text{kg}$) at both sites was higher in mountain bikers but not different between road cyclists and controls. Seventy-three professional cyclists had significantly lower BMD at the lumbar spine and femoral neck than did 30 sedentary controls.²⁴ Differences in BMD in this study were not controlled for age, body mass index, lean body mass, or body weight, despite significant differences.

Cross-Sectional Studies With Active Control Groups

Seven studies compared cyclists to active control groups (≥ 2 hours of moderate activity per week) and/or athletes in moderate to high levels of sports (Table 3). Two studies found no difference in femoral neck and lumbar spine BMD in cyclists compared with active controls.^{10,28} Two studies found that cyclists had lower lumbar spine BMD than did active controls.^{27,34} Two studies comparing cyclists to runners found that cyclists had a significantly lower lumbar spine BMD.^{29,30} One study with a small cyclist sample size showed a trend toward lower spine BMD in cyclists compared with controls.³⁵

Heinonen et al¹⁰ found no significant difference in weight-adjusted BMD at the femoral neck and lumbar spine in cyclists compared with active controls. Weight lifters had a significantly higher lumbar spine BMD than did active controls. Cyclists were not directly compared with weight lifters or other athletes. Female athletes in 11 sports showed no difference in femoral neck BMD between cyclists and the active nonathlete control group.²⁸ Athletes had significantly higher femoral neck BMD than did the control group (adjusted for age, body weight, and height), except for swimmers and cyclists. All loading types (high impact, odd impact, repetitive low impact) except swimming and cycling (repetitive nonimpact) had significant associations with BMD.

In a study comparing male cyclists aged 40 to 60 years, 25 to 35 years, and an active control group, older masters cyclists had significantly lower BMD at the lumbar spine and total hip (but not femoral neck) compared with younger cyclists and controls.²⁷ Although the controls and masters cyclists were matched for age and weight, their BMD was not adjusted for lean body mass, which was significantly different between the 2 groups. Smathers et al³⁴ did adjust for lean body mass, demonstrating significantly lower lumbar spine BMD (-7.1% difference) in cyclists compared with controls. No significant BMD differences were found at hip sites between cyclists and controls.

Runners had significantly higher lumbar spine BMD than cyclists, controlling for age, body weight, and cumulative lifetime bone loading exposure.²⁹ Compared with cyclists, resistance trainers had significantly higher unadjusted lumbar spine, hip, and femoral neck BMD and, compared with runners, higher femoral neck and total hip BMD.³⁰ When adjusted for lean body mass, lumbar spine BMD was significantly greater for runners than cyclists, but resistance

(text continues on p. 242)

Table 3. Cross-sectional studies comparing cyclists to active control groups.^a

Groups	Physical Activity	Site	Results
Heinonen et al, ¹⁰ N = 105, women ^b			Absolute BMD, g/cm ²
Orienteers, n = 30, 23.3 ± 3.1 y	446 ± 70 h/y	LS FN	1.068 ± 0.096 1.000 ± 0.106
Cyclists, n = 29, 24.0 ± 5.7 y	556 ± 338 h/y	LS FN	1.067 ± 0.117 0.963 ± 0.105
Weight lifters, n = 18, 24.6 ± 4.6 y	429 ± 129 h/y	LS FN	1.230 ± 0.132 1.082 ± 0.156
Cross-country skiers, n = 28, 21.3 ± 3.2 y	574 ± 60 h/y	LS FN	1.072 ± 0.098 1.035 ± 0.117
Controls, n = 25, 22.6 ± 2.8 y	202 ± 135 h/y	LS FN	1.071 ± 0.103 0.983 ± 0.114
Nichols et al, ²⁷ N = 67, men ^c			BMD, g/cm ²
Older cyclists, aged 40-60 y, n = 27, 51.82 ± 5.1 y	Year-round training; 150 miles/wk and minimum of 10 h/wk; compete in United States Cycling Federation races for 10+y, little to no weightbearing activity; 4.7 ± 1.3 d/wk and 12.1 ± 3.9 h/wk	LS TH FN	1.07 ± 0.15 0.93 ± 0.11 0.91 ± 0.18
Young adult cyclists, aged 25-35 y, n = 16, 31.7 ± 3.5 y	Training and racing profiles similar to older group but with a minimum of 5 y in competition. 5.5 ± 0.8 d/wk and 15.8 ± 3.8 h/wk	LS TH FN	1.20 ± 0.13 1.10 ± 0.16 1.05 ± 0.18
Nonathletes, n = 24, 51.6 ± 4.7 y	< 2 d/wk weight training and/or in competition in any sport; recreational exercise alright. 4.5 ± 1.4 d/wk and 4.5 ± 2.6 h/wk. Running/jogging, hiking, cycling, swimming, tennis	LS TH FN	1.19 ± 0.19 1.05 ± 0.18 0.99 ± 0.16
Nikander et al, ²⁸ N = 285, women ^d			BMD, g/cm ²
Volleyball, n = 21, 21.2 ± 3.0 y	9.9 ± 2.5 h/wk	FN	1.177 ± 0.114
Hurdling, n = 24, 20.2 ± 2.1	9.1 ± 2.4 h/wk	FN	1.092 ± 0.094
Squash, n = 20, 24.8 ± 3.9	6.0 ± 3.1 h/wk	FN	1.156 ± 0.112
Soccer, n = 19, 21.4 ± 3.0	8.6 ± 5.5 h/wk	FN	1.090 ± 0.113
Speed skating, n = 15, 21.9 ± 8.1	6.4 ± 3.6 h/wk	FN	1.031 ± 0.107
Step-aerobic instructors, n = 27, 28.3 ± 3.7	6.6 ± 3.7 h/wk	FN	1.041 ± 0.107
Weight lifting, n = 19, 23.8 ± 5.0	8.3 ± 2.6 h/wk	FN	1.070 ± 0.163
Orienteering, n = 29, 23.5 ± 3.1	8.6 ± 1.4 h/wk	FN	1.006 ± 0.107
Cross-country skiing, n = 25, 21.2 ± 3.1	10.9 ± 1.2 h/wk	FN	1.024 ± 0.118
Cycling, n = 29, 24.1 ± 5.4	10.2 ± 6.8 h/wk	FN	0.966 ± 0.104
Swimming, n = 27, 20.6 ± 2.8	13.5 ± 4.5 h/wk	FN	0.897 ± 0.112
Nonathletic referents, n = 30, 24.3 ± 3.1	2.9 ± 2.0 h/wk	FN	0.891 ± 0.102
Rector et al, ²⁹ N = 43, men ^e			Absolute BMD, g/cm ² (SEM)
Cyclists, n = 27, 38.1 ± 2.5 y	13.0 ± 1.2 h/wk	LS TH FN	0.99 (0.02) 1.01 (0.02) 0.87 (0.02)

(continued)

Table 3. (continued)

Groups	Physical Activity	Site	Results
Runners, n = 16, 39.8 ± 2.4 y	11.4 ± 1.5 h/wk	LS TH FN	1.10 (0.04) 1.07 (0.03) 0.90 (0.03)
Rector et al, ³⁰ N = 42, men ^f			BMD, g/cm ² (SEM)
Cyclists, n = 19, 30.4 ± 1.6 y		LS TH FN	1.05 (0.02) 1.06 (0.03) 0.94 (0.03)
Runners, n = 10, 35.8 ± 2.1 y		LS TH FN	1.18 (0.03) 1.13 (0.04) 0.99 (0.04)
Resistance trainers, n = 13, 26.4 ± 1.9 y		LS TH FN	1.11 (0.03) 1.16 (0.04) 1.01 (0.04)
Sabo et al, ³³ N = 61, men ^g			BMD, g/cm ² , difference from controls
Weight lifters, n = 28, 22.3 ± 3.9 y		AP LS Lat LS	0.252 0.200
Boxers, n = 6, 21.5 ± 2.4 y		AP LS Lat LS	0.174 0.174
Cyclists, n = 6, 26 ± 2.2 y	Professional Tour de France participants in full specific competition training	AP LS Lat LS	-0.105 -0.067
Controls, n = 21, 24 ± 1.8 y	Mixed discipline sport activity, 2.4 h/wk	AP/lat LS	Referent
Smathers et al, ⁴¹ N = 62, men ^h			BMD, g/cm ² (SE)
Cyclists, n = 32, 31.9 ± 1.2 y	Competitive club to professional cyclists at least 1 y continuously, 9.4 ± 1.1 y racing, 7-22 h/wk training (13.0 ± 0.7 h/wk)	AP LS L1-L4 Left TH Left FN	1.133 (0.022) 1.066 (0.025) 1.028 (0.023)
Controls, n = 30, 30.2 ± 1.0 y	Moderately active, 3 d/wk exercise, nonsedentary	AP LS L1-L4 Left TH Left FN	1.220 (0.028) 1.106 (0.026) 1.080 (0.026)

^aBMD, bone mineral density; LS, lumbar spine; FN, femoral neck; TH, total hip; AP, anterior-posterior; Lat, lateral. Values are mean ± sd unless otherwise noted.

^bAdjusted for body weight. Summary: Cyclists not significantly different from controls at any site. Weight lifters had higher adjusted LS than controls ($P < 0.001$). No other intergroup comparisons. Each group only compared to reference group.

^cMasters and controls age and weight matched. Summary: Older cyclists' LS and TH lower than young cyclists and nonathletes ($P < 0.033$). Older cyclists' FN lower than young cyclists ($P < 0.033$).

^dCompetitive athletes. Adjusted for age, body weight, and height. Summary: Cyclists did not differ significantly from controls, whereas all other sports except swimming had significantly higher FN than controls ($P < 0.05$).

^eMinimum 6 h/wk of sport-specific exercise over at least the past 2 y. Adjusted for age, body weight, lifetime bone loading exposure. Summary: Runners with greater LS than cyclists ($P < 0.05$).

^fParticipants in all groups had to perform a minimum of 6 h/wk of their respective category for at least the past 2 y. Adjusted for lean body mass. Summary: Resistance trainers with greater unadjusted FN, TH, and LS than cyclists and greater FN and TH than runners ($P < 0.05$). Lean body mass adjusted: Runners had greater LS than the cycling group ($P < 0.05$). Resistance trainers' LS not significantly different from cyclists or runners. No significant difference in FN or TH between groups.

^gSummary: Weight lifters and boxers had higher AP and lat LS than controls ($P < 0.05$). Cyclists had lower AP (10%) and lat LS (8%) than controls, but this difference was not statistically significant ($P > 0.05$).

^hGroups matched for age and body mass. Adjusted for percentage body fat, bone-free lean body mass, fat mass. Summary: Cyclists' AP LS lower than controls.

* $P < 0.05$.

trainers' spine BMD was no longer significantly different from that of cyclists. There were also no significant differences in adjusted femoral neck and hip BMD between groups. Runners had significantly higher cumulative bone load exposure than did cyclists, and group differences in BMD were unchanged after adjusting for load exposure (data not shown). Six Tour de France cyclists had anteroposterior and lateral spine BMD that was lower than that of active controls, 10% and 8% respectively, but this difference was not statistically significant.³³

Studies With Female Cyclists

One cross-sectional study found lumbar spine and femoral neck BMD similar between female cyclists and sedentary controls.⁶ Two cross-sectional studies found no significant differences in BMD between female cyclists and active controls.^{10,28} A prospective cohort study found lumbar spine BMD decreased in cyclists and sedentary controls but femoral neck BMD maintained in cyclists and decreased in controls.⁴

DISCUSSION

Overall, the included studies provide concerning but inconsistent, limited-quality disease-oriented evidence, primarily from cross-sectional data, suggesting that cyclists may be at risk for low bone mass, particularly at the lumbar spine. Two prospective studies did show a decrease in femoral neck, hip, or lumbar spine BMD in cyclists over the study period. In all the studies using sedentary controls, the lumbar spine, hip, and femoral neck BMD of cyclists was either lower or not significantly different from that of inactive, sedentary controls. In a number of studies using active or athlete controls, the lumbar spine BMD of cyclists was significantly lower than that of controls who engaged in weightbearing activity such as running.

All the cycling participants included in this review were amateurs or professionals who were cycling exclusively or extensively (> 6 hours per week), and 2 studies reported that cyclists had significantly lower lifetime history of bone loading physical activity compared with that of weightbearing exercise controls. Although we cannot conclude from this cross-sectional data that there is an inverse dose-response relationship between volume of cycling (number of years or hours per week) and bone health, it is plausible that a higher cumulative volume of nonweightbearing activity such as cycling does not have a positive effect on bone health. Two studies that investigated professional cyclists potentially support this relationship. Seventy-three professional and elite cyclists who were training and racing an average of 22 000 to 32 000 km per year (22-25 hours a week for 45 weeks a year) had significantly lower unadjusted lumbar spine and femoral neck BMD compared to sedentary controls.²⁴

Muscle Force Versus Gravity

Considerable debate exists in the literature whether muscular forces and/or ground reaction forces are the primary osteogenic

stimuli.^{13,15,32} Studies of triathletes suggest that the weightbearing forces of running may be protective and might offset the potential negative bone health effects of swimming and cycling.^{6,19,21} In cycling, a weight-supported sport, neither lumbar spine nor femoral neck is exposed to gravitational load from ground impact. No biomechanical data were provided in any of the studies; therefore, we cannot conclude whether bone health at the lumbar spine may be worse than that at the femoral neck in cyclists because of differences in muscular contraction forces.

Longitudinal Data

In this search, no long-term prospective studies followed cyclists for longer than 2 years. Barry and Kohrt³ found that femoral neck and hip BMD decreased over 1 competitive season and did not completely recover during the off-season, suggesting that subsequent competitive seasons could result in continued and cumulative declines in BMD. Over 18 months, Beshgetoor et al⁴ found that cyclists did not maintain lumbar spine BMD but that runners did. Baseline body mass index, height, and weight were not significantly different between these groups. These groups were active in their respective pursuits for at least 1 year before the study.

Junior Cyclists

Up to 60% of peak bone mass is acquired during the peripubertal years, and peak bone mass is a significant predictor of postmenopausal osteoporosis.^{14,17,18} There is obvious concern for optimal bone health in junior athletes who participate partly or exclusively in nonweightbearing sports. Adolescent female cyclists have had lumbar spine and femoral neck BMD similar to that of their inactive sedentary peers, although their running peers had higher femoral neck BMD.⁶ There are potential long-term consequences if adolescents achieve lower peak BMD. Numerous studies in children and adolescents have demonstrated that simple short-duration jumping activities positively affect bone health.^{11,22} There are no long-term longitudinal studies evaluating BMD in elite young athletes who begin cycling exclusively at a preadolescent or adolescent age.

Use of *T* Scores and Classification of Osteoporosis

Three studies reported *T* scores to classify osteopenia (low bone mass) or osteoporosis in cyclists.^{24,27,29,34} The 2007 official position of the International Society for Clinical Densitometry states that for BMD reporting in males younger than age 50 years, *Z* scores, not *T* scores, are preferred and that the World Health Organization densitometric classification is not applicable.⁵ Because Rector et al.²⁹ and Medelli et al.²⁴ used *T* scores for males under age 50 years, their classification of osteopenia may not be valid. Nichols et al.²⁷ reported *T* scores in master male cyclists (mean age, 51.8 years) and age-matched controls. A significantly greater percentage of master cyclists were classified as having low bone mass or osteoporosis at both the lumbar spine and the total hip when compared with nonathlete controls. These results appear to be valid and alarming.

Quality of Included Studies

All studies except 2 screened and excluded volunteers for diseases and medications adversely affecting bone health. Only 5 of the 13 studies used smoking as an exclusion criteria. Although physical activity during the adolescent and young adult years accounts for the majority of adult peak bone mass, only 3 studies assessed lifetime physical activity.^{27,29,30} It is well understood that body weight and lean body mass affect BMD and that higher body mass is associated with higher BMD.¹² Lean body mass has accounted for a large proportion of the variance in regional and total body BMD.³⁰ Unfortunately, 2 studies did not adjust BMD for body weight or lean body mass, despite significant group differences.^{24,27} It is challenging to conclude whether the BMD differences between groups are attributable to the type of activity (eg, cycling) or to anthropometric measures.

Limitations

A meta-analysis was not attempted owing to wide variability in the cyclist and control populations and to concerns about comparing data from different DXA scanners. BMD determined by DXA is a 2-dimensional measure and may not provide the best assessment of bone geometry, architecture, and strength. Several studies were excluded because they used imaging modalities other than DXA to evaluate bone health. The majority of studies have been done in male cyclists, with only 4 of 25 studies investigating females. All but 2 studies were cross-sectional, thus limiting the ability to draw conclusions about cycling as the cause of poor bone health.

In summary, cycling may not be as beneficial to bone health as running and other weightbearing activities. Cycling does not appear to be more detrimental to bone health than a sedentary lifestyle, and it is beneficial for cardiovascular health. It is unclear whether an inverse dose response relationship exists between optimal bone health and volume of cycling.

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