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# Strong Bones Start Young

As a gymnast tumbles, she runs, pounces, flips and lands with a perfect thud. Some people cringe as they imagine the sequence to be painful, but science has recently shown the pounding may actually be beneficial. Many studies have found weight-bearing exercise encourages bone repair and calcification. Additionally, those who are involved in weight-bearing exercise at a younger age are more likely to have higher bone mineral density later on in life (Dyson, 1997). Each year, over 8.9 million people across the world suffer from a fracture caused by osteoporosis, a medical condition in which the bones become brittle (Johnell, O. & Kanis, J., 2006). As the prevalence of osteoporosis is high, especially in post-menopausal women, it is crucial to study not only ways to treat it, but also how to prevent or slow down the disease. Gymnastics, a high impact sport, may be an ideal weight-bearing activity to promote a higher bone mineral density in children and young adults. Bass and colleagues (1998) proposed participation in sports during puberty may actually interfere with growth in girls due to interrupting normal hormonal cycles, which might in turn lead to lower peak bone mass.  Prior to puberty, growth is sex hormone independent and exercise works as a stimulant for growth hormone secretion. Different sports may have various effects on bone mineral density on a range of body locations. The purpose of this paper is to analyze bone mineral density in gymnasts compared to other athletes and non-athletes at different stages throughout the lifespan.

Cassell, Benedict, and Specker (1996) investigated the bone mineral density (BMD) in 45 girls age 7-9. Their focus was on comparing BMD of girls in competitive sports that involved more weight-bearing activities with girls in competitive sports without weight-bearing activities and a control group. The subjects included 14 gymnasts, 14 swimmers, and 17 controls. All competitive athletes were from established teams that practiced year-round, and all controls did not participate in year-round sports, but may have been involved in seasonal sports. Subjects were Caucasian with no medical history of disorders affecting growth, metabolism, or development. BMD was measured by a dual energy x-ray absorptiometry. The results showed 50% of the swimmers were above the 75th percentile for weight compared to gymnasts (0%) and controls (0%), which was statistically significant. BMD was greater in gymnast than other groups, and gymnasts with greater body weight had comparatively higher BMD than in lighter gymnasts. Swimmers and controls, on the other hand, had similar BMD. Some differences in weight may be caused by a bias on girls who choose to participate in the different sports due to certain body types being associated with a greater chance of success. Overall, this study supported that gymnastics is associated with greater BMD than swimming, a low-impact sport.

Mudd and colleagues (2007) found that both mass and sport were significant predictors of BMD for the lumbar spine, total body, and pelvis. Participants in this study included 99 female collegiate athletes, age 20.2 ±1.3 years who represented 12 different sports including: gymnastics, softball, cross-country, track, field hockey, soccer, crew, swimming/diving. BMD was measured at the lumbar spine, total body, and pelvis. Gymnasts had a significantly higher BMD than runners at every site ($P<0.01$), and swimmers/divers had lower BMD in all sites compared to every other group besides runners and rowers. Runners had lower BMD for total body (T-score 1.079 ±0.055), lumbar spine (T-score .988 ±0.118), and pelvis (T- score 1.023 ±0.085) than all other athletes. Running is a weight-bearing sport, especially in the lumbar spine and pelvis, so these results appear to contradict the data supporting the effect of weight bearing exercise on BMD. Other factors that affected the runners may have been any of the following: low calcium intake, disordered eating, hormone levels, or insufficient energy intake compared to expenditure. One limitation of this study was no analysis was done on dietary intake and energy expenditure, which may contribute to the unexpected results.

Despite the healthy lifestyle promoted by sports, many female athletes have amenorrhea or oligomenorrhea, which tend to lead to lower levels of BMD due to a decrease in estrogen. In order to examine this more closely, Robinson and colleagues (2009) compared the bone mineral density in collegiate gymnasts and runners who had amenorrhea and/or oligomenorrhea to controls with regular menstrual cycles. Participants in this study included 21 collegiate gymnasts, 20 collegiate runners, and 19 non-athletic women (controls) all aged 17-27 years. The control group consisted of 19 college women who did not exercise more than 3 hours per week and experienced at least 10 menstrual periods per year. All subjects completed a questionnaire regarding their nutrition, menstrual status, health, and exercise. A dual-energy x-ray absorptiometer measured BMD of the lumbar spine, proximal femur, and whole body. Bone mineral apparent density (BMAD) was calculated to adjust for differences in bone size for the femur and lumbar spine. Subjects were divided into 5 categories according to their menstrual status: (1) amenorrhea athletes with history of oligo- or amenorrhea, (2) oligomenorrhea athletes with history of oligo- or amenorrhea, (3) eumenorrheic athletes with history of oligo- or amenorrhea, (4) eumenorrheic athletes who have always had regular periods, and (5) control group who were eumenorrhea.

The results revealed runners and gymnasts shared similar values for percent body fat (14.7 ± 2.2% and 15.5 ± 2.09%, respectively), which were less than the controls (22.3

±3%). Gymnasts had higher lean body mass, once adjusted for body surface area, compared to runners and controls (p=0.001). Gymnasts also began training at a younger age (8.0 ±2.4 years) versus runners (15.9 ±2.4 years). Oligomenorrhea was prevalent in 19% of gymnasts, 15% of runners, and 0% of controls. Amenorrhea was prevalent in 28% of gymnasts, 15% of runners, and 0% of controls. Gymnasts had significantly higher BMD in the femoral neck (0.02 ±0.002 Z-score) compared to runners (0.017 ±0.002 Z-score) and controls (0.016 ±0.002 Z-score). Gymnasts also had significantly higher BMD in the lumbar spine (0.021 ±0.003 Z-score) compared to runners (0.019 ±0.002 Z-score). These results support that gymnasts have higher BMD than runners and the average college-aged woman despite having a higher prevalence of amenorrhea and oligomenorrhea. It is likely that the high-impact exercise involved in gymnastics overrides the deficit caused by the lower amount of hormones. Though running does involve impact exercising, it does not extend to the frequency and variety of exercises involved in gymnastics, which may influence the difference of BMD between the two sports.

Bass and associates (1998) compared gymnasts' BMD to controls and retired gymnasts to explore the effects of weight-bearing exercise on bone loss over time. Evidence so far has suggested exercise during growth provides the most benefit, but it is also thought that exercise during puberty might interfere with growth due to interrupting normal hormonal cycles which may lead to lower peak bone mass (Frisch 1981, Haapasalo 1994). Prior to puberty, however, growth is sex hormone independent and exercise is a stimulant for growth hormone secretion (Rogol 1992). This study by Bass and associates aimed to see if exercise during prepubertal years could increase BMD and extend benefits into adult years.

Participants included 45 active, prepubertal female gymnasts age 10.4 ± 0.3 years who trained on an elite squad at a sub-olympic standard for 15-36 hrs/wk; 36 retired female gymnasts age 25 ± 0.9 years who exercised on average 1.9 ± 0.7 hrs/wk, started training as gymnasts at age 7.5 ± 0.4 years, and trained for a range of 4-8 years; and 50 controls that consisted of 35 prepubertal girls who did not engage in more than 6 hrs/wk of weight-bearing exercise with an average of 1.7 ± 0.3 hrs/wk, and 15 controls matched for age, height, and weight of the retired gymnasts. Using the Greulich and Pyle method, prepubertal gymnasts were matched with controls by bone age. Tanner breast staging determined pubertal status. BMD and body composition were measured by dual-energy x-ray absorptiometry. BMD was expressed as an areal BMD (g/cm^2) and as a volumetric bone density (g/cm^3) and was calculated at the leg, vertebrae, arms, total body, and skull. Derived standard score (Z score) measured the deviation from the expected population mean, so 95% of the normal population will have a Z score between -2 and 2. A 12-month follow-up measured BMD again to note annual changes.

The results showed active prepubertal gymnasts had significantly higher areal BMD compared to the controls for the legs (0.75 ± 0.2), spine (0.78 ± 0.2), and arms (1.9 ± 0.25), but Z scores were not significantly different for the skull. Lumbar spine bone mass, volume, and volumetric BMD were 24 ± 3, 12 ± 3, and 12 ± 2 % respectively higher than the controls. Femoral midshaft periosteal diameter was not greater than controls, but endocortical (medullary) diameter was 19 ± 3% less, which results in a greater cortical thickness, bone mass, areal, and volumetric BMD for the gymnasts. During the 12 months of follow-up, total body, spine, and leg areal BMD growth was 30-85% more rapid in the gymnasts compared to controls. Bone mass increased more in the gymnasts at 2.28 ± 0.12 g/yr compared to the controls at 2.09 ± 0.16 g/yr. The retired gymnasts had areal BMDs that were 6-16% higher (0.7-1.4) than controls at all sites except the skull and did not diminish as time since retirement increased**.** This evidence from the retired gymnasts suggests that weight-bearing exercise before puberty, in addition to during and after puberty, benefits women into adulthood specifically because areal BMDs were higher at all weight-bearing sites, but not in the skull. It was estimated that fracture risks for gymnasts is likely 2 to 4-fold less compared to the controls. Retired gymnasts, although they had higher BMD than age-matched controls, still had lower BMD than the active prepubertal gymnasts.

Many factors influence growth during childhood including genetics, sex, body composition, physical activity, and diet. Physical activity increases areal bone mineral density (aBMD), bone mineral content (BMC), and estimated bone structural strength. Jackowski and colleagues (2015) studied the relationship between recreational gymnastics and bone strength development in children. Their mixed longitudinal study over 3 years included 127 children age 4-6, of which 59 were male and 68 were female. Of these participants, 69 were gymnasts (34 male and 35 female) and 58 were non-gymnasts (25 male and 33 female). Parents were asked to report how many hours their child had participated in gymnastics each time measurements were taken. Peripheral quantitative computed tomography (pQTC) scans were done between 2008 and 2012. Anthropometric measures were taken to include limb (radius, tibia and femur) length and weight. Cross-sectional slices of the left radius and tibia were measured with pQTC, and the forearm was scanned at the distal and shaft sites. Lower leg was also scanned at distal and shaft sites of tibia. Muscle area of the forearm and lower leg were measured with contour mode 1. Physical activity was assessed using the Netherlands Physical Activity Questionnaire. Calcium and vitamin D intake were measured using a 24-hour recall questionnaire.

Girls who were 5-years-old and not in gymnastics had a higher intake of vitamin D than gymnasts ($p<0.05$). At 7-years-old, non-gymnasts had shorter radius lengths and smaller lower-leg muscle area ($p<0.05$). At 8 years old, non-gymnasts had smaller forearm muscle ($p<0.05$). Age 5, male gymnast had a radial length of 13.9 ±0.8 cm and by age 12 it was 23.8 cm. Age 5 male non-gymnast had a radial length of 15.3 ±0.5 cm and by age 12 it was 20.6 ±0.2 cm. This shows a significant difference in length. Age 5 female gymnasts had a radial length of 14.5±1.0 cm and by age 12 it was 20.5 ±1.4 cm. The age 5 female non-gymnasts had a radial length of 14.7 ±1.0 and by age 12 it was 21.1±0.7 cm. This shows an insignificant difference in length. This study shows early exposure to gymnastics has a positive influence on total bone area at the distal radius but not at distal tibia. This lack of difference in the tibia may be because most children are running around and involved in other activities so that the two groups were more similar in this aspect. Future studies can look into more specific intensity, duration, and frequency of weight-bearing exercise is best to promote bone strength and growth.

The past decade has brought more attention to children exercising as a means to reduce risk of osteoporosis and to determine peak bone mass. In a study done by Dyson and colleagues (1997), the number of hours of training (with impact loading) was determined to examine its effect on whole-body and regional areal, apparent, and volumetric bone mineral density in pre-adolescent female gymnasts. In this study, the participants were between the age of 8 and 11 years old and separated into two groups: (1) 16 pre-adolescent female gymnasts and (2) 16 controls not in sports. Sexual maturity was determined with Tanner's stages of breast and pubic hair development. Percent body fat and areal BMD was measured with dual-energy x-ray absorptiometry (DXA). Areal BMD was measured at four sites: left trochanter neck of femur, left femoral neck, L2-L5 vertebrae, and whole body, and then converted to bone mineral apparent density - BMAD - to control for size difference. A peripheral quantitative computed tomography (pQCT) was used to measure BMD of the left distal radius.

Gymnasts were significantly shorter at 129.3 ±5.7 cm compared to controls at 136.7 ±4.4 cm. Areal BMD was higher in gymnasts: femoral neck was 8% higher than controls and the trochanter was 16% higher than controls. Gymnasts had greater BMAD (8% more) than controls for lumbar spine, 7% more for whole body, and 20% more for femoral neck. These results are similar to other studies, but these measurements are adjusted for bone-mineral apparent density, which is more sensitive to bone size differences. This study contributes to the hypothesis that gymnasts have greater BMD.

Athletic sports generally promote a healthier lifestyle and provide many benefits including, in some cases, an increase in bone mineral density (BMD) from weight-bearing exercises. Studies such as the one done by Mudd and colleagues (2007) support the interesting finding that gymnasts have higher BMD. Cassel, Benedict, and Specker (1996) found that swimmers had a similar BMD to the controls even though they exercised much more often and at a higher intensity. This suggests that exercise without a weight-bearing component may not be sufficient to stimulate increased bone mineral density. Young, prepubertal children who are consistently involved in a weight-bearing sport such as gymnastics for several hours per week are more likely to have a higher BMD. Even when comparing female athletes with decreased hormones, the study done by Robinson and colleagues (2009) still found gymnasts to have higher BMD than non-athletes with regular hormone levels.

On average, people will reach their peak bone mass at age 25, making it critical to increase bone mass before this age in the lifespan. To avoid experiencing fractures in old age, prevention must start during the time of growth, and exercise is one of the most attainable factors to modify. More research should be done as elite gymnasts age into late adulthood, especially post-menopause women, to find if the childhood sport's benefit continues and at what magnitude. The studies reviewed in this paper indicate that children and adolescents should be involved in more weight-bearing activities, which could perhaps be implemented through physical education. Study after study has supported gymnastics to be an ideal physical activity for children to participate in to promote an increase in bone mineral density. Prevention of bone loss starts long before symptoms arise.

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