Bone Mineral Density and weight bearing sports

Whittington et al. (2009) have studied to examine the BMD of a group of USA Division I Collegiate Throwers (e.g. shot put, discus, etc.) on seven throwers (4 males; 3 females) who were 19.0±0.9 years had their BMD compared to 14 age matched control group (6 men; 8 women) and normative data. BMD was measured with DXA method. Maximum isometric strength was assessed using a mid-thigh pull with standing on a force plate which generated force-time curves. Peak force (PF) and normalized peak force (PFa) were then correlated with BMDs. The results showed throwers had denser bones with male throwers tending to have a greater total BMD (p<0.05). The BMD at dominant arm was slightly greater than non-dominant arm (p<0.05). Furthermore, total body BMD was related to PF (r=0.68, r²=0.44) and PFa (r=0.56, r²=0.31). In conclusion throwers have greater BMDs than non-athletes and most other athletes. However throwers only showed a small indication of sidedness.

Gustavsson, Thorsen, & Nordström, (2003) have conducted longitudinal studies on the effect of physical activity on the accrual of bone mineral density in healthy adolescent males (16-19 years). The subjects consisted of 12 badminton players, 20 ice hockey players, and 24 age-matched controls. The BMD of the total body, spine, dominant and non-dominant humerus, head and femoral neck was measured twice with a 3-year interval by DXA. In addition, at the femoral neck, volumetric BMD was assessed. At baseline, the athletes as a whole group had significantly higher BMD at the total body (P<0.03), dominant (P<0.006) and non-dominant humerus (P<0.009) and femoral neck (P<0.007) compared to the controls.
At the 3-year follow up, the athletes had significantly higher BMD at all sites (total body; \( P<0.003 \), spine; \( P<0.02 \), dominant humerus; \( P<0.001 \), non-dominant humerus; \( P<0.001 \), femoral neck; \( P<0.001 \)) except for the head (\( P<0.91 \)) compared with controls. The athletes also had higher vBMD at the femoral neck compared with the controls (\( P<0.01 \)). Furthermore, to be an athlete was found to be independently associated with a higher increase in non-dominant humerus BMD \( (b=0.24; \ P<0.05) \) and femoral neck BMD \( (b=0.30; \ P<0.05) \) compared with the controls, during the study period. In summary, these results suggests that it is possible to achieve continuous gains in bone mass in sites exposed to osteogenic stimulation after puberty in males by engaging in weight-bearing physical activity.

Platen et al. (2001) was to determine the influence of muscle strength, training specific and anthropometric parameters on bone mineral density (BMD) in male top athletes of different sports in comparison to untrained controls. BMD was measured by dual energy X-ray absorptiometry in 173 males, aged 18 to 31 years. Of these, 104 were athletes (21 runners, 12 cyclists and 18 triathletes), heavy athletes (HA, judo and wrestling, \( n=28 \)), and team sport athletes (TS, handball, soccer, basketball, volleyball, \( n=25 \)); 44 were unspecifically trained sport students (STU); and 25 were untrained controls (UT). In group I (HA, TS, and STU), BMD at LSP and FEM were significantly \( (p<0.01) \) higher compared to UT; in group II (R and TRI), BMD at FEM but not at LSP was higher compared to UT \( (p<0.01) \); and in group III (C), no BMD value was significantly different from UT. Results revealed lean body mass to be the strongest predictor for BMD at LSP and FEM. They concluded that mechanical loads have strong effects on bone adaptation. Particularly dynamic sports with short, high, and multidimensional loads have the strongest effects on bone formation, independent of training quantity.
Calbet, Herrera, & Rodriguez, (1999) have studied to assess bone mass in male elite athletes participating in an impact loading sport (volleyball) and, in particular, to determine whether the asymmetric nature of this sport leads to differences in the skeletal tissue composition of the limbs. 15 male volleyball players (VP) and 15 non-active control subjects were studied. Whole-body BMC was higher in VP after adjustment for body mass and height (p<0.001). Axial skeleton and limb BMC and BMD were higher in VP than in control subjects (p<0.05). Adjusted lumbar spine (L2–4) BMD was 14% higher in VP than in control subjects (p<0.05). Similarly, a much greater adjusted BMD was observed in the femoral neck of VP (24%, 20%, 27% and 20% for the femoral neck, intertrochanteric, greater trochanter and Ward’s triangle subregions respectively; p<0.05). Right and left leg BMC and BMD values were similar in control subjects while 4% higher BMC values were recorded for the left leg in the VP group (p<0.05). A close relationship between left leg muscle mass and BMD was observed in the femoral neck subregions of all the subjects (r=0.81, 0.81, 0.78 and 0.79 for the femoral neck, intertrochanteric, greater trochanter and Ward’s triangle subregions respectively; p<0.001; n=30). These findings clearly demonstrate a considerably high BMC and BMD in professional volleyball players which seem to be related to the loading type of exercise they perform.

Morel, Combe, Francisco, & Bernard, (2001) analyzed the relation between sports and bone mass. 704 healthy men were questioned on their adolescent and adult sporting activities. Their total body (TB) and regional (head, spine, arms and legs) BMD were measured by DXA. Subjects (mean 30 years) were engaged in 14 sports activities: rugby, soccer, other team sports, endurance running, fighting sports, bodybuilding, multiple weight bearing activities, swimming, swimming with flippers,
biking, rowing, climbing, triathlon and multiple mixed activities. Rowers and swimmers had low TB BMD (1.22 and 1.17 g/cm²) and low leg BMD (1.37 and 1.31 g/cm²). Participants in rugby, soccer, other team sports and fighting sports had a high TB BMD (1.27-1.35 g/cm²) and high leg BMD (1.41-1.5 g/cm²). For head BMD, there was no statistical difference among the different groups. Constructed ratios pointed out the site-specific adaptation of the skeleton: soccer player and runners had a higher leg ratio; bodybuilders, fighters, climbers and swimmers had a higher arm ratio; rugby players had a higher spine ratio. Head ratio was higher in non-weight bearing sports (rowing, swimming) than in weight bearing sports (rugby, team sports, soccer, fighting sports and bodybuilding). Thus the BMD and ratio differences among the 14 disciplines seem to be site-specific and related to the supposedly high and unusual strains created at certain sites during sport training by muscle stress and gravitational forces. Head ratio is closely related to the type of practice; its value could predict whether sport participants have developed the maximal peak bone mass they could achieve.

**Snow-Harter, Bouxsein, Lewis, Carter, & Marcus**, (1992) conducted an 8 month controlled exercise trial in 31 healthy college women who were randomly assigned to a control group or to progressive training in jogging or weight lifting. They measured the BMD of the spine (L2–L4) and right proximal femur using dual-energy x-ray absorptiometry, dynamic muscle strength using the 1-RM method, and endurance performance using the 1.5 mile walk/run field test. Lumbar BMD increased ($p<0.05$) in both runners (1.3 ± 1.6%) and weight trainers (1.2 ± 1.8%). These results did not differ from each other but were both significantly greater than results in control subjects, in whom bone mineral did not change. No measure of bone mineral at the proximal femur changed significantly in any group. These results demonstrate
that 8 months of supervised progressive training in either running or resistance exercise modestly increases lumbar spine mineral in young women.

Egan, Reilly, Giacomoni, Redmond, & Turner, (2006) have studied on training for and participation in impact-loading sports is associated with alterations in bone strength which are specific to anatomical site and type of strain. The effect of exercise on BMD depends on the type of activity engaged in. Sports with high impact loading seem to have a positive effect in promoting bone mineralization, whereas those with low impacts may have negative or no effects. The aims of the present study were to compare BMD and body composition measures among female participants in three distinctly different sports and investigate differences from sedentary control subjects. Participants were 30 Rugby Union football players, 20 netball players, 11 distance runners at club and university level and 25 sedentary controls. With the exception of three distance runners, all participants were eumenorrhoeic. BMD scans were performed for whole-body, left proximal femur, and lumbar spine (L1–L4) using DXA. The runners had a lower fat mass and percent body fat compared to the other sports participants and the controls. All sports groups had higher BMD values than had the controls. Density of bone in the upper body was most pronounced in the rugby football players and least pronounced in the runners. Positive effects were evident at all sites for the rugby players. There were significant correlations between BMD and fat-free soft tissue mass, BMD and body mass, and BMD and training volume. It is concluded that sports participation has positive effects on BMD. The effects are site-specific and depend on the loading characteristics of the sport.

Calbet, Dorado, Diaz-Herrera, & Rodriguez-Rodriguez, (2001) examined the effect that long-term football (soccer) participation may have on areal BMD and
BMC in male football players. 33 recreational male football players active in football for the last 12 years and 19 non-active subjects participated in study. The football players showed 8% greater total lean mass (P<0.001), 13% greater whole-body BMC (P<0.001), and 5 units lower percentage body fat (P<0.001) than control subjects. Lumbar spine (L2–L4) BMC and BMD were 13% and 10% higher, respectively, in the football players than in the control subjects (P<0.05). Furthermore, football players displayed higher femoral neck BMC (24%, 18%, 23%, and 24% for the femoral neck, intertrochanteric, greater trochanter, and Ward’s triangle subregions, respectively, P<0.05) and BMD (21%, 19%, 21%, and 27%, respectively, P<0.05) than controls. BMC in the whole leg was 16-17% greater in the football players, mainly because of enhanced BMD (9–10%) but also because of bone hypertrophy, since the area occupied by the osseous pixels was 7% higher (867 ± 63 cm$^2$ vs 814±26 cm$^2$, P<0.05). Leg muscle mass was 11% higher in the football players than in the control subjects (20,635±2.073 g vs 18,331±2.301g, P<0.001). No differences were found between the legs in either groups for BMC, BMD, and muscle mass. Left leg muscle mass was correlated with femoral neck BMC and BMD (P<0.001), as well as with lumbar spine (L2–L4) BMC and BMD (P<0.001). In conclusion, long-term football participation, starting at prepubertal age, is associated with markedly increased BMC and BMD at the femoral neck and lumbar spine regions.

Tsuzuku, Shimokata, Ikegami, Yabe, & Wasnich, (2001) investigated the effect of high-intensity and low-intensity resistance training upon bone mineral density (BMD) by comparing the BMD of young male power lifters, recreational trainees and controls (all, n=5). Lumbar spine (L2-L4), proximal femur, and whole body BMDs were measured using DXA. The high-intensity group showed a significantly greater BMD when the whole body and trochanter regions were
measured than the low-intensity and control group. The BMD of the lumbar spine, femoral neck, and Ward's triangle was greater in the high-intensity group compared with the control group. There was no significant BMD difference between the low-intensity and control group except at the trochanter region. These results suggest that high-intensity resistance training is effective for increasing BMD, but low-intensity resistance training is not.

**Tsuzuku, Ikegami, & Yabe**, (1998) have investigated the effects of high-intensity resistance training on BMD and its relationship to strength. Lumbar spine (L2-L4), proximal femur, and whole body BMD were measured in 10 male powerlifters and 11 controls using DXA. There were significant differences in lumbar spine and whole body BMD between powerlifters and controls, but not in proximal femur BMD. A significant correlation was found between lumbar spine BMD and powerlifting performance. These results suggest that high-intensity resistance training is effective in increasing the lumbar spine and whole body BMD.

**Sherk, Bemben. M, & Bemben. D**, (2010) compared total body, lumbar spine, proximal femur, and forearm areal BMD and tibia and forearm bone quality in 15 male rock climbers (RC), 16 resistances trained (RT), and 16 untrained controls (CTR). Total body, anteroposterior (AP) lumbar spine, proximal femur, and forearm aBMD and body composition were measured using DXA. Volumetric BMD (vBMD), bone content, bone area, and muscle cross-sectional area (MCSA) of the tibia and forearm were measured using pQCT (peripheral quantitative computed tomography). Lumbar spine and femoral neck aBMD were significantly (p<0.05) greater in RT compared to both RC and CTR. RC had significantly (p<0.05) lower aBMD at the 33% radius site than CTR. Forearm MCSA was significantly (p<0.05) lower in CTR.
than in the other groups. No significant differences were seen between groups for vBMD or bone area of the tibia and forearm. In conclusion, resistance-trained men had higher bone density at the central skeletal sites than rock climbers; however, bone quality variables of the peripheral limbs were similar in rock climber and resistance trained groups. In conclusion, resistance trained men had higher bone density at the central skeletal sites than rock climbers; however bone quality variables of the peripheral limbs were similar in rock climber and resistance trained groups.

Duncan et al. (2002) investigated the influence of different exercise types and differences in anatomical distribution of mechanical loading patterns on bone mineral density (BMD) in elite female cyclists, runners, swimmers, triathletes, and controls (all, \(n=15\)). Associations between leg strength and BMD were also examined. Areal BMD (g/cm\(^2\)) was assessed by DXA (total body (TB), lumbar spine (LS), femoral neck (FN), legs, and arms). Right knee flexion and extension strength was measured using a Cybex Norm isokinetic dynamometer at 60°·s\(^{-1}\). This results showed runners had significantly higher unadjusted TB, LS, FN, and leg BMD than controls (\(P<0.05\)); higher TB, FN, and leg BMD than swimmers (\(P<0.05\)); and greater leg BMD than cyclists (\(P<0.05\)). Absolute knee extension strength was significantly (\(P<0.01\)) correlated (0.33<\(r<0.44\)) with TB, FN, LS, and leg BMD for all groups combined. Weaker but still significant correlations (0.28<\(r<0.33\)) existed for normalized (per leg lean tissue mass) knee extension strength and all BMD sites, except FN BMD. There were no significant correlations between absolute or normalized knee flexion strength and any of the BMD variables. Absolute knee extension strength was entered as the second independent predictor for LS and leg BMD in stepwise multiple linear regression analysis, accounting for increments of 4% and 12%, respectively, in total explained variation. In conclusion running, a weight bearing exercise, is associated
with larger site-specific BMD than swimming or cycling, that the generalized anatomical distribution of loads in triathlon appears not to significantly enhance total body BMD status, and that knee extension strength is only a weak correlate and independent predictor of BMD in adolescent females.

**Bennell et al.** (1997) performed a one year longitudinal cohort study comparing bone mass and bone turnover in elite and sub-elite track and field athletes and less active controls. The cohort comprised 50 power athletes (sprinters, jumpers, hurdlers, multi-event athletes; 23 women, 27 men), 61 endurance athletes (middle-distance runners, distance runners; 30 women, 31 men), and 55 non-athlete controls (28 women, 27 men) aged 17-26 years. Total BMC, BMD, and soft tissue composition were measured by DXA. Baseline results showed that power athletes had higher regional BMD at lower limb, lumbar spine, and upper limb sites compared with controls (p<0.05). Endurance athletes had higher BMD than controls in lower limb sites only (p<0.05). Maximal differences in BMD between athletes and controls were noted at sites loaded by exercise. Male and female power athletes had greater bone density at the lumbar spine than endurance athletes. Over the one year, both athletes and controls showed modest but significant increases in total body BMC and femur BMD (p<0.001). Changes in bone density were independent of exercise status except at the lumbar spine. At this site, power athletes gained significantly more bone density than the other groups. Levels of bone formation were not elevated in athletes and levels of bone turnover were not predictive of subsequent changes in bone mass. Our results provide further support for the concept that bone response to mechanical loading depends upon the bone site and the mode of exercise.

**Quintas, Ortega, López-Sobaler, Garrido, & Requejo,** (2003) have studied on the influence of dietetic and anthropometric data, as well as the sport practiced, on
the bone density of different groups of sportswomen. 74 women who practiced different sports (15 skiers, 26 basketball players and 33 ballet dancers), and compared to those of 90 women who led sedentary lifestyles participated in this study. Results showed the sportswomen had higher bone mineral contents and bone densities than controls. However, the dancers showed similar spinal and hip values as those of controls, and lower forearm values. Low body weight and body mass index, and insufficient energy intake–characteristic of the dancers–were associated with poorer bone mineralization status. Increased energy, protein, vitamin D, calcium, zinc and magnesium intakes were associated with greater bone density and mineral content at different sites. In conclusions, the worst bone density status was that of the dancers, who, as a group, displayed characteristics that have negative impacts in this respect (low energy intakes and low body weight). Dancers should therefore take steps to avoid suffering fractures and skeletomuscular lesions which could negatively influence their health and physical performance. The greater consumption of milk products and calcium and better Ca/P ratio seen in the dancers could help this group to avoid bone deterioration.

**Nordström, A., Olsson, T., & Nordström, P.,** (2005) investigated the effect of training and detraining on bone mineral density of both weight-bearing and non-weight-bearing bone in a cohort of young males who participated in 43 adolescent healthy ice hockey players and 25 control subjects were included in this longitudinal study. BMD of the arms, the dominant and non-dominant humerus, dominant and non-dominant femur, and the right femoral neck, total hip, and bone area of the femur, humerus and hip were measured at baseline and again after 30 and 70 months using DXA. From baseline to the first follow-up, athletes gained significantly more BMD in the femoral neck (0.07 versus 0.03 g/cm²) and arms (0.09 versus 0.06 g/cm²)
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compared with the controls (P<0.04 for both). Between the first and the second follow-up, 21 ice hockey players stopped their active sports career. These men lost significantly more BMD at the femoral neck (0.02 versus 0.10 g/cm², P<0.001), total hip (0.05 versus 0.09, P<0.04), dominant (0.02 versus 0.03 g/cm², P<0.009) and non-dominant humerus (0.03 versus 0.01 g/cm², P<0.03) than the still active 22 ice hockey players. At the second follow-up examination, at 22 years of age, the former ice hockey players still had significantly higher BMD at the non-dominant humerus than the controls (P<0.01). During the total study period, the still 22 active athletes gained significantly more BMD compared with the controls at the femoral neck (0.09 g/cm²; P<0.008), total hip (0.05 g/cm², P<0.04) and arms (0.07 g/cm²; P<0.01). No differences were seen in bone areas when comparing the different groups. In conclusion, training associated with ice hockey is related to continuous accumulation of BMD after puberty in males. Reduced activity is followed by BMD loss within 3 years of cessation of sports career at predominantly weight-bearing sites. The effects are confined to bone density and not bone size.

Fredericson et al. (2007) have investigated the association of elite male (20–30 years) soccer playing and long-distance running with total and regional BMD, on soccer players, long-distance runners and sedentary controls and controls (all, n=15). BMD of the lumbar spine (L1–L4), right hip, right leg and total body were assessed by DXA, and a scan of the right calcaneus was performed with a peripheral instantaneous x-ray imaging bone densitometer. Results showed after adjustment for age, weight and percentage body fat, soccer players had significantly higher whole body, spine, right hip, right leg and calcaneal BMD than controls (p<0.008, p<0.041, p<0.001, p<0.019, p<0.001, respectively) and significantly higher right hip and spine BMD than runners (p<0.012 and p<0.009, respectively). Runners had higher
calcaneal BMD than controls (p<0.002). 40% of the runners had T-scores of the lumbar spine between 21 and 22.5. Controls were similar: 34% had T-scores below 21 (including 7% with T-scores lower than 22.5). In conclusions, playing soccer is associated with higher BMD of the skeleton at all sites measured. Running is associated with higher BMD at directly loaded sites (the calcaneus) but not at relatively unloaded sites (the spine). Specific loading conditions, seen in ball sports or in running, play a pivotal role in skeletal adaptation. The importance of including an appropriate control group in clinical studies is underlined.

Andreoli et al. (2001) have studied on the effects of different high-intensity activities on BMD in highly trained athletes. 62 male subjects aged 18–25 years participated in the study. The sample included 21 judo, 14 karate, and 24 water polo athletes who all competed at national and international level. 12 age-matched nonathletic individuals served as the control group. Results showed Total BMD of control was significantly lower (mean ± SD: 1.27±0.06 g/cm$^2$, $P<0.05$) than either judo or karate athletes (total BMD judo (1.4±0.06 g/cm$^2$) and total BMD karate (1.36±0.08 g/cm$^2$)) but not different from the water polo athletes (total BMDW (1.31±0.09 g/cm$^2$)). In conclusions study has shown that athletes, especially those engaged in high-impact sports, have significantly higher total BMD than controls. These results suggest that the type of sport activity may be an important factor in achieving a high peak bone mass and reducing osteoporosis risk.

Hinrichs, Chae, Lehmann, Allolio, & Platen, (2010) assessed BMD of the lumbar spine and the proximal femur in male and female athletes performing different high level sports, in unspecifically trained sport students and in untrained subjects. BMD of lumbar spine and proximal femur were measured by DXA in 209 female and 173 male subjects aged 17-30 years (37 runners (R), 16 cyclists (C), 22 triathletes
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(TRI), 62 team sport athletes (TS), 45 combat/power athletes (P), 13 ballet dancers (BL), 126 sport students, 61 untrained controls (UT)). Results of this study showed highest BMD values were found in P and TS. Lowest values were found in UT, BL and endurance trained athletes (R/C/TRI). In Conclusions, BMD is probably dependent on the specific mechanical demands of different sports.

Bone Mineral Density and non-weight bearing sports

Taaffe and Marcus (1999) have examined the role of long-term swimming exercise on regional and total body BMD in 11 elite males' collegiate swimmers and non athletic controls. They measured BMD of the lumbar spine (L2-L4), proximal femur (femoral neck, trochanter and WARD's triangle), whole body and various sub-region of body by DXA. The results showed that there was no significant difference between groups for regional or total body BMD. In stepwise multiple regression analysis, body weight was a consistent independent predictor of regional and total body BMD. They recommended that long term swimming is not an osteogenic mode of training in college-age males.

Olmedillas, González-Agüero, Moreno, Casajus, & Vicente-Rodríguez, (2011) have studied to describe bone status and analyze bone mass in adolescent cyclists. 22 Male road cyclists who had been training for (2-7 years) were compared to 22 age-matched controls involved in recreational sports activities. Subjects were divided in 2 groups based on age: adolescents under 17 yrs (11 cyclists; 13 controls) and over 17 yrs (11 cyclists; 9 controls). Peak oxygen uptake (Vo2max) was measured on a cycloergometer. Whole body, lumbar spine, and hip BMC, BMD and bone area were assessed using DXA. Volumetric BMD (vBMD) and bone mineral apparent density (BMAD) were also estimated. Results showed the BMC of cyclists
was lower for the whole body, pelvis, femoral neck and legs; BMD for the pelvis, hip, legs and whole body and legs bone area was lower but higher in the hip area (all, P<0.05) after adjusting by lean mass and height. The BMC of young cyclists was 10% lower in the leg and 8% higher in the hip area than young controls (P<0.05). The BMC of cyclists over 17 yrs was 26.5%, 15.8% and 14.4% lower BMC at the pelvis, femoral neck and legs respectively while the BMD was 8.9% to 24.5% lower for the whole body, pelvis, total hip, trochanter, intertrochanter, femoral neck and legs and 17.1% lower the vBMD at the femoral neck (all, P<0.05). In conclusion, Cycling performed throughout adolescence may negatively affect bone health, then compromising the acquisition of peak bone mass.

**Bone Mineral Density and Physical activity**

Madsen, Schaadt, Bliddal, Egsmose, & Sylvest, (1993) studied on the relationship of quadriceps strength to site-specific BMD of the proximal tibia and to BMD of the distal forearm in 66 healthy women (21–78 years), BMD was measured by dual-photon absorptiometry. Isometric and isokinetic strength of the quadriceps was measured using an isokinetic dynamometer (Cybex II). Highly significant correlations between BMD of the proximal tibia and quadriceps strength were found ($R_S$ from 0.79-0.84, $p<0.001$). Also, BMD of the distal forearm was correlated with quadriceps strength ($R_S$ from 0.59-0.62, $p<0.001$). Quadriceps strength was a better predictor of tibial BMD than age, body height, or weight. However, age, height, and weight were more predictive of forearm BMD than quadriceps strength. When studying the pre- and postmenopausal women separately, quadriceps strength was correlated with BMD of the proximal tibia but not to forearm BMD. In conclusion, the study provides support for a site-specific relationship between muscle and bone.
Nilsson, Ohlsson, Sundh, Mellström, & Lorentzon, (2010) have investigated whether present (type and amount) and previous duration of physical activity were associated with trabecular microstructure and cortical cross sectional area (CSA) in weight-bearing bone in 829 Swedish young males. They were assessed several microstructural trabecular and cortical traits with high-resolution three-dimensional peripheral quantitative computed tomography at distal tibia and radius. A standardized questionnaire was used to collect information about amount, duration, and type of physical activity. The results showed men with the highest physical activity strain score had higher tibial trabecular bone volume fraction (13.9%) and trabecular number (12.7%) than men with the lowest strain score (P< 0.001). Men in the group with the longest duration of physical activity had higher tibial cortical CSA (16.1%) than the sedentary men (P<0.001). Inclusion of all physical activity variables in a linear regression model revealed that strain score independently predicted trabecular bone volume fraction, and trabecular number (P<0.001) and that duration of previous physical activity independently predicted cortical CSA (P<0.001) of the tibia. In conclusions, the degree of mechanical loading due to type of physical activity was predominantly associated with trabecular microstructure, whereas duration of previous physical activity was mainly related to parameters reflecting cortical bone size in weight-bearing bone.

Nordström, Pettersson, & Lorentzon (1998) conducted a study to evaluate the influence of different types of weight-bearing physical activity, muscle strength, and puberty on BMD and bone area in 12 adolescent badminton players 28 ice hockey players and 24 controls adolescent boys. The groups were matched for age, height, and pubertal stage. BMD, BMC and the bone area of the total body, lumbar spine, hip, femur and tibia diaphyses, distal femur, proximal tibia, and humerus were measured.
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using DXA. When adjusting for the difference in body weight between the groups, the badminton players were found to have significantly higher BMD (p < 0.05) of the trochanter and distal femur compared with the ice hockey players despite a significantly lower weekly average training. The badminton players had higher BMD compared with the control group at all weight-bearing BMD sites, except at the diaphyses of the femur and tibia and lumbar spine. The independent predictors of bone density were estimated by adjusting BMC for the bone area in a multivariate analysis among all subjects (n=64). Accordingly, the bone density of all sites except the spine was significantly related to muscle strength and height, and the bone density of the total body, neck, trochanter, distal femur, and proximal tibia was significantly related to type of physical activity (b=0.09–0.33, p<0.05). The bone area values at different sites were strongly related to muscle strength and height and less strongly related to the type of physical activity and pubertal stage. In conclusion, it seems that during late puberty in adolescent boys the type of weight-bearing physical activity is an important determinant of bone density, while the bone area is largely determined by parameters related to body size. The higher BMD at weight-bearing sites in badminton players compared with ice hockey players, despite significantly less average weekly training, indicates that physical activity including jumps in unusual directions has a great osteogenic potential.

Pettersson, Nordström, Alfredson, Henriksson-Larsen, & Lorentzon, (2000) investigated the influence of two different types of weight-bearing activity, muscle strength, and body composition on BMD, BMC and bone area in three different groups’ of late adolescent girls. 10 competitive rope-skipping females, 15 soccer players and 25 controls participated in this study. The groups were matched for age, height, and weight. BMD (g/cm²), BMC (g), and bone area (cm²)) of the
The total body, lumbar spine, hip, total femur, distal femur, diaphyses of femur and tibia, proximal tibia, and humerus were measured using DXA. Bone density was also assessed in the radial forearm site of the dominant limb in the rope skippers and in 10 matched controls. The rope skippers had 22% higher BMD at the ultradistal site (P<0.01). Both high-activity groups had significantly higher BMD (P<0.05) at most loaded sites compared with the control group. When adjusting for differences in lean mass and starting age of sport-specific training between the activity groups, the rope-skipping group had a higher BMD of the total body, lumbar spine, and right humerus compared with the soccer group. They also had a significantly higher bone area of the total body, total femur, and the proximal femur than both other groups, and a significantly higher bone area of the tibia diaphysis, compared with the soccer group. In a multivariate analysis among all subjects (n=50), all BMD sites, except the femur diaphysis, distal femur, and proximal tibia, were significantly related to type of physical activity (beta=0.25-0.43, P<0.05). The bone area values at different sites were strongly related to muscle strength and parameters related to body size (height, weight, lean mass, fat mass, and BMI). In conclusion, it appears that in late adolescent women, weight-bearing activities are an important determinant for bone density, and high impact activities such as jumping also seem to be associated with a modification of the bone geometry (hence, the bone width) at the loaded sites.

Vicente-Rodriguez, Dorado, Perez-Gomez, Gonzalez-Henriquez, & Calbet, (2004) evaluated the effect of physical activity on the BMC and BMD in 51 girls (24 handballers and 27 inactive control group). Bone mass and areal density was measured by DXA. The maximal leg extension isometric force in the squat position with knees bent at 90° and the peak force, mean power, and height jumped during vertical squat jump were assessed with a force plate. Additionally, 30-m run (running
speed) and 300-m run (anaerobic capacity) tests were also performed. Maximal aerobic capacity was estimated using the 20-m shuttle-run tests. Compared to the controls, handballers attained better results in the physical fitness tests and had a 6% and 11% higher total body and right upper extremity lean mass (all, \( P < 0.05 \)). The handballers showed enhanced BMC and BMD in the lumbar spine, pelvic region, and lower extremity (all, \( P < 0.05 \)). They also showed greater BMC in the whole body and enhanced BMD in the right upper extremity and femoral neck than the control subjects (all, \( P < 0.05 \)). As expected, total lean mass strongly correlated with total and regional BMC and BMD (\( r = 0.79–0.91 \ P < 0.001 \)). Interestingly, 30-m running speed correlated with BMC and BMD variables (\( r = 0.59–0.67 \) and \( r = 0.60–0.70 \), respectively; all, \( P < 0.001 \)). Multiple regression analysis showed that the 30-m running speed test, combined with the height and body mass, has also predictive value for whole-body BMC and BMD (\( r = 0.93 \) and \( r = 0.90 \), \( P < 0.001 \)). In conclusion, handball participation is associated with improved physical fitness, increased lean and bone masses and enhanced axial and appendicular BMD in young girls. The combination of anthropometric and fitness-related variables may be used to detect girls with potentially reduced bone mass.

*Sööt, Jürimäe, T., Jürimäe, J., Gapeyeva, & Pääsuke*, (2005) examined knee extensor muscle isometric, isokinetic, and isoinertial strength values in women with different physical activity and body composition patterns are related to leg BMD and BMC values. A total of 129 women aged 17–40 participated in this study and divided into four groups: 33 strength-trained, 32 endurance-trained, 41 normal weight sedentary and 23 overweight sedentary women. BMD and BMC for both legs (LBMD and LBMC, respectively) and for the dominant leg alone (DLBMC), body fat percentage and LBM, maximal knee extension isometric (ISOM) and isokinetic
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(ISOK) strength at the angular velocity of 60deg·s\(^{-1}\), and isoinertial leg explosive strengths (countermovement jump CMJ) were measured. In endurance trained women, LBMD was dependent on BMI (33.7% of the variance, \(R^2=100\)), and in the physically active group and the total group with LBM (14.6% and 15.6%, respectively). In the overweight group, LBMD was dependent on ISOK strength (21.7% of the variance, \(R^2=100\)). In the sedentary and total groups, ISOM strength was more important (10.3% and 5.0%, respectively); in the strength-trained group, body weight influenced LBMC, accounting for 71.6% of the variance (\(R^2=100\)). In the endurance-trained women, height influenced LMBC (37.9%, \(R^2=100\)). In sedentary and overweight women, LBM accounted for 52.1% and 61.4% of the total variance in LBMC. In these groups, ISOM strength accounted for 15.3% and 25.9% of the variance in LBMC. In overweight women, ISOM and ISOK strength together influenced LBMC highly (64.8% of the variance, \(R^2=100\)). In the sedentary group, the influence of LBM on LBMC was higher than in the active group (82.1% and 50.5% of the variance, respectively). In the total group, LBM influenced LBMC, accounting for 54.5% of the variance (\(R^2=100\)). ISOM strength (22.7%) alone or in combination with ISOK strength (35.8%) and CMJ (41.7%) (\(R^2=100\)) in LBMC in the sedentary group explained the variance. In the total group, ISOM strength alone (13.2%) or in combination with CMJ (17.1%) influenced LBMC (\(R^2=100\)). The results suggested muscle strength and anthropometrical parameters were associated with LBMD; LBM and ISOM strength had a significant relationship with DLBMC and LBMC only in nonathletic women; and strength measured with different regimens highly influenced LBMC compared with LBMD, especially in the sedentary groups.

Hara et al, (2001) have studied on, 91 healthy premenopausal women (20-39 years) and investigated to the effect of physical activities during their teenage years.
on their current BMD. They measured whole-body BMD (WBMD), lumbar BMD (LBMD), and radial BMD (RBMD) with DXA and used a questionnaire, about physical activities during junior and senior high school and at present and about their current nutritional status and past and current milk intake. After adjusting for age, BMI, current total calorie and calcium (Ca) intake, and milk intake when they were teenagers and at present, and determined that subjects who exercised during extracurricular activities at each of the three periods (during junior and senior high school and at present) had significantly higher WBMD and LBMD (P<0.01) than did those who did not exercise at those times. Subjects who played high-impact sports at each period had significantly higher WBMD and LBMD than did subjects who played low-impact sports (P<0.05). Subjects who had exercised regularly from their teenage years to the present had significantly higher BMD at all sites than BMD in other subjects after adjusting for the potential confounders described above (P<0.05). The data suggested that continuous exercise beginning in junior high school, especially high-impact sports, may be associated with greater current bone mass. It is important to incorporate adequate exercise beginning in the teenage years to lower one's future risk for osteoporosis.

*Pettersson, Nordström, & Lorentzon (1999)* investigated differences in bone mass at different sites between young adults subjected to a high physical activity and a group of young adults with a low level of physical activity. And compared the relationship among bone mass, muscle strength, and body constitution in 20 ice hockey players and the age, height, and weight matched control group. Areal BMD was measured in total body, head, humerus, spine, pelvis, femur, femoral neck, Ward’s triangle, trochanter, femur diaphysis, proximal tibia, and tibia diaphysis using DXA. BMD was significantly higher in the total body (8.1%), humerus (11.4%),
spine (12.7%), pelvis (12.4%), femoral neck (10.3%), femur (7.4%), proximal tibia (9.8%), and tibia diaphysis (7.5%) in the high activity group. Fat mass was significantly lower in the high activity group (18.7%). In the reference group, there was a general strong independent relationship between muscle strength of the thigh and all BMD sites, except for the head, tibia diaphysis, and proximal tibia. Furthermore, in the same group, BMI independently predicted pelvis BMD. On the contrary, in the high activity group, muscle strength did not predict any BMD site at all. In the same group, body constitutional parameters (weight, height, and fat mass) independently predicted pelvis BMD, and BMI was shown to be an independent predictor of humerus BMD. The differences in BMD between the groups seem to be site-specific and may be related with the type and amount of loading during off season training and preferentially during ice hockey. High physical activity seems to weaken the association between BMD and muscle strength. Hence, impact forces may be of greater importance in regulating bone mass than muscle strength in itself in highly trained sportspersons.

Snow-Harter et al. (1990) accepted that physical activity is useful to bone. However, the specific relationships of muscle strength to BMD are poorly understood. They examined strength and BMD in 59 women (18-31 years). Mineral density of the right proximal femur (hip) and spine (L2-L4) was evaluated by DXA. BMD at the midradius was measured by single-photon absorptiometry. Dynamic strength (1RM) was measured for the following muscle groups: back, elbow flexors (biceps), leg extensors (quadriceps), and the hip flexors, extensors, adductors, and abductors. Isometric grip strength was assessed by dynamometry. Mineral density at the hip correlated independently with muscle strength and body weight, but not with age. Specifically, femoral neck BMD was significantly associated with back strength and
weight, whereas trochanter and overall hip mineral density were significantly related to biceps, back, and hip adductor strength. Hip mineral density was not related to strength of the quadriceps group or to that of the hip flexors, extensors, or abductors. In addition, muscle strength was an independent predictor of lumbar spine and midradius mineral density. In stepwise multiple regression analysis, biceps strength proved the most robust predictor of hip BMD and grip strength best predicted bone density at the lumbar spine and radius. They conclude that muscle strength is an independent predictor of bone mineral density, accounting for 15-20% of the total variance in bone density of young women. In addition, it appears that muscle groups with attachments that are distant from the spine and hip may exert an important influence on BMD at these sites.

Pocock et al. (1989) investigated the mechanism of the age-related decline in proximal femoral BMD; they examined the relative importance of muscle strength, physical fitness, and BMI in addition to age in the determination of proximal femoral BMD in 73 healthy female volunteers (20–75 years). Muscle strength was an independent predictor of BMD at all three sites in the proximal femur as well as in the lumbar spine and forearm; proximal femur BMD was also predicted by physical fitness. BMI was a positive predictor of bone mass at all sites. In the proximal femur, age was not an independent predictor of BMD at any site. In postmenopausal women muscle strength was a significant predictor of bone mass in the femur and forearm, but not in the spine. However, BMI remained predictive of bone mineral at all sites. Muscle strength, physical fitness, and weight appear to exert independent effects upon bone mass.
Anthropometric data, Body composition and bone mineral Density

Rector, Rogers, Ruebel, Widzer, & Hinton, (2009) determined the effects of long-term running, cycling, and resistance training on whole-body and regional BMD, adjusting for body weight and composition. 19 Cyclists, 10 runners and 13 resistance trained men (19–45 years) participated in this cross-sectional study. Whole body and regional BMD and body composition were assessed using DXA. Bone turnover markers and hormones were measured in fasting serum samples. Unadjusted BMD at all sites was significantly greater in the resistance trained compared with cyclists and runners. After adjusting for LBM, runners had significantly greater spine BMD than cyclists. Subjects’ LBM was a significant predictor of BMD in resistance trained and cyclists but not in runners, suggesting that high-impact activity may override the benefits of LBM on BMD. Current bone loading was positively associated with serum osteocalcin concentrations (r=0.480, p<0.002). In conclusion, the results of the present study reveal that long-term running and resistance training increase BMD compared with cycling. However, it seems that high-impact activities, such as running, have a greater positive effect on BMD than resistance training.

Chumlea, Wisemandle, Guo, & Siervogel, (2002) investigated the relation between bicristal, elbow, knee, biacromial, and wrist breadths and measures of total body fat (TBF), fat-free mass (FFM), BMC, and BMD from DXA on 224 white men and 277 white women (23–65 years). Results of this study illustrated that Frame-size measures were significantly and positively related with all body-composition and bone mineral measures in bivariate analysis. In both men and women, the significant models explained more of the variance in measures of TBF (r²=0.51 and 0.66, respectively) and FFM (r²=0.35 and 0.39, respectively) than in measures of BMC (r²=0.18 and 0.23, respectively) and BMD (r²=0.08 and 0.18, respectively). Bicristal,
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knee, and wrist breadths were associated with TBF, and biacromial, knee, and wrist breadths were positively associated with FFM. Biacromial breadth was positively related with BMC and BMD. In conclusion, frame size was more closely associated with TBF and FFM than with BMC and BMD. The relationship between frame size and body composition seems to be more structural than substantive. The relations between frame size and BMC and BMD are weak and apparently not related to body composition.

Jürimäe, T., Sööt, & Jürimäe, J. (2005) have studied on relationships of anthropometrical parameters, somatotype and body composition parameters with BMC and BMD, total body, the dominant arm distal radius, antero-posterior lumbar spine L2-L4, femoral neck) in 33 strength and 32 endurance trained and 41 sedentary normal-weight and 23 overweight young females. Their body height and mass were measured and BMI calculated. 9 skinfolds, 13 girths, 8 lengths and 8 breadths/lengths were measured. Whole body fat percentage, fat mass, LBM, BMC and BMD were measured by DXA. In all groups, BMC is highly dependent on the body mass (31.5–81.2%, R2=100). In the endurance-trained females, BMD is dependent on LBM, especially in both weight-bearing sites (66.2% in L2–L4 and 35.3% in the femoral neck). LBM explained 77.0% of the total variance of BMC in this group. BMC in the strength-trained group is dependent on the lower body anthropometrical parameters-thigh skinfold (18.2%), calf girth (25.2%), trochanterion length (24.1%) and sitting height (51.4%). From the endurance-trained group, BMC is dependent on hip girth (75.2%) or in combination with ankle girth (81.2%). From the length parameters, trochanterion is the most important (55.8%) and from breadths/lengths, sitting height (57.1%). In the normal-weight females, BMC is dependent on the calf girth (31.1%), trochanterion length (28.2%) and sitting height (29.8%). In the overweight group,
only chest girth (20.1%) and biacromial breadth/length (27.0%) had a relationship with BMC. From somatotype components, only ectomorphy explained BMD in the endurance-trained females in the femoral neck (21.3%) and in the lumbar spine (20.9%). They concluded that from the body composition parameters, LBM is a powerful predictor of BMC and BMD. From the anthropometrical parameters measured, lower body parameters are the most important. Somatotype components (ectomorphy) had a relationship with BMD only in the endurance-trained group. There are some differences that depend on the specific physical activity field. In the endurance-trained group, the anthropometry is more important than in the strength-trained group.

The purpose of the study conducted by Thorsen, Nordström, Lorentzon, & Dahlén, (1999) was to evaluate the relationship between bone mass, body constitution, muscle strength in 47 Caucasian male adolescents (mean age, 16.9 year). BMD and body composition were measured by DXA, muscle strength of thigh using an isokinetic dynamometer. After multiple regression and principal component (PC) analysis, the so-called PC body size (weight, fat mass, lean body mass and muscle strength) was the most significant predictor of BMD (b=0.28–0.51, \( P<0.05–0.01 \)), followed by the so called PC physical activity (b=0.28–0.38, \( P<0.05–0.01 \), weight bearing locations). The present investigation confirms that BMD, body size, and muscle strength are closely associated and that the level of physical activity is a most important determinant of BMD.

Madsen, Adams, & Van Loan (1998) examined the association between body weight and composition, muscular strength, physical activity, and BMD and BMC of the total body and BMD of the lumbar spine (L2-L4) and femoral neck via DXA in 60 eumenorrheic college-aged women. They divided into: low body weight athletes
involved in weight-bearing, collegiate sports, matched low body weight and sedentary and average body weight and sedentary (n=20 for all groups and matched for height, age, and age at menarche). The results of this study showed the athletes had significantly greater (P<0.05), total body BMD (1.164), L2-L4 BMD (1.24), femoral neck BMD (1.144) and total body BMC (2.44 kg) than the low body weight, sedentary (LWS) group, but were only greater than the average body weight sedentary group (AWS) for femoral neck BMD. Significant correlations were found between LBM and all BMD variables (P<0.001). A significant correlation (P<0.01) was found between fat mass and all BMD variables in the sedentary subjects alone (n=40), but with inclusion of the athletes (n=60), none of the correlations between fat mass and BMD were significant. Arm and leg strength isometric torque values corrected for muscle + bone cross-sectional area (M + B CSA) were not significantly different between the athletes and LWS group, but the athletes were greater (P<0.05) than the AWS group for both arm and leg strength/M + B CSA. No significant, site-specific correlations were found between strength/M + B and BMD. In summary, the athletes had significantly greater BMD, BMC, and LBM than the LWS group and, except for a greater femoral neck BMD, similar BMD, BMC, and LBM as the AWS group. These results suggest that LBM and weight-bearing exercise both enhance BMD in eumenorrheic young adult women.