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Bone mineral density, muscle strength and physical activity

A population-based study of 332 subjects aged 15–42 years

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The aim of this population-based study was to find out whether differences in levels of physical activity have an influence on bone mass quantity and whether quadriceps muscle strength is a reliable determinant of bone mass. Included were 175 men and 157 women, aged 15–42 years. Bone mineral density (BMD) was measured at various sites by dual X-ray absorptiometry (DXA) and single photon absorptiometry (SPA). Muscle strength was assessed using an isokinetic muscle force meter. A questionnaire was used to estimate the level of physical activity. We found a positive correlation between physical activity and BMD for boys at the distal forearm and for girls at the trochanter (age group 15–16 years). Active men (age group 21–42 years) had up to 9% higher BMD levels at the hip than those who were less active. Quadriceps muscle torque was not an independent predictor of BMD.

Our data suggest that a higher level of physical activity—within the limits of a "normal life style"—may have a positive effect on BMD in the proximal femur of young adults, which in turn may lessen the subsequent risk of fracture.

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Peak bone mass is believed to be one of the major determinants of bone quantity later in life, since a high peak bone mass seems to reduce the risk of subsequent fracture (Smith et al. 1973, Wasnich 1987, Hui et al. 1989, Cummings et al. 1990). The development of bone mass towards its peak is governed mainly by hereditary factors, as demonstrated by twin and parent-offspring studies (Pocock et al. 1987, Gärdsell et al. 1989, Seeman et al. 1989). Nutritional factors, especially calcium intake, may have an influence (Sandler et al. 1985, Halioua and Anderson 1989, Matkovik et al. 1990), as well as some life-style factors, such as smoking and excessive alcohol intake.

A number of studies of bone mineral density (BMD) show that physical activity is an important factor in the development and maintenance of bone mass (Grimby et al. 1971, Nilsson and Westlin 1971, Huddlestone et al. 1980, Slemenda et al. 1991, Heinonen et al. 1993). Moreover, studies of the effect of exercise programs to increase BMD have shown beneficial (Margulies et al. 1986, Colletti et al. 1989, Karlsson et al. 1993) as well as negative effects (Rockwell et al. 1990). However, most studies in this field have focused on the effect of exercise programs or various athletic activities on BMD, and not as in the present study, on various degrees of physical activity in a "normal" population, in adolescence and early adulthood. This is of interest since recent studies show that a reduction of habitual physical activity is an important risk factor for osteoporotic fractures (Law et al. 1991, Johnell et al. 1992, Kanis 1993).

Several studies have indicated that higher BMD may be a function of greater muscle strength (Pocock et al. 1989, Snow-Harter et al. 1990, Snow-Harter et al. 1992, Hyakutake et al. 1994), but conflicting results have also been presented (Sinaki et al. 1974).

The aim of this study was to find out whether differences in levels of physical activity have an influence on bone mass quantity in a "normal" population before (15–16 years) and at or just after the peak bone mass is thought to have been reached (21–42 years) and, further, whether quadriceps muscle strength is a reliable determinant of bone mass.

Material and methods

Study design and participants

This is a population-based, cross-sectional study, for which 395 individuals, 15–16, 21–22, 26–27, 31–32, 36–37 and 41–42 years old, were randomly selected from school records and city files. Excluded were subjects with endocrine disorders known to affect calcium metabolism, on steroid therapy, and those who were pregnant or lactating. Of the 395 invited, 332 (175 men, 157 women) responded (84%). All subjects were living in the suburban community of Kirseberg, Malmö (11,000 residents). The demographic structure of this population is well characterized by the Department of Community Health Sciences, Lund University, and was found to be similar to that of the entire city (Hanson and Larsson 1991). Participation in the study was rewarded by two tickets to the movies.

Bone mass measurements

Bone mineral density (BMD) was assessed by SPA according to the method of Nauclér et al. (1974). A ^{241}Am radiation source was used. Transverse scans of the radius and ulna at a distance of 1 (SPA1—mainly trabecular bone) and 6 cm (SPA 6—mainly cortical bone) from the tip of the styloid process of the ulna were made and BMD (mg/cm^2) was calculated as the average thickness of bone mineral in the pathway of the beam. Both forearms were measured and the average was used. The BMD (g/cm^2) in the spine (L1-4), proximal femur (neck, trochanter and Ward's triangle) and total body was measured using dual-energy X-ray absorptiometry (Lunar, DPX®). Since measurements of BMC (bone mineral content) may be more interesting and meaningful than BMD measurements in growth and development, BMC values were used as well as BMD values for calculations in the youngest group (15–16 years).

The precision of the BMD measurement in our laboratory, as determined by double measurements in healthy individuals, is 0.4% for total body and 1.6% for the hip (neck) with the DXA technique and 1–2 % for forearm measurements with the SPA technique.

Acquisition and analysis of bone mass data were performed by a trained person.

Muscle strength and anthropometric measurements

Measurements were made on the leg (mainly the quadriceps), using an isokinetic muscle force meter (Biodex®, Smith & Nephew). As a determinant for muscle strength, PT 60 (peak torque, angular velocity 60 deg/sec) was assessed, on the same leg as the DXA measurement at the proximal femur was performed. After providing detailed instructions, tests were carried out by the same physiotherapist on all subjects. Only peak torque levels achieved in the muscle force meter were used for our calculations in order to minimize the risk of bias due to differences in motivation to perform the test.

Height and body weight were measured, with the subjects wearing sports clothes, but no shoes.

Physical activity

A questionnaire (appendix) was used to assess physical activity levels at work and during leisure. The questionnaire has been used in several previous studies for the assessment of levels of physical activity (Grimby et al. 1971, Hanson and Larsson 1991), and has given reliable and reproducible data. Each participant was asked to state which of a series of statements corresponded best with his or her own level of activity at work over recent years. Physical activity during leisure was assessed in a similar way, but here a score was created, to take into account seasonal variations. The results obtained were also used to create two separate groups, distinguishing subjects with low from those with high levels of activity (for scoring, see appendix).

Moreover, in order to pinpoint further the level of activity, or rather, the attitude towards physical activity, the number of hours watching TV was recorded, as well as the means of transportation to and from school/work (walking, cycling, using public transportation, driving, etc). Attitudes towards physical training at school in the adolescent group (15–16 years) were also assessed.

Statistics

Statistical analyses included standard descriptive statistics, Student's t-test between means, correlation analysis, partial correlations, Spearman's rank correlation and the Mann-Whitney U-test.

Results

Adolescence (15-16 years)

Boys were taller, heavier and stronger than girls, but there was no statistically significant difference in the physical activity score (based on the answers in the questionnaire). Statistically significant positive correlations were found between physical activity and BMD at the distal forearm site in boys (r = 0.30) and in the trochanter in girls (r = 0.31) (Table 1). In the other hip sites in girls, there was a trend towards a positive correlation between physical activity and BMD. These results were not influenced by an adjustment for age and weight.

We found a positive correlation between quadriceps muscle strength and BMD at almost all measured sites in boys, excxept in one of the forearm sites (SPA 1). In girls, this relationship was seen only between muscle strength and total body BMD. However, when adjusting for age and weight, it became apparent that quadriceps strength was not an independent predictor of BMD at any site, in either sex (data

Table 1. Correlations between physical activity level, weight and BMD and, in the adolescent group, BMC in adolescent (15–16 years) and young adult groups (21–42 years). Spearman r and 95% confidence intervals (CI)

Physical activity level	Boys		Girls	
	r	95% CI	r	95% CI
Age 15–16 years	(n 58)		(n 44)	
BMD				
SPA 1 cm	0.30	0.05–0.57	0.19	-0.10–0.49
SPA 6 cm	0.11	-0.15–0.37	0.01	-0.29–0.31
Total body	0.10	-0.16–0.36	0.15	-0.14–0.45
Spine (L1–4)	0.09	-0.17–0.35	0.06	-0.24–0.36
Femoral neck	0.12	-0.14–0.38	0.26	-0.03–0.56
Ward's triangle	0.08	-0.18–0.34	0.22	-0.07–0.52
Trochanter	0.08	-0.18–0.34	0.31	0.03–0.62
BMC				
Total body	0.05	-0.21–0.31	0.08	-0.22–0.38
Spine (L1–4)	0.07	-0.19–0.33	0.01	-0.29–0.31
Femoral neck	0.01	-0.25–0.27	0.18	-0.11–0.48
Weight	0.02	-0.24–0.28	-0.01	-0.31–0.29
Age 21–42 years	(n 116)		(n 111)	
BMD				
SPA 1 cm	0.05	-0.13–0.23	0.07	-0.12–0.26
SPA 6 cm	0.07	-0.11–0.25	-0.06	-0.25–0.13
Total body	0.12	-0.06–0.30	0.07	-0.12–0.26
Spine (L1–4)	0.18	0.00–0.36	0.06	-0.13–0.25
Femoral neck	0.34	0.17–0.54	0.06	-0.13–0.25
Ward's triangle	0.30	0.13–0.49	0.09	-0.10–0.28
Trochanter	0.31	0.14–0.50	0.14	-0.05–0.33
Weight	-0.06	-0.24–0.12	-0.04	-0.23–0.15

not shown).

When comparing subjects classified as having a low level of activity with those having a high level, no statistically significant differences in BMD were found, although it appears that physical activity has some influence on bone mass in the hip of girls (Table 2).

The use of BMC instead of BMD in the calculations above did not significantly influence the outcome.

Neither the time spent watching TV nor the means of transportation to and from school had any significant influence on bone mass or muscle strength, nor did attitudes towards physical training at school.

Young adults (21–42 years)

In this group, men were more physically active than women during leisure, as judged by answers in the questionnaire (mean score: men 5.20 and women 4.59, $p = 0.003$). With regard to physical activity at work, men had a higher mean score (men 3.20 and women 3.04), but this difference was not statistically significant.

In men, physical activity seems to have an influence on bone mass in the hip. When correlating physical activity during leisure to bone mass in the hip, a statistically significant positive correlation was found (Table 1). When comparing the group classified as having low levels of activity during leisure with those with high levels, the latter group had statistically significant higher BMD values in the hip (Table 3). The same trend was seen when comparing those with low and high levels of activity at work (Table 4). In women, similar influences on bone mass of physical activity could be traced, but differences were smaller and not statistically significant. The outcomes of these

Table 2. Mean values for weight, height, BMD and BMC for adoloescent (15–16 years) boys and girls with low and high levels of physical activity. The mean difference high–low is presented with 95% confidence intervals (CI) and in percent

	Boys					Girls				
	Physical activity		Difference (high–low)			Physical activity		Difference (high–low)		
	Low	High	Mean	95% CI	%	Low	High	Mean	95% CI	%
Cases	26	29				28	16			
Weight (kg)	60.3	60.7	0.4	-4.3–0.4		57.5	56.3	-1.2	-5.9–3.6	
Height (cm)	174.0	173.7	-0.3	-5.0–4.4		167.2	167.9	0.7	-3.0–4.4	
BMD (mg/cm^2)										
SPA 1 [a]	376	384	8	-31–46	2.1	310	335	25	-16–67	8.1
SPA 6 [b]	532	523	-8	-40–25	-1.7	489	477	-12	-43–18	-2.5
BMD (g/cm^2)										
Total body	1.08	1.08	0	0.0–0.0	0.0	1.10	1.12	0.02	-0.03–0.06	1.8
Spine (L1–4)	1.10	1.10	0	-0.1–0.1	0	1.13	1.16	0.03	-0.09–0.16	2.7
Femoral neck	1.06	1.05	-0.01	-0.1–0.1	-0.9	1.02	1.07	0.05	-0.04–0.13	4.9
Ward's triangle	1.06	1.04	-0.02	-0.1–0.1	-1.9	1.02	1.06	0.04	-0.07–0.15	3.9
Trochanter	0.97	0.96	-0.01	-0.1–0.1	-1.0	0.91	0.97	0.06	-0.02–0.14	6.6
BMC (g)										
Total body	2627	2643	16	-232–265	0.6	2445	2474	29	-177–235	1.2
Spine (L1–4)	101.4	97.4	-4.0	-20.7–12.8	-3.9	97.9	95.8	-2.1	-20.2–16.0	-2.1
Femoral neck	5.77	5.69	-0.08	-0.6–0.45	-1.6	5.15	5.22	0.07	-0.50–0.62	1.4

[a] radius, mostly trabecular; [b] radius, mostly cortical

Table 3. Mean values for weight, height and BMD for subjects with low and high levels of physical activity, during leisure in young adults (21–42 years). The mean difference high–low is presented with 95% confidence intervals (CI) and in percent

	Men					Women				
During leisure	Physical activity		Difference (high–low)			Physical activity		Difference (high–low)		
	Low	High	Mean	95% CI	%	Low	High	Mean	95% CI	%
Cases	62	54				79	31			
Weight (kg)	77.8	76.2	1.6	-2.5–5.8		65.2	62.4	-2.8	-7.4–1.9	
Height (cm)	178.6	181.9	3.3	0.9–5.7		166.9	166.5	-0.4	-3.1–2.3	
BMD (mg/cm^2)										
SPA 1	417	417	0	-22–23	0	314	326	12	-12–12	3.8
SPA 6	617	627	10	-12–33	1.6	536	534	-2	-22–24	-0.4
BMD (g/cm^2)										
Total body	1.19	1.20	0.01	0.01–0.0	0.8	1.15	1.17	0.02	0.03–0.0	1.7
Spine (L 1-4)	1.27	1.30	0.03	0.02–0.0	2.4	1.31	1.31	0.00	0.05–0.0	0.0
Femoral neck	0.99	1.08	0.09	0.03–0.14	9.1	1.00	1.02	0.02	0.03–0.0	2.0
Ward's triangle	0.90	0.98	0.08	0.02–0.02	8.9	0.94	0.97	0.03	0.04–0.0	3.2
Trochanter	0.87	0.94	0.07	0.02–0.12	8.1	0.83	0.86	0.03	0.02–0.0	3.5

[a] radius, mostly trabecular; [b] radius, mostly cortical

Table 4. Mean values for weight, height and BMD for subjects with low and high levels of physical activity, at work in young adults (21–42 years). The mean difference high–low is presented with 95% confidence intervals (CI) and in percent

	Men					Women				
At work	Physical activity		Difference (high–low)			Physical activity		Difference (high–low)		
	Low	High	Mean	95% CI	%	Low	High	Mean	95% CI	%
Cases	62	54				69	42			
Weight (kg)	76.4	77.9	1.5	-2.6–5.7		64.0	66.6	2.6	-2.0–7.4	
Height (cm)	179.7	180.7	1.0	-1.5–3.5		166.6	167.6	1.0	-1.5–3.6	
BMD (mg/cm^2)										
SPA 1 [a]	413	422	9	-14–32	2.2	310	332	22	-1–43	7.1
SPA 6 [b]	614	630	16	-6–39	2.5	530	541	11	-10–32	2.1
BMD (g/cm^2)										
Total body	1.18	1.21	0.03	0.001–0.0	2.5	1.15	1.16	0.01	0.01–0.0	0.9
Spine (L1–4)	1.27	1.30	0.03	0.02–0.0	2.3	1.30	1.33	0.03	0.03–0.0	2.3
Femoral neck	1.01	1.06	0.05	0.001–0.1	5.0	1.01	1.02	0.01	0.05–0.0	1.0
Ward's triangle	0.91	0.98	0.07	0.01–0.0	7.7	0.96	0.96	0.00	0.07–0.0	0.0
Trochanteric	0.89	0.92	0.03	0.02–0.0	3.4	0.83	0.85	0.02	0.03–0.0	2.4

[a] radius, mostly trabecular; [b] radius, mostly cortical

calculations were not influenced by an adjustment for age and weight.

As with the adolescent group, a statistically significant, positive correlation between quadriceps muscle strength and BMD was found at all sites measured in men, except the forearm sites. In this group, muscle strength could also predict BMD in the spine, femoral neck and proximal forearm site (SPA 6) in women. However, as in the younger group, an adjustment for age and body weight revealed that quadriceps muscle strength was not an independent BMD predictor (data not shown).

The number of hours watching TV and the means of transportation to and from work did not significantly influence the outcome of the BMD measurements.

Discussion

Our main aim was to find out whether various levels of physical activity have an influence on bone mass in a population which, regarding physical activity, leads a "normal life". The study is strictly population-based, with randomly selected subjects, and efforts have been made to achieve a high participation rate, since we know from previous studies that this is of importance in order to reduce bias when collecting "normative" bone mass data (Düppe et al. 1992, 1996). Our questionnaire revealed that no high-level athletes or individuals with extremely low levels of activity were among those selected. Differences in bone mass between individuals or groups of individuals in a study population of this kind are smaller than when comparing groups with more extreme life styles. Studies of the extremes tell us that physical load has a major effect on bone structure but bears little relevance to the effect of physical activity and muscle strength on bone in normal individuals. Even small changes in bone mass can be of importance. We know that a reduction of peak bone mass by one standard deviation, is believed to be associated with a 50–100% increase in the risk of subsequent fractures (Wasnich 1987, Hui et al. 1989, Cummings et al. 1990). The question is whether a general increase in physical activity in a population—within the limits of what can be considered to be a "normal life style"—is sufficient to raise BMD levels and perhaps consequently reduce the subsequent incidence of fractures. The question is not answered by our study, but our findings indicate that even relatively small differences in physical activity have an effect on bone mass levels. The greatest effect of physical activity on bone mass levels was found in the hip of young active male adults who had substantially higher levels (up to 9%) than those less physically active. A similar pattern was seen in the female hip, but the differences were not statistically significant, perhaps due to limited sample size. These results confirm previous studies in normal, healthy individuals (Chow et al. 1986, Pocock et al. 1986, 1989, Aloia et al. 1988). In our study, it appears that physical activity has the greatest effect on bone mass in the hip of male adults, which is somewhat contradictory to the belief that exercise has a greater effect on bone-mass during skeletal development than during adult life (Eisman et al. 1993). A possible explanation of this is that the variation in levels of physical activity in a "normal" population—such as the one studied here—is much greater in male adults than in female adults and adolescents of both sexes. Further, we believe that women as a group, tend to reduce their level of physical activity more than men after the age of 20 due to changes in life style, with increasing domestic demands, etc. The reason why the hip seems to be the site most "sensitive" to different levels of physical activity may be that differences in skeletal load are most pronounced here because of the larger increment of load at this site than on, e.g., the spine, when changing from a sitting to a standing position, as suggested by Pocock et al. (1989).

Our results with regard to physical activity at work, where workload is positively correlated to bone mass, are similar to those of Jonsson et al. (1993). In their study, this correlation was also regarded as a tentative explanation of differences in fracture prevalence between a rural population, with heavier workload, and a city population.

We found a positive correlation between muscle strength (quadriceps torque) and bone mass in most sites measured. However, after adjusting for weight and age, the quadriceps muscle was no longer an independent predictor of BMD at any site. Our results support previous findings by Snow-Harter et al. (1990) that quadriceps torque does not independently predict BMD in women (mainly in their third decade) in either the spine or the hip. Hyakutake et al. (1994) reported an independent relationship between femoral BMD and quadriceps torque in women from the fourth to the seventh decades and in men in the fourth decade, but not in younger individuals, indicating that this relationship may be age-dependent. A reason for this may be that younger people in our society tend to exercise only for relatively short periods, while their level of activity is otherwise fairly low. This will result in an increase in muscle strength, but not so much in bone mass, since the period during which the skeleton is loaded is comparatively short. However, comparisons between subjects with high and those with low levels of activity in our study showed a pattern in which those with higher levels of activity tended to have a larger bone mass (most sites) as well as greater muscle strength, even when taking age and weight into consideration. Thus, hypothetically, in order to influence bone mass positively, skeletal load has to be increased over longer periods.

The life style which a person chooses is to a great extent the result of his or her attitudes in various other matters. By recording the time spent watching TV, the means of transportation to and from school/work and his or her opinion of physical training at school, we hoped to reflect different attitudes towards physical activity. However, we found no correlations between these "life style" questions and BMD levels.

The questionnaire used to assess physical activity (appendix) is of a semi-quantitative nature and relies on estimates of habitual physical activity. It has been validated in previous research by other institutions, but has not previously been used in bone mass research. However, the different levels of activity stipulated in this questionnaire are few and distinct, which leads us to believe that it was easy for participants to assess their own level of activity.

In summary, our data suggest that a higher level of physical activity, within the limits of a "normal life style", may preserve BMD in the proximal femur of men (21–42 years), which may contribute to a lower subsequent risk of fracture. Quadriceps muscle strength was not an independent predictor of BMD in any of the skeletal sites measured.

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