Chapter Two

REVIEW OF LITERATURE
The present research work intended to explore the relationship of bone mineral density (BMD) among athletes with diverse loading patterns and non-athletes. The study further intended to assess the influence of muscular performance on BMD. Relevant information regarding the area of present exploration has been extensively obtained with the help of experts in exercise physiology, related books, journals, sport magazines, and newspapers. A brief account of the review of literature related to the study gathered from various sources is provided below.

Studies exploring association between load parameters and BMD

Penteado, et al. (2010) investigated food intake, body composition, and bone mass in well-trained young adult cyclists compared with those in sedentary controls. Four-day estimated diet records were used to study dietary intake in 31 cyclists and 28 sedentary controls (all male, 24yr old on average), together with maximal oxygen uptake, body composition, and bone mass measurements. The maximal oxygen uptake values were twice as high as those in the cyclists, whereas no significant difference in bone mass was observed between cyclists and controls. A total of 10 cyclists and 9 controls had low bone mass. Total-body lean mass and appendicular skeletal muscle mass were higher in cyclists, whereas percentage of body fat was lower compared with that of the controls. Energy and macro- and micronutrient intake was higher in the cyclists than in the controls. Energy consumption was considered adequate in the cyclists, whereas lipid and protein intake was
higher than the American College of Sports Medicine recommendation. Lipid consumption negatively correlated with bone mass in the athletes. Results of the study demonstrated that cycling was associated with greater aerobic conditioning and lean mass without significant association with bone mass compared with sedentary controls.

Nazarian, Khayambashi and Rahnama (2010) compared the bone mineral density (BMD) in dominant and non-dominant leg between professional soccer players and non-athlete subjects. Fifteen professional soccer players (mean±SD; age: 23.2±0.3 years, height: 174±1 cm, weight: 70.3±1.8 kg) and fourteen healthy non-athlete subjects (mean±SD; age: 22 years, height: 173±1.2 cm, weight: 61.6±2.4 kg) participated in the study. All soccer players and control group were free of any illness such as diabetes, hyperthyroidism, hyperparathyroidism, cardiovascular disease and were not taking any medication. The participants did not report use of any anti seizure drugs, alcohol and cortone consumption, neither smoking cigarette. The activity levels and dietary habits of all subjects were noted. BMD was measured by dual energy x-ray absorptiometry (DXA) at the femoral neck and femoral trochanter of dominant and non-dominant legs. Paired sample and independent t-test were used to analyze the data. Due to more frequent engagement of non-dominant leg in take off, landing and stance in shooting, BMD is higher than the other leg. Furthermore, it seemed that soccer leads to increase of BMD in non-dominant and dominant leg in soccer players, which may be beneficial in the prevention of osteoporosis.

Bone health later in life may rely on bone mass accumulation during growth. In fact, the risk of osteoporosis is affected by the peak bone mass attained. In general, before the age of 20, the bone mass accrual is mostly marked between 11 and 14 years of age in girls. It has been demonstrated that weight-bearing physical activities increase bone mass
acquisition. Rahnama, et. al. (2009) compared BMD of upper body and dominant and non-dominant leg in professional female handball, futsal players and non-athletes. Fifteen handball players (mean±SD, age: 23.6±3.1 years, height: 169.4±3.6 cm, weight: 62.9±5.7 kg) and 15 futsal players (mean±SD, age: 24.3±2.8 years, height: 161.1±4.4 cm, weight: 54.3±7 kg) and 15 healthy non-athlete females (mean±SD, age: 23.8±2 years, height: 160.9±7 cm, weight: 51.5±9.6 kg) were selected for the study. The level of activity and habits of all subjects were noted. BMD was measured by DXA at the lumbar spines and femoral neck, femoral trochanter of dominant and non-dominant legs. ANOVA was used for analysis of data. BMD values of upper body in futsal players were significantly higher than two other groups (handball players and non-athletes). BMDs of dominant leg in futsal players were significantly higher than other groups. BMDs of non-dominant leg in futsal players were significantly higher than other groups. It was concluded by the researchers that BMDs of all measured parts in futsal players were higher than the other two groups and differences of these values between handball players and non-athlete females were not significant.

Inomoto (2008) observed the amount of exercise of Japanese schoolchildren as recorded by pedometer. Schools are necessary venues to increase children's mobility, but home environments are hotbeds for lack of exercise on weekends and during holidays and vacations. This research measured the lumbar (L 2-4) BMD of 185 male and female primary schoolchildren using DXA method. Results showed significant partial correlations for measurements of boys' grip strength, boys' standing broad jump, and girls' grip strength, indicating the influence of mechanical stress. In a parallel study, lumbar (2-4)BMD measurements for high school athletic club members (14 and 10 sports for boys...
and girls respectively) were taken, and it was found that the lumbar (2-4) BMD (60 kg/weight) values were significantly higher than the control values for boys' boxing and weightlifting but significantly lower for boys' sumo. No significance was found in lumbar (2-4) BMD (50 kg/weight) among the different girls' sports. From both studies, it was concluded that with approximately 2 hours of moderate play and exercise daily, the bone density of children rises with increase of overall muscle quantity, resulting in higher athletic ability and overall physical strength.

Mudd, Fornetti and Pivarnik (2007) compared site-specific BMD among National Collegiate Athletic Association Division I varsity female athletes and to determine predictor variables of BMD measurements. All women varsity athletes were invited to participate in a cross-sectional study. Of 12 sports, complete data from 99 women (mean age = 20.2±1.3 years) representing gymnastics, softball, cross country, track, field hockey, soccer, crew, and swimming/diving were obtained. Each participant was weighed, measured, and questioned about her menstrual status. Using DXA, researchers measured total-body BMD and region-of-interest scores for lumbar spine, pelvis, and average leg (average from right and left leg measurements) BMD. Using analyses of covariance, investigators compared BMD measurements among sports at each site while controlling for menstrual status and mass, and performed a stepwise regression analysis to determine significant predictors of BMD at each site. Twenty-three athletes were oligomenorrheic or amenorrheic. Runners had the lowest total-body and site-specific BMD values for every site except average leg score when compared with gymnasts and softball players. Swimmers and divers had significantly lower average leg BMD than athletes in every other sport except runners and rowers. Regression analysis revealed only mass and sport as
significant predictors of total-body BMD. Runners and swimmers and divers demonstrated some deficits in site-specific BMD values when compared with athletes in other sports. It was concluded that, during treatment of a female varsity athlete, athletic trainers should consider her mass and sport type with regard to her bone health.

Vainionpaa (2007) conducted a 12-month population-based randomized controlled exercise intervention in 120 premenopausal women. The aim was to investigate the effect of impact exercise on bone mineral density, geometry and metabolism in healthy women with the intention of assessing the intensity and amount of impact loading with a novel accelerometer-based measurement device. Training effects on risk factors of osteoporotic fractures, physical performance and risk factors of cardiovascular diseases were also evaluated. The study demonstrated that 12 months of regular impact exercise favored bone formation, increased bone mineral density in weight-bearing bones, especially at the hip, and led to geometric adaptations by increasing periosteal circumference. Bone adaptations had a dose and intensity dependent relationship with measured impact loading. Changes in proximal femur were threshold dependent, indicating the importance of high impacts exceeding acceleration of 4g as an osteogenic stimulus. The number of impacts needed to achieve this stimulation was 60 per day. Impact exercise also had a favorable effect on physical performance and cardio respiratory risk factors by increasing maximal oxygen uptake, dynamic leg strength and decreasing low-density lipoproteins and waist circumference. Changes were dose-dependent with impact loading at wide intensity range. Bone adapts to impact loading through various mechanisms to ensure optimal bone strength. The number of impacts needed to achieve bone stimulation appeared to be 60 per
day, comparable to the same number of daily jumps. If done on a regular basis, impact exercise may be an efficient and safe way of preventing osteoporosis.

Magkos, et. al. (2007) examined whether skeletal adaptations to chronic non-weight-bearing exercise depend on the type of aquatic exercise (swimming or water polo) as well as on sex (men or women). A total of 43 water polo players, 26 swimmers, and 30 sedentary individuals, aged 17 to 34 years, were recruited (52 men, 47 women). Athletes participating in long-term water polo playing and swimming have substantially different total and regional BMD. The effect is not mediated by sex in water polo players; however, sex may mediate the differences between swimmers and controls. Whether the observed differences between athlete groups and sexes arise from different bone adaptations to activity or from other factors cannot be answered by the current data. Water polo playing may be preferable over swimming for maintaining bone health; both types of aquatic exercise at the elite level of participation, however, have unfavorable effects on the lower limb bones.

Elizabeth, et. al. (2006) compared BMD and body composition measures among female participants in three distinctly different sports and investigate differences from sedentary control subjects. Participants were club and university level Rugby Union football players, netball players, distance runners, and 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 (L1–4) using DXA. Fat mass, percent body fat and fat-free soft tissue mass were assessed from whole-body scans. Regional and segmental analysis was also carried out on whole-body BMD data using
standard procedures. 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 was concluded that sports participation has positive effects on BMD. The effects are site-specific and depend on the loading characteristics of the sport.

Stager, et. al. (2006) examined the prevalence of activities of daily living, as well as the impact of leisure time activities, on BMD in urban adolescent girls. Patients completed a 23-item physical activity questionnaire at baseline, recording time spent in various activities in the previous 7 days. In addition to leisure time activities, activities of daily life were also considered. Activities were characterized and scored by metabolic intensity and mechanical strain on bone. In this population of urban adolescent girls, activities of daily living were reported with a higher frequency than sports activities. Results indicated a positive association between the time spent in metabolically intense activities and bone mineral density. There also appears to be a threshold effect for the relationship between activities with the highest mechanical strain and bone mineral density.

James and Laura (2006) examined the effect of sports of varying skeletal loading on bone density in adolescent female athletes. Between-sport comparisons were made using a one-way analysis of covariance with age and body mass index as covariates and group BMD was compared to the World Health Organization's (WHO) normative values
for adult females. It was concluded that, participation in sports such as soccer or weight lifting with significant skeletal loading may enhance BMD in adolescent females.

Torstveit and Sundgot-Borgen (2005) compared BMD, investigate factors associated with BMD, and examine the prevalence of low BMD in athletes and non-athletic controls. The study included a questionnaire (part I), measurement of BMD (part II), and a clinical interview (part III). All Norwegian female athletes on national teams (n = 938) and an aged matched random sample of non-athletic controls (N=900) were invited to participate. The questionnaire was completed by 88% of athletes and 70% of controls. A random sample of these athletes (N=300) and controls (N=300) was invited to participate in parts II and III. All parts were completed by 186 athletes (62%) and 145 controls (48%). In the conclusion it was observed that female elite athletes have 3–20% higher BMD than non-athletic controls and HI sports athletes have 3–22% higher BMD compared with MI and LI sports athletes. Low BMD is two to three times more common in non-athletic premenopausal women than in elite athletes.

Yung, et al. (2005) designed a study to investigate bone properties using heel quantitative ultrasound (QUS) in young adults participating in various sports. A cross sectional study was performed on Chinese male students (N=55), aged 18–22 years. Subjects with previous fractures or suffering from any diseases known to affect bone metabolism or taking any medication with such an effect, were not included. The subjects were categorized according to their main sporting activities, including soccer (n = 15) (a high impact, weight bearing exercise), dancing (N=10) (a low impact, weight bearing exercise), and swimming (N=15) (non-weight bearing exercise). A sedentary group acted as controls (N=15). A reproducibility study of the velocity of sound (VOS) and the broad
band ultrasound attenuation (BUA) measurement was performed and analysed using the intra class correlation coefficient (ICC). Results of the study indicated that regular participation in weight bearing exercise in young people might be beneficial for accruing peak bone mass and optimizing bone structure.

Falk, et. al. (2004) examined bone properties, as measured by quantitative ultrasound, among female swimmers in comparison with control girls and women. Subjects included 61 swimmers and 71 controls aged 8.5 to 26.5 years. None of the swimmers was at the elite level and none had included resistance training in her schedule. Bone speed of sound (SOS) was measured bilaterally at the distal radius and the mid-tibia. Swimming appeared to be associated with higher bone SOS in the lower but not in the upper extremities. Further studies were felt essential to assess whether this difference reflects higher habitual activity among the swimmers or swimming specific mechanisms.

Maimoun, et. al. (2004) determined the effect on bone remodeling of physical activities that induce moderate external loading on the skeleton. Thirty-eight male athletes aged 18-39 years (cyclists, N=11; swimmers, N=13; tri athletes, N=14) and 10 age-matched sedentary controls aged 22-35 years participated in the study. The study combined measurement of BMD by DXA and bone turnover assessment from specific biochemical markers: serum bone-specific alkaline phosphatase, osteocalcin, urinary type I collagen C-telopeptide and calcium. Bone turnover differed in athletes compared with controls, suggesting that bone turnover may be sport-practice dependent. Despite some encouraging observations, it was not possible to show that changes in the bone remodeling process were sport-discipline dependent.
Kerry, et. al. (2003) implemented a high-impact, circuit-based, jumping intervention (10 minutes, 3 times a week) over 2 school years and compared changes in bone mineral content (BMC) over 20 months (2 school years) in 9.9±0.6 year old intervention girls (N=32) and controls (10.3±0.4 years, N=43). BMC for the total body, lumbar spine, proximal femur (and femoral neck and trochanteric sub regions), and lean and fat mass by DXA (Hologic QDR 4500), and height, sitting height, leg length, and weight at baseline and 20 months was measured. Tanner stage, general physical activity, and calcium intake was measured by a questionnaire. The researchers found three brief sessions of high-impact exercise per week implemented over 2 consecutive years within the elementary school curriculum brought about substantial bone mineral accrual advantage in pubertal girls.

Huang, et. al. (2003) investigated the effects of exercise mode on growing bone, 29 male Wistar rats (7 wk old) were randomly assigned to a running exercise group (N=9), a swimming exercise group (N=10), or a non exercise control group (N=10). During an 8-wk training session (20–60 min/day, 5 days/wk), the Run rats were trained at progressively increasing running speeds (12–22 m/min), and weights attached to the tail of the Swim rats were progressively increased from 0 to 2% of their body weight. The BMD of the proximal tibiae of the Run rats was significantly higher than in the Swim (P=0.05). Femoral wet weights of the two exercise groups were significantly higher than in the control group (P=0.05). Interestingly, the percent difference between the tissue wet weight and dry weight (water content ratio), which is related to bone mechanical properties, was significantly higher in the tibiae of the Swim rats and the femora of both exercise groups compared with controls (P=0.05). Extrinsic as well as intrinsic biomechanical material
properties were measured in a three point bending test. Bone mechanical properties of the tibiae and femora of rats in the Swim and Run groups were significantly greater than those in the control group ($P < 0.05$). In summary, different modes of exercise may benefit bone mechanical properties in different ways. The specific effects of swimming exercise (non-weight-bearing exercise) on bone required further study.

Langendonck, et al. (2003) examined whether participation in high-impact sports during adolescence and adulthood contributes to bone health in males aged 40 years. Data were analyzed on 154 Belgian men aged 13 years at study onset in 1969 and aged 40 years at the end of the 27-year follow-up. In a second analysis, subjects were divided into three groups according to their sports participation history: participation during adolescence and adulthood in high impact sports (HH; N=18), participation during adolescence in high-impact sports and during adulthood in nonimpact sports or no sports (HN; N=15), and participation during adolescence and adulthood in non impact sports or no sports (NN; N=14). Body mass and impact loading during adulthood were significant predictors of total body BMD and lumbar spine BMD. Analysis of variance revealed significant differences for lumbar spine BMD between the HH group and the HN and NN groups. Total body BMD was also higher in the HH group at age 40 years, but not significantly. Covariance analyses for total body BMD and lumbar spine BMD, with body mass and time spent participating in sports as covariates, confirmed these results. Continued participation in impact sports is beneficial for the skeletal health of males aged 40 years.

Creighton, et al. (2001) evaluated BMD and markers of bone turnover in female athletes (N= 41, age 20.7 yr) comparing three impact groups, high impact (High, basketball and volleyball, N= 14), medium impact (Med, soccer and track, N=13), and
nonimpact (N=7), with sedentary age-matched controls (N=7). BMD was assessed by DXA at the lumbar spine, femoral neck, Ward’s triangle, and trochanter; bone resorption estimated from urinary cross-linked N-telopeptides; and bone formation determined from serum osteocalcin. Results indicated that women who participate in impact sports such as volleyball and basketball had higher BMDs and bone formation values than female swimmers.

Platen, et. al. (2001) determined the influence of muscle strength, training specific and anthropometric parameters on BMD in male top athletes of different sports in comparison to untrained controls. BMD was measured by DXA in 173 males, aged 18 to 31 years. Of these, 104 were athletes (runners, N=21; cyclists, N=12; tri athletes, N=18), 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). Sport- and group-specific differences were found in anthropometric but not strength parameters. Marked sport- and group-specific differences were found for BMD at lumbar spine (LSP) and the femoral sites (FEM). Group-specific effects on BMD were clearest when calculating percent differences between BMD of athletes and UT: In group I (HA, TS, and STU), BMD at LSP and FEM were significantly (p<.01) higher compared to UT; in group II (R and TRI), BMD at FEM but not at LSP was higher compared to UT (p<.01); and in group III (C), no BMD value was significantly different from UT. Multiple regression analysis revealed lean body mass to be the strongest predictor for BMD at LSP and FEM. We conclude that mechanical loads have strong effects on bone adaptation. Sport-specific and body region-specific effects have to be taken into account for evaluation of osteogenic effects of exercise. Particularly dynamic
sports with short, high, and multidimensional loads have the strongest effects on bone formation, independent of training quantity.

Fernanda, et. al. (2001) compared BMD, body composition, hormonal profile, and bone biochemical markers of adolescent athletes active in sports involved in impact load sports with those participating in active load sports. Forty-five male Caucasian athletes aged 12-18 yr were divided into two groups according to type of skeleton loading, impact (N=18), or active (N=27). Twenty-four male Caucasian adolescents (12-18 yr) served as controls and only performed the activities included in their physical education classes. All subjects were assessed for bone mass, body composition, and bone age by DEXA. Serum calcium, phosphorus, bone-specific alkaline phosphatase, total testosterone, FSH, LH, urinary calcium to creatinine ratio, and urinary deoxypyridinoline crosslinks to creatinine ratio were measured. High-impact load exercises have a beneficial effect on bone mass in male adolescents. There is also a positive correlation of weight and body composition with BMD. However, further longitudinal studies are necessary to determine whether there is a delay in bone growth acquisition among adolescents involved in a non weight-bearing exercise regimen and its association with sex hormones.

Andreoli, et. al. (2001) investigated the effects of different high-intensity activities on BMD and appendicular muscle mass (AMM) in highly trained athletes. Sixty-two male subjects aged 18-25 yr participated in the study. The sample included judo (N=21), karate (N=14), and water polo (N=24) athletes who all competed at national and international level. Twelve age-matched nonathletic individuals served as the control group. All athletes exercised regularly for at least 3 h·d-1, 6 d·wk-1. Segmental, total BMD and AMM were measured with a DEXA (Lunar Corp., Madison, WI). DXA analysis also includes bone
mineral content and fat and lean masses. This cross-sectional study has shown that athletes, especially those engaged in high-impact sports, have significantly higher total BMD and AMM 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.

French, Fulkerson and Story (2000) evaluated the current state-of-the-science for interventions to increase bone mass gains in children and adolescents using weight-bearing physical activity or calcium supplementation. Increases in weight-bearing physical activity or calcium intake have positive effects on bone mass gains in children and adolescents. Researchers felt the need for further research to evaluate: (a) the long-term durability of these effects; (b) specific dose-response associations; (c) interactions between weight-bearing physical activity and calcium intake; and (d) interactions between pubertal development and weight-bearing physical activity or calcium intake on bone mass outcomes.

Kemper, et. al. (2000) monitored daily physical activity and fitness among a group of 182 males and females from age 13 to 29 years. At a mean age of 28 years, BMD was measured at three sites with DEXA: in the lumbar region (lumbar BMD), the femoral neck (hip BMD), and the distal radius (wrist BMD). Physical activity (PA) was estimated from a cross-check activity interview taking in consideration all daily physical activities during the last 3 months; PA was scored in two different ways: (1) metabolic physical activity score (METPA) by weighting the intensity (multiples of basic metabolic rate) and duration (minutes per week); and (2) mechanic physical activity score by weighting the peak strain (ground reaction forces as multiples of body mass) irrespective of frequency and duration of the physical activities. Physical fitness was measured with a neuro motor fitness test.
(composite of six strength, flexibility, and speed tests) and as cardiopulmonary fitness (maximal oxygen uptake). It was concluded that daily physical activity during adolescence and in the young adult period is significantly related to the BMD at the lumbar spine and femoral neck at age 28 of males and females. Only neuro motor fitness and not cardiopulmonary fitness during adolescence and young adulthood is related to the BMD of males and females at age 28 years.

Daly, Rich, and Klein (1997) compared ultrasound bone measurements, serum alkaline phosphatase, serum osteocalcin, and dietary calcium in highly active and normal healthy male children. Subjects were 33 elite and sub elite male gymnasts and 40 normoactive controls matched for age (9.4±1.1 years), height (133.9±5.9 cm), and weight (30.1±3.8 kg). Measurements of broadband ultrasound attenuation through the calcaneus and ultrasound velocity (m/s) through the calcaneus, distal radius, and proximal phalanx of the index finger were performed using a Contact Ultrasonic Bone Analyzer. These preliminary results suggested that the heavy musculoskeletal loading inherent in gymnastics training produces positive adaptive responses in the growing skeleton. Furthermore, ultrasound appears to provide a safe, noninvasive means of comparing the skeletal status of exercising and normal healthy children, whereas single samples of biochemical markers did not discriminate between the groups.

Bennell, et al. (1997) performed a 12 month 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 nonathletic controls (28 women, 27 men) aged 17-26
years. Total bone mineral content, regional BMD, and soft tissue composition were measured by DEXA. Bone turnover was assessed by serum osteocalcin (human immune radiometric assay) indicative of bone formation, and urinary pyridinium cross links (high-performance liquid chromatography) indicative of bone resorption. Questionnaires quantified menstrual, dietary and physical activity characteristics. 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.

BMD of the vertebral spine, appendicular skeleton and whole body was studied by Fiore, et. al. (1996) in male athletes who were chronically trained by different forms of skeletal loading. Eighteen subjects performed weight-bearing activity (canoeists, N=18), and 14 performed non-weight-bearing activity (cyclists, N=14). Twenty-eight age-matched male students served as non-athletic controls. The canoeists had significantly higher spine, pelvic and total body BMD than cyclists and controls. No intergroup difference was observed in the BMD of arms and legs despite the fact that physical activity of canoeists and cyclists were characterized by forceful muscular contractions. It is concluded that weight-bearing activity is essential to obtain beneficial skeletal effects on total and regional bone mass in young subjects.

In order to evaluate the effect of exercise on BMD of adolescent athletes, twenty-nine Chinese male adolescent athletes, each of whom had regular training in his major
sport which included baseball, swimming, judo and middle/long-distance running for one
to six years and eight age-matched non-athletic controls were studied by Tsai, Kao and
Wang (1996). BMD was measured in all study subjects using dual photo absorptiometry at
the second to fourth lumbar spines (L2-4) and the right femoral neck. Researchers
concluded that (1) physical activity during adolescence may contribute significantly
towards increasing BMD of athletes and (2) the training type may provide a specific
stimulus for increasing BMD at specific localized sites experienced in training.

Cassell, Benedict and Specker (1996) studied 14 gymnasts, 14 swimmers, and 17
controls to investigate whether participation in different types of sports among girls 7-9 yr
of age is associated with higher total body BMD. Gymnasts were lighter than both
swimmers and controls, and a larger percent of gymnasts compared with swimmers and
controls were below the 25th percentile for height and weight. Fat mass, percent body fat
and lean mass were less in gymnasts compared with swimmers and controls. The
relationship between total body BMD and body weight differed among the three groups
interaction term of weight and sport the increase in BMD per unit increase in body weight
was more among gymnasts than among swimmers and controls. Results indicated that high
impact bone loading activities may lead to increased bone density among young girls.

Duppe, et. al. (1996) examined the BMD of female junior and senior football
(soccer) players with different training regimens and histories, female former football
players, and their respective controls. Active junior (age 13-17 years, N=62) and senior
(age 18-28 years, N=34) players, representing three teams with different levels of
performance and training, were compared reciprocally and with matched controls (N=90).
Former players (age 34-84 years, N=25) who had ended their careers on average 9.7 years previously and their matched controls (N=57) were also studied. Body composition and total body, lumbar spine and proximal femur BMD were measured with DXA. Former players and their controls were asked in a questionnaire to specify their current level of physical activity. It was concluded that the training in female football, which is an impact-loading activity, has a site-specific, positive effect on bone formation that is not increased over a certain level of physical activity. The BMD advantage attained appeared to be preserved to some extent after the termination of the athlete's active career, which may have a positive effect on future fracture risk.

In order to address the hypothesis that osteogenic effect of physical loading increases with increasing strain rates and peak forces, Heinonen, et. al. (1995) examined 59 competitive Finnish female athletes (representing three sports with different skeletal loading characteristics), physically active referents (they reported an average of five various types of exercise sessions per week), and sedentary referents (two sessions per week) using DXA. The measured anatomic sites were at the lumbar spine, femoral neck, distal femur, patella, proximal tibia, calcaneus, and distal radius. The athlete group consisted of aerobic dancers (N=27), squash players (N=18), and speed skaters (N=14). The squash players had the highest values for weight-adjusted BMD at the lumbar spine as compared with the sedentary reference group, femoral neck, proximal tibia and calcaneus. Aerobic dancers and speed skaters also had significantly higher BMD values at the loaded sites than the sedentary reference group, the difference ranging from 5.3% to 13.5%. The physically active referents' BMD values did not differ from those of the sedentary referents at any site. The results support the concept that training, including high strain rates in
versatile movements and high peak forces, is more effective in bone formation than training with a large number of low-force repetitions.

Fehling, et. al. (1995) compared BMD of collegiate female athletes who compete in impact loading sports; volleyball players (N=8) and gymnasts (N=13), to a group of athletes who participate in an active loading sport; swimmers (N=7), and a group of controls (N=17). All of the volleyball, swimming, and control subjects were eumenorrheic (10-12 cycles/year), whereas two of the gymnasts were amenorrheic (0-3 cycles/year), eight were oligomenorrheic (4-8 cycles/year), and three were eumenorrheic (10-12 cycles/year). Lumbar spine, proximal femur, and total body BMD were measured with DXA. The groups were compared with respect to the following regions: lumbar spine (L1-4); femoral neck; Ward's triangle; right and left arms; right and left legs; pelvis; and torso. When controlling for differences in height and weight the impact loading group (volleyball and gymnastic) had significantly greater BMD at the lumbar spine, femoral neck, Ward's Triangle, and total body when compared to the active loading (swimming) and control groups. The regional analysis from the total body scan revealed that the gymnasts had significantly (p < 0.05) greater BMD than all other groups at the right and left arm sites. The impact loading groups (gymnastic and volleyball) had a greater BMD in the legs and pelvis than the active loading (swimming) and control groups. Furthermore, the impact loading group had a greater torso BMD than the control group. There were no differences at any site between the active loading group (swimming) and control groups.

In order to evaluate the possible relationships among hormonal status, physical activity and bone density, Guglielmini, et. al. (1995) carried out a study on two groups of female athletes engaged in different levels of physical activity. Researchers measured the
various hormones apart from BMD. All the variables were related to the amount of work performed during training. The groups were defined as follows: medium workload (N=10) and heavy workload (N=20), engaged in 10 and 18 hours of weekly training at 35 and 60 average percent of VO2max, respectively. All of the hormones and the markers of calcium-phosphate metabolism studied were normal; BMD was also normal for all subjects except for two sisters in Medium workload group with reduced BMD. The athletes in heavy workload group with regular menstrual cycles were found to have an upper limit normal BMD. From these data investigators conclude that in regularly menstruating athletes an increase in BMD induced by heavy physical activity is evident, while in dysmenorrheic athletes the effect of physical activity compensates, to some extent, for the hypothetical bone mineral reduction possibly caused by the hormonal imbalance.

Heinonen, et. al. (1993) studied anthropometry, training history, cardiorespiratory and muscular performance capacity, and BMD in female orienteers (N=30), cross-country skiers (N=28), cyclists (N=29), weight lifters (N=18) and in a reference group (N=25). BMD was measured at lumbar spine, femoral neck, distal femur, patella, proximal tibia, calcaneus and distal radius by DXA. The weight lifters had significantly higher weight adjusted BMD than the referents at all sites except in femoral neck and calcaneus. Of the endurance athletes, the orienteers were the only group which had significantly higher BMD than referents, only at distal femur and proximal tibia. BMD did not differ significantly at any skeletal site between subjects with different calcium intake. Weight training seemed to provide more effective osteogenic stimulus than endurance training. The differences in BMD at different sites between the groups were consistent with specificity of the stimulus to the training of the studied sports.
Grimston, Willows and Hanley (1993) tested the hypothesis that differences in mechanical loading regime were important when evaluating the potential role of physical activity on bone density in children. Seventeen children competing regularly in weight-bearing sports producing loads of at least 3 times body weight (Impact Load) were matched for race, gender, stage of puberty, body weight, and average daily training time with children involved in competitive swimming (Active Load). Bone mineral density (BMD) was measured using dual photon absorptiometry at the lumbar spine (L2-L4) and femoral neck (FN), Tanner staging was used to assess puberty, diet was evaluated based on 3-d dietary records from two occasions, and a questionnaire assessed average daily non weight-bearing hours. There were no significant differences in age, height, or weight between Impact and Active Load groups. Impact Load children had significantly greater FN BMD than Active Load children and a tendency for greater BMD L2-L4; 0.70 +/- 0.03 and 0.66 +/- 0.03, respectively. These data indicate that children involved in sports producing significant impact loading on the skeleton had greater femoral neck bone density and a trend for greater spinal bone density, than children in sports producing loads to bone primarily through muscular contraction.

The effects of sporting activity and of menstrual status on the bone mineral content of the femoral mid-shaft were investigated by Wolman, et. al. (1991). The cohort consisted of 67 elite, female athletes comprising 21 runners, 36 rowers, and 10 dancers. Twenty five of these athletes were amenorrhoeic, 27 eumenorrhoeic, and 15 were taking the oral contraceptive. The bone mineral content was also measured in 13 eumenorrhoeic, sedentary women. The mean bone mineral content in the runners was 1.51 g/cm2, which was significantly higher than in the rowers, dancers, and sedentary controls whose values
were 1.43 and 1.40 g/cm² respectively. There was no significant difference in the bone mineral content between the amenorrhoeic, eumenorrhoeic, and oral contraceptive taking athletes.

On the basis of the reviews gone through in this section it is evident that the BMD is dependent on several factors including participation in physical activities and sport. Evidences are available to prove the association between BMD and involvement in different forms of physical activities. It was observed that there is substantial disagreement among scholars regarding type of activity, frequency and other load parameters in acquiring high BMD.

**Studies exploring association between muscle performance and BMD**

Tamci, et. al. (2009) investigated the relationship between handgrip strength and phalangeal BMD and evaluated the confounding factors in highly trained male athletes. A total of 57 highly trained athletes; with a mean age of 23.5±4.1 (17-37) years were included in the study. Age, smoking status, alcohol consumption, medications, previous fractures, calcium intake, and the duration of sports participation, weekly training time, height and weight of the subjects were recorded. Handgrip strength was measured by a hand-held dynamometer and BMD was measured with radiographic absorbtiometry in both hands. Significant positive correlations were found between BMD and handgrip strength, age, weight and height (p<0.01). When stepwise regression analysis was performed, two variables were found to be significantly related to BMD: handgrip strength and weight. R² value was 0.29 (F=8.71, p=0.001). To eliminate the effect of body weight on BMD researchers compared BMD and grip strength in the dominant and non-dominant hands. Bone mineral density, t-scores and the handgrip strength were significantly higher in the
dominant hand (p<0.05). Thus it was concluded in their study that the handgrip strength was an independent predictor of phalangeal bone mineral density in highly trained male athletes.

Fonseca, Franca and Praagh (2008) investigated the relationship between health-related physical fitness and BMD in adolescents. One hundred forty-four adolescents (65 boys and 79 girls) between 15 and 18 years of age were recruited to this cross-sectional study. Subjects were evaluated in aerobic fitness, muscular fitness, flexibility, body composition, and maturation. BMD of the lumbar spine, total body, and proximal femur were measured by DXA. Pearson’s correlation and stepwise multiple regression analyses were used (p<.05). Lean body mass (LBM) and abdominal muscular fitness explained 35–40% of proximal femur BMD in whole group and boys’ total body BMD (43%); however, VO2max and LBM predicted girls’ total body BMD (23%). Lumbar spine BMD was predicted only by LBM for both genders (18% boys, 15% girls). In summary, lean body mass was found to be the main predictor of bone mass during the end of adolescence, regardless of gender, whereas muscular fitness contributes more to bone mass among males than among females.

Ozgocmen, et. al. (2000) determined the site-specific relationship between grip strength and hand BMD measured with DXA in healthy women. The correlation of hand BMD and BMD at axial sites had also been assessed. Twenty-nine healthy housewives, aged 30-70, were included in the study. Women were grouped according to their menopausal status (12 premenopausal and 17 postmenopausal). Grip strength of the dominant hand was measured using a Jamar dynamometer. BMD of the antero-posterior spine, femoral neck, trochanter, and Ward’s triangle were measured with DXA. For the
hand BMD measurements, the analysis software, which was modified from the software of small animals and developed for hand BMD measurements, was used. Grip strength was found to be an independent indicator of hand BMD in postmenopausal women, and also a site-specific relationship. The results indicated hand BMD measurements to be indirect reflectors of the BMD at axial sites especially in postmenopausal women.

Nordstrom, et. al. (1996) evaluated the relationships in adolescent boys subjected to high physical activity and also to compare the bone mass of the same group with that of adolescents on a moderate level of physical activity. The reference group consisted of 24 boys, age 15.9 +/- 0.3 years, not training for more than 3 h per week. The ice hockey players consisted of 20 boys, age 15.9 +/- 0.3 years, from an ice hockey junior team training for about 10 h per week. The groups were matched according to age, pubertal stage, and weight. Areal BMD was measured in total body, head, humerus, spine, femur, and proximal femur using DXA. In conclusion, the higher BMD demonstrated in the ice hockey players seems to be site-specific and may well be associated with the type and magnitude of loading from predominantly ice hockey. High physical activity seems to weaken the relationship between BMD, muscle strength, and body constitution demonstrated in adolescent boys on a low or moderate level of physical activity.

BMD is dependent on multiple influences including genetics, mechanical forces, hormonal changes and nutritional mechanisms. The mechanical forces are, in part, influenced by muscle strength. Eickhoff, et. al. (1993) examined the relationships between BMD of the spine and femur with muscle strength. Eighty-one healthy, non-athletic women aged 20-30 years were the subjects in the study. BMD was measured by DXA. Trunk strength was measured by a Wagner Dynamometer or a Cable Tensiometer and leg
strength was measured with a Cybex II isokinetic dynamometer. Trunk, leg, and hip strength was also measured using 1 RM (one repetition maximum). Multiple regression analysis showed that amongst young adult female’s weight and trunk extensor muscle strength contributed about equally to spine density. Flexor muscle strength did not influence bone density.

According to the sources available it is observed that muscle performance capability significantly affects BMD. Discrepancies among scholars have opened avenues for future research on the association between muscle performance and BMD.

Studies on unique factions

Miyahara, et. al. (2008) carried out a measurement of body composition and a nutrition survey, targeting 28 male wheelchair athletes and comparing them with 25 male physically able healthy athletes as the controls. The DEXA method was used to measure BMD, percentage of body fat (% body fat), and lean body mass (LBM). Possible factors affecting the BMD of the wheelchair athletes with spinal injuries were analyzed including age, body part, type of sport, area of injury, length of injury, and the length of time it took before restarting sports activity after injury. BMD in the arms, body trunk, legs, and entire body was measured. There were no significant differences in the BMD of the wheelchair athletes by age group (from 20 to 29, from 30 to 39, and 40 years and older), by sports (basketball, track and field, and tennis), and by area of injury (high and low paraplegia). BMD in the legs, body trunk, and entire body of the wheelchair athletes was negatively correlated with the period since injury; however, no such a relationship was observed in the arms. In addition, the multiple regression analysis for BMD of each body region showed that the earlier the wheelchair athletes restarted sports after injury, the higher
values the BMD of legs, body trunk, and entire body, independent of age and sports. The leg BMD of the wheelchair athletes was lower than that of the physically able athletes, with a BMD 76.5% of the controls. The present study suggests that restarting sports activity in a timely manner after treatment and rehabilitation for the injury is useful in preventing loss of BMD in wheelchair athletes and ultimately improving their quality of life.

Kuruvilla, et. al. (2008) hypothesized that bone adaptation to loads differs among mice breeds and bone sites. Forty-five adult female mice from three inbred strains (C57BL/6 [B6], C3H/HeJ [C3], and DBA/2J [D2]) were loaded at the right tibia and ulna in vivo with non-invasive loading devices. Each loading session consisted of 99 cycles at a force range that induced ~2000 microstrain (μstrain) at the mid-shaft of the tibia (2.5 to 3.5 N force) and ulna (1.5 to 2 N force). The right and left ulnae and tibiae were collected and processed using protocols for histological under calcified cortical bone slides. Standard histomorphometry techniques were used to quantify new bone formation. The histomorphometric variables include percentage mineralizing surface (%MS), mineral apposition rate, and bone formation rate. Net loading response [right-left limb] was compared between different breeds at tibial and ulnar sites using two-way ANOVA with repeated measures (p<0.05). Significant site differences in bone adaptation response were present within each breed (p<0.005). In all the three breeds, the tibiae showed greater percentage MS, MAR and BFR than the ulna at similar in vivo load or mechanical stimulus (strain). These data suggest that the bone formation due to loading is greater in the tibiae than the ulnae. Although, no significant breed-related differences were found in response to loading, the data showed greater trends in tibial bone response in B6 mice as
compared to D2 and C3 mice. Data of the study conducted by these researchers indicate that there are site-specific skeletal differences in bone adaptation response to similar mechanical stimulus.

Ausili, et. al. (2008) investigated the relationship between body composition, bone mineral density, walking ability and sport activity in myelomeningocele children. Myelomeningocele causes serious locomotor disability, osteoporosis and pathologic fractures. 60 patients aged between 5 and 14 yrs with myelomeningocele (22 ambulatory and 38 non ambulatory), were studied. Fat mass and fat free-mass were calculated by anthropometry. The bone mineral densities at lumbar and femoral neck were evaluated. Bone mineral density at the lumbar and femoral neck was lower than in the normal population. In the non-ambulatory group, bone mineral density was ~1 SD lower than in the ambulatory one (p<0.01). Fat mass was greater than expected but without significant differences between walking group (mean 26%) and wheel-chair users (25%). Patients practiced sport activity had a better bone mineral density and body fat compared with other patients with the same disability. Patients with myelomeningocele have decreased bone mineral density and are at higher risk of pathologic bone fractures. All subjects showed an excess of fat as percentage of body weight and are shorter than normal children. The measurement of bone mineral density may help to identify those patients at greatest risk of suffering of multiple fractures. Walk ability and sport activity, associated with the development of muscle mass, are important factors in promoting bone and body growth, to reduce the risk of obesity and of pathological fractures.

Kemmler, et. al. (2004) determined the effects of habitual physical activity, non-athletic exercise muscle strength, VO2max and anthropometric parameters on BMD in
early post-menopausal women. 150 early postmenopausal women (55.5±3.4 years), which were free of diseases or medication affecting bone metabolism and had no athletic history were investigated. The influence of weight, body composition, physical activity, isometric strength, VO2max, and nutritional intake on BMD was measured at multiple sites using different techniques. Further bone markers were determined. Activity and weight-bearing activity were assessed by questionnaire. Maximum strength was measured isometrically. Aerobic capacity was measured with a spirometric system in a stepwise treadmill test and dietary intake was monitored over 5 days. The isolated effect of habitual physical activity, unspecific exercise participation, and muscle strength on bone parameters is rather low in (early-) postmenopausal women. Thus it was concluded that, women at risk should take specific exercise programs into consideration rather than to increasing the amount of habitual physical activity.

Stewart, et. al. (2002) determined relationships of BMD with fitness, physical activity, and body composition and fat distribution. Men (N=38) and women (N=46), aged 55–75 years with high normal blood pressure or mild hypertension but otherwise healthy were selected as subjects for the study. Aerobic fitness (oxygen uptake) was measured on a treadmill, muscle strength by one-repetition maximum, activity by questionnaire, abdominal obesity by magnetic resonance imaging; anthropometrics, and body composition by DEXA which measured total fat and lean mass, and BMD for the total skeleton, lumbar spine (L1–L4) and total hip. Abdominal obesity and muscle strength emerged as predominant correlates of BMD in older persons with stronger relationships seen in women. Body weight and HRT also explained portions of the variance in BMD in
women. Investigators concluded that, whether abdominal obesity is simply a marker for general obesity or has independent protective effects on bone is yet to be determined.

In a cross-sectional study, 91 healthy premenopausal women aged 20-39 years were investigated by Hara, et. al. (2001) and determined the effect of physical activities during their teenage years on their current BMD. Investigators measured whole-body BMD, lumbar BMD, and radial BMD with DXA. Using a questionnaire, women were asked about their physical activities during junior and senior high school and at present. Information on current nutritional status and past and current milk intake were also asked. After adjusting for age, body mass index BMI, current total calorie and calcium intake, and milk intake when they were teenagers and at present, it was 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 whole body BMD and lumbar BMD than did those who did not exercise at those times. Subjects who played high-impact sports at each period had significantly higher whole body BMD and lumbar BMD than did subjects who played low-impact sports. 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. Our data suggest 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.

Kelley, Kelly and Tran (2000) used the meta-analytic approach to examine the effects of exercise on BMD in men. A total of 26 effect sizes representing 225 subjects from 8 studies met the criteria for inclusion. The results of this study suggested that site-
specific exercise may help improve and maintain BMD at the femur, lumbar, and oscalcis sites in older men. However, the biological importance of the small changes observed for most outcomes, quality of studies, and limited data pool prevent us from forming any firm conclusion regarding the use of exercise for maintaining and/or improving BMD in men. Clearly, a need exists for additional studies.

Monica, Charles and Barbara (1996) conducted a case-control study examining the differences in BMD between amenorrheic and eumenorrheic athletes. Forty-nine athletes, aged 17 to 39 years, were selected from those responding to advertisements in local sporting-goods stores and a track and-field newsletter. Athletes were defined as amenorrheic if they had had fewer than 2 menstrual cycles in the last 12 months or none in the past 6 months, or eumenorrheic if they had had 10 to 13 cycles in the previous year. Only women who met these criteria, confirmed by tests for estradiol and progesterone levels, were enrolled in the study. Bone mineral density was measured by DXA. It was concluded that extended periods of amenorrhea may result in low bone density at multiple skeletal sites including those subjected to impact loading during exercise.

Investigations on wheelchair athletes, individuals with serious health disorders, amenorrheic, obese, sedentary and post menopausal population revealed probable association between BMD and physical activity. Further, a similar relationship was also observed in a study conducted on rats. All these results have indicated probable connection among BMD and human involvement in physical activities.
Studies exploring association between combined effects of load parameters and muscle performance on BMD

Gruodyte, et. al. (2009) investigated the relationship between jumping height and BMD at femoral neck and lumbar spine in pubertal girls with different physical activity pattern. The participants were 202 adolescent girls aged 13-15 years comprising six groups: controls (N=43); sport games (N=56); track sprint (N=25); rhythmic gymnastics (N=29); swimming (N=32); and cross-country skiing (N=17). Body height, sitting height, and body mass were measured. Predicted age at peak height velocity, biological maturity age, and pubertal status by Tanner (1962) of the participants was estimated. Femoral neck and lumbar spine (L2-L4) BMD was measured by DXA. The height of vertical jumps, i.e., countermovement jump, and rebound jumps for 15 and 30 seconds was obtained. BMD at femoral neck appears to be more sensitive to the mechanical loading compared to the BMD at lumbar spine. Repeated jumps tests characterize bone development better than single maximal jump test in pubertal girls.

Tamaki (2008) examined the following four variables for impact on adolescent bone growth: the degree of impact, and the period, frequency, and daily duration of physical activity. Researchers studied 127 boys and 136 girls between the ages of 12 and 15 years from northern Japan. BMD at the spine and hip were measured using DXA, and histories of participation in sports club activities beginning in first grade of elementary school were obtained through a questionnaire. The time spent participating in sports club activities between fourth and sixth grades during elementary school (E4-E6) was predictive of increased BMD, adjusted for height, weight, onset of pubic hair appearance, calcium intake, and grip strength, with the exception of hip BMD in females. Analysis of the
period, frequency, daily duration of sports club activity, and a score of mechanical impact of physical activity as substitute for time spent during E4-E6 revealed a significant relationship between the period of activity and BMD, with the exception of spine BMD in females. Activities performed two or more times a week during E4-E6 was also associated with an increased BMD at the hip for males and the spine region for females. Thus, the period and frequency of sports club activity, independent of its degree of impact or daily duration, in the age range of 9 to 12 years may be important for bone growth in children and adolescents.

Duncan, et. al. (2002) investigated the influence of different exercise types and differences in anatomical distribution of mechanical loading patterns on BMD in elite female cyclists, runners, swimmers, tri athletes, and controls (N=15 per group). Associations between leg strength and BMD were also examined. Areal BMD was assessed by DXA total body, lumbar spine, femoral neck, legs, and arms). Right knee flexion and extension strength was measured using a Cybex Norm isokinetic dynamometer at 60 degrees. Researchers concluded that 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.

Pettersson, Nordstrom and Lorentzon (1999) investigated any 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. In addition, we compared the relationship among bone mass, muscle strength, and body constitution in these two groups.
The reference group consisted of 20 men (age 24.6+/−2.3 years) not training for more than 3 hours per week. The ice hockey players consisted of 20 players (age 23.4+/−4.9 years) from an ice hockey team in the second highest national Swedish league, training for about 10 hours per week. The groups were matched according to age, height, and weight. 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. The differences in BMD between the groups seem to be site-specific and may be associated with the type and magnitude of loading during off season training and preferentially during ice hockey. High physical activity seems to weaken the relationship 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 athletes.

Nordstrom, Pettersson and Lorentzon (1999) evaluated the influence of different types of weight-bearing physical activity, muscle strength, and puberty on BMD (g/cm2) and bone area in adolescent boys. Three different groups were investigated. The first group consisted of 12 adolescent badminton players (age 17.0+/−0.8 years) training for 5.2+/−1.9 h/week. The second group consisted of 28 ice hockey players (age 16.9+/−0.3 years) training for 8.5+/−2.2 h/week. The third group consisted of 24 controls (age 16.8+/−0.3 years) training for 1.4+/−1.4h/week. The groups were matched for age, height, and pubertal stage. BMD, bone mineral content (BMC, g), and the bone area of the total body, lumbar spine, hip, femur and tibia diaphyses, distal femur, proximal tibia, and humerus were measured using DXA. 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.

Henrik, et. al. (1997) conducted a population-based study 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. Subjects included were 175 men and 157 women, aged 15-42 years. BMD was measured at various sites by 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. Investigators 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. Results of the study suggested 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.

Studies exploring additional elements influencing BMD

Laabes, et. al. (2008) recruited 102 male athletes: this included football (N=68), running (N=15), handball (N=7), taekwondo (N=6), cycling (N=2), judo (1), badminton (1) and high jump (1). Anthropometric data were first recorded on a structured form and energy expenditure was indirectly estimated with a validated questionnaire. Bone density was assessed using the Lunar Achilles+ calcaneal ultrasonometer. The mean age of athletes
was 25±6 years. The means of BMI and energy expenditure were 21.9±2.0 kg/m² and 35.0±13.7 kcal/kg/day, respectively. Footballers were younger and heavier than runners. Football was a significant determinant of BUA independent of age, BMI and energy expenditure. Football was also a significant determinant of SOS independent of age, height, weight and BMI. The mean SI was 127±16 and the median T-score was 0.82. The mean SI of footballers (130±15), runners (130±12) and other sportsmen (115±18) differed significantly. Multivariate analyses revealed that football (p<0.001) and running were significant determinants of SI independent of age and BMI. Footballers when compared with other sportsmen had a higher mean SI independent of age and BMI. Age was not correlated with SI. The median ‘t’ score of footballers, 0.94 was higher than that of other sportsmen. Repetitive skeletal loading at the heel has the potential to improve bone density in black male athletes. The magnitude of increase may be higher in medium impact sports such as soccer and running compared with low or non-impact sports such as judo or taekwondo, and is independent of age and BMI. However, future longitudinal data will be required to support our observations.

Arabi, et. al. (2004) aimed at establishing normative data for BMD in healthy Lebanese children and adolescents. Three hundred sixty-three healthy children aged 10 to 17 years (mean+/−SD: 13.1+/−2.0) were studied. BMD, bone mineral content, and lean mass were measured by DEXA using a Hologic 4500A device, and apparent volumetric BMD (BMAD) of the lumbar spine and the femoral neck were calculated. BMD, BMC, and BMAD were expressed by age groups and Tanner stages for boys and girls separately. In both genders, children of lower socioeconomic status tended to have lower BMD than those from a higher socioeconomic background. This study allowed additional insight into
gender dimorphism in mineral accretion during puberty. It also provided a valuable reference database for the assessment of BMD in children with pubertal or growth disorders who are of Middle Eastern origin.

Quintas, et. al. (2003) analysed the influence of dietetic and anthropometric data, as well as the sport practiced, on the bone density of different groups of sportswomen. Dietetic, anthropometric and bone density data were collected from 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. 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 mineralisation status. Increased energy, protein, vitamin D, calcium, zinc and magnesium intakes were associated with greater bone density and mineral content at different sites. 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 skeleto-muscular 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.

McClanahan, et. al. (2002) investigated the effects of participation in various sports on side-to-side (contra lateral) differences in BMD of the upper and lower limbs. The BMD of the arms and legs was measured using DXA. The subjects were 184 collegiate athletes, both men and women, who participated in NCAA Division I-A baseball,
basketball, football, golf, soccer, tennis, cross-country, indoor/outdoor track, and volleyball. Results revealed greater BMD of the right arms compared with the left arms for all teams, with the most pronounced differences observed in men's and women's tennis and men's baseball. Differences in the lower limbs were less common. No significant differences in lower limb BMD were found in the women. In men, differences in lower limb BMD were found in the football and tennis teams, with the non dominant leg having greater bone mass.

In conclusion, it is admitted that a possible connection between BMD and various other factors including loading patterns, strength factors, nutritional aspects, and maturational elements are elicited in variety of individuals. The research reviews indicate higher BMD among individuals who are physically active, irrespective of age and health conditions. Hence, a study in this direction was felt utmost essential in the Indian perspective.