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The muscle strength and bone density relationship in young women: dependence on exercise status

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Aim. **Numerous studies report an association between muscle strength and bone mineral density (BMD) in young and older women. However, the participants are generally non-athletes, thus it is unclear if the relationship varies by exercise status. Therefore, the purpose was to examine the relationships between BMD and muscle strength in young women with markedly different exercise levels.**

Methods. **Experimental design: cross-sectional. Setting: a University research laboratory. Participants: 18 collegiate gymnasts and 22 age- and weight-matched recreationally active control women. Measures: lumbar spine, femoral neck, arm, leg and whole body BMD (g/cm^2) were assessed by dual X-ray absorptiometry. In addition, lumbar spine and femoral neck bone mineral apparent density (BMAD, g/cm^3) was calculated. Handgrip strength and knee extensor and flexor torque (60°/s) were determined by dynamometry, and bench press and leg press strength (1-RM) using isotonic equipment.**

Results. **BMD at all sites and bench press, leg press and knee flexor strength were greater in gymnasts than controls ($p<0.001$). In controls, knee extensor torque was significantly correlated to femoral neck, limb and whole body BMD ($r=0.47-0.55$, $p<0.05$), leg press strength was associated with limb and whole body BMD ($r=0.52-0.74$, $p<0.05$), and bench press strength with arm BMD ($r=0.50$, $p=0.019$). In partial correlations controlling for weight, leg press strength was related to leg and whole body BMD ($r=0.46-0.63$, $p<0.05$). There was no association between muscle strength and BMD in gymnasts.**

Conclusion. **These results suggest that the association between muscle strength and BMD in young women is dependent on exercise status. The osteogenic effect of increased mechanical loading associated with gymnastics training likely contributes to the dissociation of the relationship in gymnasts.**

KEY WORDS: Bone density - Muscle, skeletal, physiology - Exercise - Tensile strength.

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Numerous studies in young [1-3] and older [4-8] women report an association between muscle strength and bone mineral density (BMD). For instance, site-specific associations have been found, such as trunk extensor force and the lumbar spine,[4, 5] and quadriceps strength and the proximal tibia.[7] However, unrelated functional and anatomical sites have also shown significant associations, suggesting that the relationship may be more global than that predicted by the action of direct muscular insertions on bone.[1-3]

Importantly, several studies report muscle strength to predict BMD independent of body weight,[1, 5] a potential confounder in the association between strength and bone density. These associations lend support for the importance of muscle forces resulting from physical activity on the axial and appendicular skeleton.[9, 10] This bone-muscle coupling is of importance in prescription of appropriate physical activity for bone mineral accretion and attainment of peak bone mass, as well as for the preservation of BMD with aging in women. However, the relationships reported between muscle strength and BMD have generally been for non-athletic individuals, those not engaged in heavy exercise training. Some recent reports in female athletes suggest that high levels of physical activity undertaken in volleyball,[3] ice hockey [11] and soccer [12] may weaken the muscle strength and BMD relationship.

One group of athletes whose skeleton undergoes unique loading forces are those engaged in artistic gymnastics. Gymnastics training involves bounding, jumping, tumbling, vertical landings, as well as rapid acceleration and deceleration movements, which invoke high-impact loading strains, high strain rates and varied strain distribution patterns on the skeleton. Based on cross-sectional [13] and prospective [14] data, we reported that these forces may be particularly osteogenic as evidenced by high regional BMD values, particularly at the hip, in collegiate gymnasts compared to other athletic populations and non-active controls.

Therefore, to determine if the muscle strength-bone relationship is consistent in young women or is dependent on exercise status, we compared groups with markedly different exercise levels, collegiate artistic gymnasts and healthy recreationally active peers.

Materials and methods

Subjects

Subjects were 18 collegiate gymnasts and 22 age- and weight-matched recreationally active women. Characteristics of the subjects have been described previously.[15] Briefly, gymnasts participated for Stanford University and San Jose State University in the National Collegiate Athletic Association Division I competition and trained on average for 21.0 hours per week. The recreationally active control women exercised an average 4.9 hours per week, predominantly undertaking step aerobics. All subjects were in good health and none took medication affecting bone metabolism except for 2 gymnasts and 11 controls who took oral contraceptives; the duration of oral contraceptive usage was 1 to 3 years. One gymnast was amenorrheic and 5 gymnasts and 3 controls were oligomenorrheic (4-9 menstrual cycles per year); the number of menstrual cycles in the previous year were 9.5±3.6 for gymnasts and 11.2±1.7 for controls ($p=0.055$). There was no difference between groups in energy (gymnasts 1 482±505, controls 1 313±458 kcal, $p=0.356$) or calcium (gymnasts 774±371, controls 695±316 mg, $p=0.546$) intake as assessed by a food frequency questionnaire.[16] The Human Subjects Committee of Stanford University approved the procedures, and all subjects gave written consent.

Bone mineral density

Bone mineral density (BMD, g/cm^2) of the lumbar spine (L_{2-4}), femoral neck, and whole body was assessed by dual X-ray absorptiometry (DXA, Hologic QDR 1000/W, Waltham, MA, USA). In addition, subregion analysis of the whole body scan permitted BMD evaluation of the arms and legs. BMD is an areal density derived from a 2-D image and, as such, is influenced by bone size. To adjust for differences in bone size, bone mineral apparent density (BMAD, g/cm^3) for the lumbar spine and femoral neck was calculated, as previously described.[17, 18] The coefficient of variation for replicate measurements of regional and whole body BMD is less than 1.1%.

Muscle strength

Prior to determination of muscle strength, participants underwent a familiarization session that included instruction on correct lifting technique. Dynamic bench press (upper body) and leg press (lower body) strength was measured with a multi-station weight machine (Universal Gym Equipment, Cedar Rapids, IA, USA) using the 1-repetition maximum (1-RM) method. Briefly, the 1-RM method is the maximal weight an individual can move through a full range of motion one time without change in body position other than that dictated by the specific exercise motion. After an initial warm-up period, subjects performed the exercise at a low resistance 10 times to enhance preparedness of the respective muscle groups. The 1-RM test began with a weight close to the suspected maximum to minimize repetition fatigue. Most subjects required no more than 5 repetitions to reach maximum. Knee extension and flexion peak torque was determined using a Cybex 6000 isokinetic dynamometer (Cybex Division of Lumex, Inc., NY, USA) at an angular velocity of 60°/s (1.05 rad · s^{-1}). Isokinetic measurements were made on the right side of the body with the subject strapped in at the trunk proximal to the knee. Isometric grip strength of the right hand was obtained by dynamometry (Jamar, TEC, Clifton, NJ, USA). Triplicate measurements for knee extensor and flexor torque and grip strength were obtained with the highest values reported. The coefficient of variation for muscle strength measurements is 3-8%.

Statistical analysis

Data were analyzed using the SPSS (SPSS Inc., Chicago, IL, USA) statistical software package. Analyses included standard descriptive statistics, 2-tailed 1-sample and unpaired "t" tests, Pearson correlation and partial correlation. To determine if allometric scaling was required to normalise muscle strength for body weight, the slope coefficient of the log transformed independent (body weight) and dependent (muscle strength) variables was calculated. If the 95% confidence interval of the slope coefficient does not include the value of 1.0 or 0, then the slope coefficient is used as the numerical exponent to which body weight is raised prior to normalising muscle strength.[19] An α level of 0.05 was required for significance. Results are given as the mean±SD.

Results

Although there was no difference in age or body weight, gymnasts were shorter with less body fat than controls (Table I). Gymnasts were also stronger than controls for the bench press, leg press and knee flexors and had higher regional and whole body BMD, and lumbar spine and femoral neck BMAD. When compared with percent of normative values for peak bone mass (T score) for the spine and hip supplied by the manufacturer, gymnasts were higher at the lumbar spine (109.7%, p=0.003) and femoral neck (125.1%, p<0.001). In contrast, there was no difference at the femoral neck (99.0%, p=0.737) for controls, although they were lower at the spine (96.1%, p=0.047) compared to normative values.

Muscle strength of the knee extensors (knee extension and leg press) was significantly correlated to limb and whole body BMD in controls (Table II). In addition, knee extensor torque was associated with femoral neck BMD while bench press strength was correlated to arm BMD. There was no association between muscle strength and lumbar spine or femoral neck BMAD.

TABLE I.—*Subjects characteristics (mean±SD).*

Variables	Gymnasts (n=18)	Control (n=22)	p value
Age (y)	19.2±1.2	19.9±1.6	0.146
Weight (kg)	56.5±3.7	58.5±6.9	0.257
Height (cm)	159.2±4.6	164.4±5.5	0.003
Body fat (%)	17.9±1.7	24.8±3.4	<0.001
Muscle strength			
Hand grip (kg)	34.0±4.3	34.0±3.4	0.981
Bench press (kg)	45.9±5.3	29.2±3.6	<0.001
Leg press (kg)	158.0±23.7	121.0±24.0	<0.001
Knee extension (Nm)	140.6±16.1	127.6±24.8	0.063
Knee flexion (Nm)	85.2±13.9	66.0±13.7	<0.001
Bone mineral density (BMD, g/cm²)			
Lumbar spine (L_{2-4})	1.118±0.128	1.038±0.093	<0.001
Femoral neck	1.119±0.123	0.884±0.116	<0.001
Arm	0.873±0.058	0.779±0.035	<0.001
Leg	1.173±0.066	1.085±0.089	0.001
Whole body	1.125±0.065	1.054±0.064	0.001
Bone mineral apparent density (BMAD, g/cm³)			
Lumbar spine (L_{2-4})	0.182±0.018	0.157±0.014	<0.001
Femoral neck	0.254±0.054	0.177±0.029	<0.001

However, body weight was significantly correlated to femoral neck, limb and whole body BMD, and to leg press (r=0.53, p=0.011), knee extension (r=0.72, p<0.001) and knee flexion (r=0.70, p<0.001) strength.

As the association between muscle strength and bone density may have been influenced by body weight, first-order partial correlations between muscle strength and bone density, controlling for body weight, were calculated (Table III). Although the magnitude of the associations was reduced, leg press strength remained significantly correlated to leg and whole body BMD. Partial correlations between knee extensor torque and BMD and bench press and arm BMD were not significant. Third-order partial correlations for leg press strength and leg and whole body BMD were also performed controlling for body weight, use of birth control pills and menstrual cycles, however the associations remained significant ($r_{12.345}$=0.64 and 0.57, respectively, p<0.001). To determine if allometric scaling should be performed, the slope coefficient of the log-transformed leg press strength and body weight was calculated. However, the 95% confidence interval included 1 so scaling for body weight was not undertaken.

In contrast to the significant correlations between muscle strength and bone density in controls, there was no association between muscle strength and BMD in gymnasts (Table IV). Further, weight was not significantly correlated to any skeletal site nor to muscle

TABLE II.—*Bivariate correlations between bone density site and height, weigth and muscle strengh in controls.*

Bone site	Height	Weight	Grip strength	Bench press	Leg press	Knee exten	Knee flex
Lumbar spine BMD	0.09	0.37	-0.08	0.38	0.41	0.30	0.25
Femoral neck BMD	0.03	0.43*	-0.05	0.21	0.37	0.51*	0.20
Arm BMD	0.12	0.45*	-0.08	0.50*	0.52*	0.47*	0.15
Leg BMD	0.09	0.59**	0.07	0.23	0.74***	0.55**	0.22
Whole body BMD	0.09	0.66**	0.01	0.33	0.64**	0.54**	0.31
Lumbar spine BMAD	-0.17	0.18	-0.09	0.22	0.25	0.26	0.03
Femoral neck BMAD	-0.20	0.30	0.00	0.14	0.31	0.41	0.10

BMD: bone mineral density (g/cm^2); BMAD: bone mineral apparent density (g/cm^3); knee exten: knee extension; knee flex: knee flexion.
*) p<0.05; **) p<0.01; ***) p<0.001.

TABLE III.—*Partial correlations (controlling for body weight) between bone density site and muscle strength in controls.*

Bone site	Grip strength	Bench press	Leg press	Knee exten	Knee flex
Lumbar spine BMD	-0.05	0.29	0.27	0.04	-0.02
Femoral neck BMD	-0.01	0.07	0.19	0.32	-0.15
Arm BMD	-0.04	0.40	0.37	0.23	-0.26
Leg BMD	0.15	0.03	0.63**	0.22	-0.32
Whole body BMD	0.09	0.14	0.46*	0.13	-0.28
Lumbar spine BMAD	-0.08	0.17	0.19	0.19	-0.14
Femoral neck BMAD	0.03	0.04	0.19	0.29	-0.16

BMD: bone mineral density (g/cm^2); BMAD: bone mineral apparent density (g/cm^3).
*) p<0.05; **) p<0.01.

TABLE IV.—*Bivariate correlations between bone density site and height, weight and muscle strength in gymnasts.*

Bone site	Height	Weight	Grip strength	Bench press	Leg press	Knee exten	Knee flex
Lumbar spine BMD	0.03	-0.03	0.15	-0.34	0.43	-0.08	-0.30
Femoral neck BMD	0.10	0.25	0.33	-0.04	-0.11	0.18	0.04
Arm BMD	0.22	-0.24	0.22	-0.20	0.22	0.33	-0.06
Leg BMD	-0.08	-0.32	0.07	-0.24	0.29	0.13	-0.15
Whole body BMD	-0.21	0.08	0.16	-0.25	0.28	-0.07	-0.18
Lumbar spine BMAD	-0.20	-0.16	-0.13	-0.28	0.37	-0.27	-0.28
Femoral neck BMAD	-0.08	0.17	0.40	0.41	0.17	0.30	0.36

BMD: bone mineral density (g/cm^2); BMAD: bone mineral apparent density (g/cm^3); knee exten: knee extension; knee flex: knee flexion.

strength, except for knee flexor torque (r=0.49, p=0.039).

Discussion and conclusions

Results of this study indicate that the association between muscle strength and BMD in young adult women is dependent on exercise status. In recreationally active women, there were significant associations among functionally and anatomically related and distant sites. Moreover, after controlling for the co-dependency on body weight as well as other potential confounding variables, the relationships between leg press strength and lower limb and whole body bone density remained significant. In contrast, there was no association between muscle strength and axial or appendicular BMD in gymnasts.

Participants in this investigation had markedly different exercise regimens. Gymnasts trained for 21 hours per week, which included sport-specific training as well as resistance training 2-3 times per week. The age- and weight-matched controls were participating in low-to-moderate physical activity, predominantly step aerobics. Although this is weight-bearing activity, activities do not include high impacts as occurs with various gymnastics maneuvers, and their femoral neck BMD was not different from the normative database supplied by the DXA manufacturer. The divergence in exercise backgrounds is also evident in the participants body composition, with 18% body fat in gymnasts compared to 25% in controls. Muscle strength was substantially higher in gymnasts for the bench press, leg press and knee flexor strength. Apart from differences in muscle size, the gymnasts may have a greater neural drive as a result of undertaking resistance exercise as part of their training regimen, in addition to the muscular forces they must generate in performing various gymnastics maneuvers.

It is recognised that the greatest loads on the skeleton come from muscle forces and these forces are primarily the result of muscle contraction.[9, 10] Consequently, bone strength should correlate better with muscle strength than with body weight.[20] Although we did not measure bone strength directly, bone mass/density accounts for 50-80% of the variance in bone strength,[21] and we found that knee extensor strength and body weight were similarly associated with BMD in controls. However, in gymnasts, neither body weight or muscle strength was associated with bone density.

In controls, due to the relationship between body weight and strength and body weight and bone density, controlling for weight in partial correlations reduced the association between muscle strength and each skeletal site. In contrast, body weight was not significantly correlated to any bone site in gymnasts or to muscle strength, except for the knee flexors. Two factors likely contribute to the lack of relationship of body weight to bone density and muscle strength in gymnasts. The 1st is the high-impact loading forces that the skeleton is subjected to with gymnastics training. For instance, forces at the hip in gymnastics training are as great as 10-12 times body weight.[22] These forces on the skeleton are considerably greater than those imparted through activities such as walking and running, which are 2-5 times body weight.[23] It has been proposed that a diverse exercise regimen, which characterizes the various bounding, jumping, landing and tumbling movements in gymnastics, may provide a particularly strong osteotrophic effect.[24] The 2nd factor is the potentially enhanced neural drive in gymnasts undertaking muscle strength testing. Apart from undertaking resistance training, gymnasts are required to exert various levels of force, including maximal voluntary force, in the performance of their various gymnastic maneuvers.

Our results show a lack of relationship between muscle strength and bone density in our cohort of gymnasts who display elevated bone density. These findings concur with others who have reported lower correlations between muscle strength and BMD in female [3, 11] and male [25, 26] athletic populations than in inactive individuals. Sandstrom *et al.*[11] reported higher regional and whole body BMD and higher knee extensor and flexor peak torque in 14 young adult female ice hockey players compared to 14 inactive controls. Although knee flexor torque was significantly correlated to femoral neck BMD in ice hockey athletes, the associations were stronger and muscle strength was related to more skeletal sites in controls. Alfredson *et al.*[3] reported higher regional and whole body BMD but no difference in knee extensor and flexor strength in 13 female volleyball players compared to 13 nonactive females. In bivariate correlations, muscle strength in controls was associated with adjacent and nonadjacent skeletal sites while quadriceps strength was only associated with BMD of the humerus in athletes.

In contrast to the above studies, Pettersson *et al.*[27] reported a stronger relationship between muscle strength of the thigh and regional and whole body BMD in 16 female adolescent cross-country skiers than in age-matched non-active females. However, in studying adolescent female soccer players and non-active females, the same researchers [12] found several positive bivariate associations between thigh muscle strength and hip BMD in non-active controls but only one association between quadriceps strength at 90°/s and the femoral neck in soccer players.

Not surprisingly, several gymnasts in the present study as well as 3 controls had menstrual dysfunction, although there was no group difference in the number of menstrual cycles in the previous year. It has been proposed that estrogen deprivation raises the bone strain threshold resulting in bone loss through the process of remodeling.[20] In addition, estrogen withdrawal would also raise the modeling threshold and compromise peak bone mass in adolescent and young adult women. However, we have previously reported that the mechanical forces generated from gymnastics training appear to counteract the effects of compromised menstrual status on bone mineral.[28] In controls, we adjusted for menstrual cycles as well as usage of birth control pills; however, leg press strength remained significantly associated with leg and whole body BMD. Although low dose oral contraceptive therapy protects against bone loss, it does not apparently augment axial or appendicular bone density.[29]

In summary, the association between muscle strength and BMD in young women is dependent on exercise status. In non-athletes, there is a significant relationship between muscle strength and BMD, especially for muscle strength of the thigh and leg bone density. However, there is no relationship in gymnasts, probably due to the osteotrophic effect of increased mechanical loading associated with their training regimens.

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