BONE ADAPTATIONS IN MALE COLLEGIATE-LEVEL CHEERLEADERS

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Education with a major in Exercise Science.

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ABSTRACT

Involvement in resistance or high-impact sports is a known contributor to bone health in young athletes. However, no study to date has examined the sport of cheerleading and its potential impact on bone mineral density (BMD) and lean body mass. The purpose of this study was to assess BMD of the lumbar spine and the proximal femur in male cheerleaders. A secondary purpose was to examine measures of body composition. Twelve male collegiate-level cheerleaders and 12 age, height and weight matched recreationally active males (CON) volunteered for the study. The cheerleaders' appendicular lean mass and total lean mass were significantly greater (33.56 ± 3.37 and 72.22 ± 6.56 kg) compared to CON (29.57 ± 2.73 and 66.19 ± 5.09), $P<0.05$. The cheerleaders also had a lower percentage of body fat and total fat mass (13.1 ± 4.48% and 11.66 ± 5.10kg) compared to CON (18.92 ± 4.53% and 16.30 ± 4.66kg), $P<0.05$. Although there were no statistically significant differences in any of the BMD variables between groups, the average Z-scores at clinically significant sites ranged from 0.3 to 1.3 standard deviations above the age and ethnicity-related population norm, as defined by the World Health Organization. These data suggest that cheerleading has a positive influence on bone health and measures of body composition.

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CHAPTER 1

INTRODUCTION

Studies have shown that exercise has a positive effect on bone health (Korhonen et al., 2012). In addition, it is apparent that the greatest accrual of bone mineral density (BMD) occurs during the early adolescent years, and this may lead to a positive advantage in bone strength during adulthood when a reduction in BMD becomes prevalent. Severe depletion of bone tissue may lead to the degenerative condition, osteoporosis, which is a major and debilitating disease of aging (Ali, Shonk, & El-Sayed, 2009). Osteoporosis is the structural deterioration of bone tissue. Osteoporosis is a clinically measurable deficit in BMD affecting approximately 24 million Americans (Otto, 1998). Osteoporosis and osteoporotic bone fractures represent a significant health problem, and result in substantial morbidity and mortality. Physical activity increases the length, width, and mineral content of bones during childhood and adolescence, as a result of complex torsional interactions between bone and muscle tissue (Ali et al., 2009). These positive effects on bone accrual are greater in trained athletes, where a relationship has been noted between medium and high impact sports activity and BMD levels, provided adequate caloric and calcium intakes are maintained (Turner & Robling, 2003).

Cheerleading, usually considered a nonathletic activity, has developed in the last three decades into a competitive sport requiring a high level of fitness. Decades ago, cheerleaders performed basic maneuvers such as toe-touch jumps and the splits. Today cheerleading has developed into a demanding athletic sport that integrates elements of dance, gymnastic tumbling runs and partner stunts (Miller & Washington, 2011). College teams have moved towards competitive cheer pulling off intricate tumbling passes; throwing basket tosses where a girl flies 30 feet in the air; building human pyramids where a slip can send a dozen people tumbling to the ground; and performing partner stunts where "flyers" pull acrobatic moves, balancing in the palm of their partner's hand (Shields & Smith, 2009).

Due to its competiveness and physical demands, cheerleading requires specialized training as is necessary for other competitive sports (SooHoo, Sell, & Reel, 2005). Although cheerleading has evolved into one of the most popular activities with hundreds of thousands of high school and collegiate participants, there are surprisingly very few research publications studying this population.

Strenuous training can result in amenorrhoea, which contributes to bone loss in some female collegiate athletes (Egan, Reilly, Giacomoni, Redmond, & Turner, 2006). However, the sport-specific impact of cheerleading on bone mineral density (BMD) in male collegiate athletes is less well understood.

1.1 Purpose of Study

The purpose of this study was to examine bone mineral density of the lumbar spine and hips in male collegiate cheerleaders and compare these values to a height, weight and age-matched group of recreationally active men. A secondary purpose was to compare measures of body composition.

1.2 Research Question

Will bone mineral density and body composition in male collegiate cheerleaders differ from their height, weight and age matched recreationally active counterparts?

1.3 Hypothesis

Male Cheerleaders will have higher BMD of the hips and lumbar spine as well as greater lean mass and lower fat mass compared to their height, weight and age matched recreationally active counterparts.

1.4 Significance

There is currently very little information on cheerleading even though it is one of the fastest growing sports. This study will help to describe the impact of competitive cheerleading on bone health and soft tissue adaptations in males.

1.5 Variables

1.5.1 Independent Variable

The independent variable in this study was cheerleading.

1.5.2 Dependent Variable

The dependent variables in this study were BMD of the lumbar spine, and hips assessed by dual x-ray absorptiometry (DXA) technique, and body fat percentage, total lean mass and fat mass.

1.6 Assumptions

- Subjects answered questionnaires truthfully
- Subjects fasted overnight before day of testing

1.7 Limitations

- Exercise training done outside of cheerleading may impact the dependent-variable.
- The time in which the study is being done is after the main season for cheerleading.
- The number of athletes analyzed had an impact on the study. Our sample size was relatively small so it is difficult to find significant relationships from the data, as statistical tests normally require a larger sample size to ensure a representative distribution of the population and to be considered representative of groups of people to whom results will be generalized or transferred.
- Lack of prior research studies on the topic has added another limitation to the study. There are not many

scholarly research studies published that deal with male collegiate-level cheerleaders.

- All the participants do additional exercise activities outside of the allotted cheerleading practices.

1.8 Delimitations

- Male collegiate cheerleaders.
- Recreational male college students (Physical activity 2-4 days/week).

1.9 Definitions

- **Bone mineral density (BMD):** the adjusted value of hydroxyapatites with respect to measured bone area; measured and calculated commonly with DXA, expressed in units of g/cm^2.
- **Bone remodeling:** a dynamic, lifelong process of reshaping and replacing bone during growth and after injury (Papachroni, Karatzas, Papavassiliou, Basdra, & Papavassiliou, 2009).
- **Osteoblast:** a cell originating from mesenchymal stem cells, responsible for the synthesis of bone matrix (Papachroni et al., 2009)
- **Osteoclast:** a multinucleated cell, differentiated from hematopoietic monocyte and macrophage precursors, which coordinates resorption of bone (Papachroni et al., 2009)
- **Osteocyte:** a terminally differentiated osteoblast trapped in its secreted matrix. Osteocytes sense mechanical signals and initiate events of bone remodeling (Papachroni et al., 2009).

- **Bone multicellular unit (BMU)**: a local group of cells with finite lifetime that mediate bone remodeling. Each unit consists of bone-lining cells, osteoblasts, osteocytes, osteoclasts, their precursor cells and their associated cells (endothelial and nerve cells) (Papachroni et al., 2009).
- **Mechanotransduction**: a three-leg conversion of mechanical cues to electrical or biochemical signals, involving mechanosensing, signal transduction and effector-cell response (Papachroni et al., 2009).
- **Osteopenia**: a condition of bone in which there is a generalized reduction in bone mass; however this is less severe than that in osteoporosis (Papachroni et al., 2009).
- **Osteoporosis**: skeletal abnormality characterized by decreased bone mass owing to the resorption of bone at a rate that exceeds bone synthesis (Papachroni et al., 2009).
- **Base**: A cheerleader, male or female, who lifts and holds flyers in the air.
- **Coed**: A division of cheerleading where men and women compete together.
- **Flyer**: A female cheerleader who is lifted into stunts and pyramids and thrown in basket tosses. Will generally be very small.

- **Pyramid:** A cheerleading formation created by stacking bodies vertically, often by one person climbing or being thrown on top of others.
- **Shoulder Stand:** A stunt where a flyer climbs or is tossed onto their base’s shoulders.
- **Spotter:** A cheerleader who stands in the most effective place to prevent injuries.
- **Stunt:** One of the basic building blocks of a cheerleading routine where a base or group of bases lift or toss a flyer overhead to perform tricks in the air.
- **Toss:** When a base grips the waist of his or her flyer and throws them upwards as the flyer jumps. Often added in front of a stunt’s name (such as Toss Awesome, Toss Liberty, etc).

CHAPTER 2

LITERATURE REVIEW

2.1 Bone Physiology

Bone is a living, growing tissue. Bone has four key functions within the body (Boskey & Posner, 1984). First, it provides structural support for mechanical action of soft tissues and general locomotion. Second, it shields vital internal organs. Third, it provides a protective site for the blood-forming tissue; the bone marrow where hematopoiesis takes place. Last, it is the mineral reservoir of calcium and phosphate for the body(Boskey & Posner, 1984). It is a porous mineralized structure, made up of cells, vessels, crystals of calcium compounds (hydroxyapatite), the proportion of which varies according to bone types and regions. Each bone constantly undergoes modeling during life to help it adapt to changing biomechanical forces, as well as remodeling to remove old, micro damaged bone and replace it with new, mechanically stronger bone to help preserve bone strength(Flynn, 2003). All these functions make the approximately 206 bones of the human body an organ that is essential to our daily existence (Trussel, Muller, & Webster, 2012).

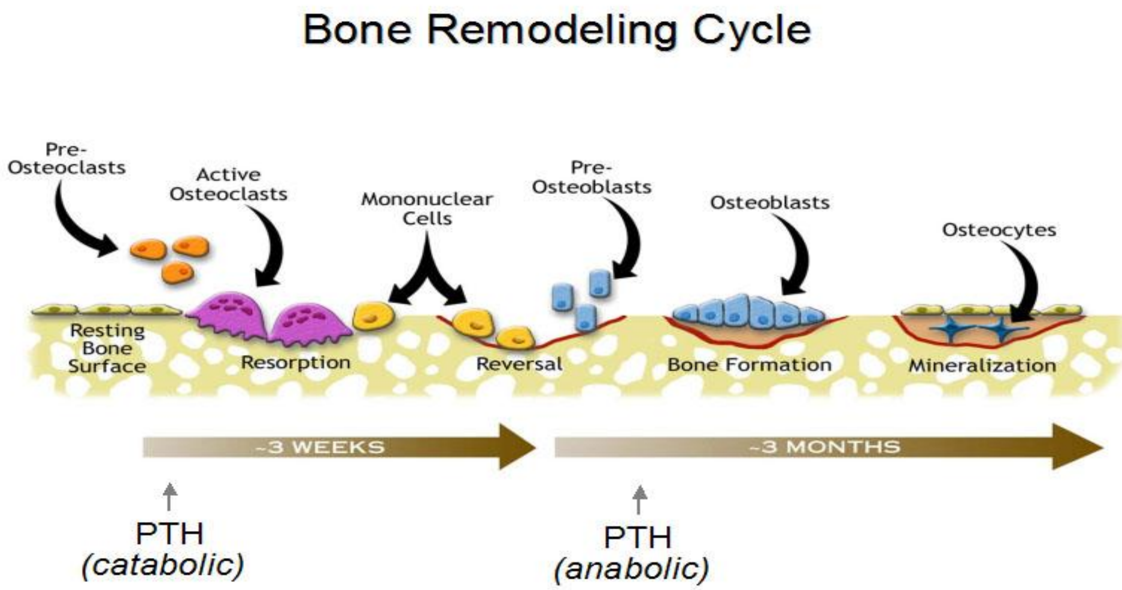
There are two kinds of bone tissue: compact and spongy bone. The compact bone is a thick and dense layer of calcified tissue that forms the outer surfaces of most bones and the shafts of long bone. They provide stability to the skeleton (Hadjidakis & Androulakis, 2006). Compact bone consists of cylindrical units called osteons. Each osteon contains concentric lamellae (layers) of hard, calcified matrix with osteocytes (bone cells) lodged in lacunae (spaces) between the lamellae. Smaller canals, or canaliculi, radiate outward from a central canal, which contains blood vessels and nerve fibers (Flynn, 2003). Osteocytes within an osteon are connected to each other and to the central canal by fine cellular extensions. Through these cellular extensions, nutrients and waste are exchanged between the osteocytes and the blood vessels (Fehling, Alekel, Clasey, Rector, & Stillman, 1995). Perforating canals provide channels that allow the blood vessels that run through the central canals to connect to the blood vessels in the periosteum that surrounds the bone (Clarke, 2008).

Spongy bone consists of thin, irregularly shaped plates called trabeculae, arranged in a latticework network (Caetano-Lopes, Canhao, & Fonseca, 2009). Trabeculae are similar to osteons in that both have osteocytes in lacunae that lie between calcified lamellae. As in osteons, canaliculi present in trabeculae provide connections between osteocytes. However, since each trabecula is only a few cell layers thick, each osteocyte is able to exchange nutrients with nearby blood vessels(Boskey & Posner, 1984).

2.2 Bone Remodeling

There are three distinctive types of bone cells present in bone tissue. Each cell type has their own crucial function. Working together, osteoblasts, osteoclasts, and osteocytes are responsible for the proper development and maintenance of the skeleton, as well as regulating levels of minerals present in the bloodstream and throughout the body(Hadjidakis & Androulakis, 2006). Osteoblasts are cells which originate in the bone marrow and contribute to the production of new bone (Caetano-Lopes et al., 2009). These cells synthesize the matrix of the bone structure and also play a role in the mineralization of the bone matrix(Rodan & Martin, 1981). Bone is constantly being synthesized and degraded by the body, making osteoblasts rather critical (Rodan & Martin, 1981). The counterpart to the osteoblast is the osteoclast, a cell which is responsible for bone resorption. Osteoclasts are large bone cells formed in the marrow of the bone (Mohan & Baylink, 1991). Similar in structure to white blood cells, they are responsible for resorping bone tissue, which is required for bone growth and healing. They start out as smaller cells called osteoclast precursors, but fuse together into osteoclasts with multiple nuclei when they find places on the bone that need to be broken down (Burr, 1997). Osteoclasts also helps regulate minerals in the bloodstream. As these cells break down bone, they release calcium and phosphate into the blood, where these minerals play an important role in many biochemical processes (Clarke, 2008). Osteoclasts are also involved in the development of red blood cells in the bone marrow. After the new bone tissue has been built, those osteoblasts that don't become lining cells remain deep in the bone matrix and become osteocytes cells with long branches through the bone tissue that form a network (Ali et al., 2009). Osteocytes function as a control center, directing mineral deposits and sending osteoclasts to start repairing damage to the bone tissue as needed. They also are responsible for signaling the release of minerals such as calcium into the bloodstream to maintain good health (Karlsson, Johnell, & Obrant, 1993).

Bone structure and function are dependent on complex interactions between cells, matrix, cell-derived factors, and systemic factors. The deposition of mineral in bone, which enables the skeleton to function properly, is described as a four-step process of matrix modification, crystal nucleation, crystal growth, and remodeling (Rahimian, 2004). Bone remodeling is a complex process regulated by hormones and growth factors (Olsen, Reginato, & Wang, 2000). Bone remodeling involves the removal of mineralized bone by osteoclasts followed by the formation of bone matrix through the osteoblasts that subsequently become mineralized (Kanis et al., 2002). The remodeling cycle consists of three consecutive phases: resorption, during which osteoclasts digest old bone; reversal, when mononuclear cells appear on the bone surface; and formation, when osteoblasts lay down new bone until the resorbed bone is completely replaced (Brunader & Shelton, 2002). Bone remodeling serves to adjust bone architecture to meet changing mechanical needs and it helps to repair microdamages in bone matrix preventing the accumulation of old bone (Egan et al., 2006). It also plays an important role in maintaining plasma calcium homeostasis (Otto et al., 1997). The regulation of bone remodeling is both systemic and local. The major systemic regulators include parathyroid hormone (PTH), calcitriol, and other hormones such as growth hormone, glucocorticoids, thyroid hormones, and sex hormones. Factors such as insulin-like growth factors (IGFs), prostaglandins, tumor growth factor-beta (TGF-beta), bone morphogenetic proteins (BMP), and cytokines are involved as well (Kohrt, Barry, & Schwartz, 2009).



2.3 Bone Density

Bone density, also known as bone mineral density, is the measurement of density of minerals, such as calcium, present in an individual's bones. The basic idea is that more dense bones will be stronger bones. Bone densitometry has four major applications in clinical practice: quantification of bone mass or density; assessment of fracture risk; and skeletal changes (Otto et al., 1997). Epidemiological studies have convincingly shown that BMC and BMD are closely associated with the risk of sustaining a fracture (Nilsson & Westlin, 1971). A 10% decrease in BMD (corresponding to one standard deviation; SD) is associated with a doubled fracture risk (Cummings et al., 1995). Measuring bone mineral density can be performed for four general reasons: to confirm suspected bone loss visible on a standard radiograph; to diagnose osteoporosis; to record effects of disease progression that alter bone mineral content (BMC) or density; and to monitor effects of disease process or response to therapy over time (Marshall, Johnell, & Wedel, 1996). Bone density tests are often administered to estimate the strength of an individual's bones and to determine the risk of various bone density disorders, such as osteoporosis (Dawson-Hughes, Harris, Krall, & Dallal, 1997). Much of the formation of bones takes place in one's childhood and teen years. Therefore, it is important to ingest the essential nutrients for bone development, such as calcium and vitamin D, from a young age. It is particularly important for those who lead very active lifestyles to maintain healthy bone density.

Bone density can be measured through a bone mineral density test, which can be taken in many different ways. X-rays and ultrasounds are two methods commonly used to measure one's BMD. The process of measuring bone mineral density is known as densitometry (Carter, Bouxsein, & Marcus, 1992). Bone density naturally declines as people age. The production of new bone slows down and can't keep up with the rate at which old bone breaks down. Bones become thinner and more porous as density decreases and tend to lack important minerals such as calcium (Rahimian, 2004). Techniques used to study BMD and bone metabolism are useful for establishing baseline values for an individual or cross-sectional population as well as for monitoring changes in BMD or the rate of bone turnover with time (Andreoli et al., 2001). Assessment of BMD has become the essential diagnostic procedure for evaluation of patients at risk for osteoporosis (Cummings Sr, 2002). Although various BMD technologies exist in clinical practice, dual energy X-ray absorptiometry (DXA) is currently the leading bone density technique. Early methods of bone mass measurement (cortical index, radiographic densitometry) were rather unrefined and imprecise. The first valid technique of BMD measurement, introduced in 1963, was single photon absorptiometry (SPA) of the forearm (Adams, 1992; Maricic & Chen, 2000). From its clinical introduction in 1987, DXA has become the gold standard for bone densitometry because of its high image quality, accuracy and precision, fast scanning times, and low radiation exposure (Ott, 1998.) Dual energy X-ray absorptiometry is a highly validated tool for analyzing BMC and BMD (Shore and Posnanski 1996). Photons at two different energy levels, which are absorbed by body tissue, are omitted by DXA. Whole body and site-specific BMC and BMD, lean body mass, and fat mass can then be calculated. Results of DXA represent a composite measure of both cortical and trabecular bone, and are reported as an areal density in g/cm2.

2.4 Mechanical Loading

The ability of bone to respond to mechanical stimuli has been known for over a century; however, it has only been in the past several decades that great gains have been made in terms of understanding the factors that influence this response. The skeleton serves as a reservoir for essential minerals, and provides rigid levers for muscles to act against. Although the role of bones in maintaining mineral homeostasis is clearly important, the skeleton's mechanical function certainly has equal importance for the regulation of bone cell biology (Turner, 1999). Total bone mineral content is more strongly associated with muscle mass than with fat mass or total body mass, supporting that muscle forces are closely interrelated with bone mass (Hind & Burrows, 2007). Most mechanical forces acting on the skeleton are generated either through impact with the ground (i.e., gravitational loading) or through muscle contractions (i.e., muscle loading). Laboratory studies of limb loading in animals show that although mechanical stress results in very small gains in total bone, these increments occur at skeletal surfaces subjected to the highest strain wherein they are most needed to resist fracture (Fehling et al., 1995). Experiments utilizing such models have demonstrated that to optimize bone formation, mechanical loading must be dynamic rather than static (Robling, Duijvelaar, Geevers, Ohashi, &

Turner, 2001). The adaptive response of bone to mechanical loading is highly site specific. This is clearly evident on the whole bone (organ) level, with only the bones that are actually loaded undergoing adaptation. Critical weight bearing skeletal sites including the femoral neck appear to be highly sensitive to impact loading and may require ground reaction forces to maintain bone mineral content and structure (Martyn-St James & Carroll, 2010). As an example, competitive male cyclists generate very high leg muscle forces, but their bone density at all measured skeletal sites including the femoral neck is lower than that of nonathletes (Smathers, Bemben, & Bemben, 2009). Many cross-sectional studies that have also shown that there is a higher BMD among athletes taking part in high-impact sports (such as racket sports and gymnastics) than among athletes taking part in low-impact sport sports (such as swimming and cycling) (Nilsson & Westlin, 1971). The site-specific depositing of new bone is functionally important. It adds new bone and increases bone strength where it is needed most, in the direction of loading, while not overtly increasing the overall weight of the bone (Levasseur et al., 2003).

2.5 Resistance Exercise and Bone Adaptation

Regular exercise effects bone density, size, and shape, resulting in improvements in mechanical strength. Weight-bearing exercise is advocated as a strategy for preventing osteoporosis.

Osteoporosis is a major cause of morbidity and mortality, especially among older adults. There is compelling evidence indicating that physical activity affects the skeleton and the BMC and BMD in an anabolic way (Hind & Burrows, 2007). It is thought that there is a bone remodeling set point, the point at which bone begins to remodel or form. Mechanical stresses, such as weight-bearing exercise, will decrease this set point, meaning that it is easier for bone to form (Little & Clapp, 1998). One mechanism through which physical activity could increase bone strength is by increasing muscle mass. Lean body mass is thought to increase bone mineral density through mechanical loading of the skeleton. Muscle, a component of lean mass, is important because muscle contractions exert a greater force on bones than do other weight-associated gravitational forces (Burr, 1997). Furthermore, recent research in humans and animals suggest that muscle contractions resulting from applying mechanical vibrations can increase the amount and quality of bone (Robling et al., 2008). The required mechanical load needed to initiate new bone formation decreases as the loading frequency increases, indicating that it is important to develop a high frequency loading program that will improve cortical bone mass and bone strength (Turner & Robling, 2003).

Although aerobic exercise is important in maintaining overall health, the resistance type of muscle training may be more applicable to the basic rules of bone adaptation and site-specific effects of exercise, have more favorable effects in maintaining or improving bone mass and architecture, and safe and feasible for older people. It has been suggested that there is an opportunity for resistance training, for improved effects on BMD in postmenopausal women in bones which have less daily loading (Suominen, 2006). Resistance training as a means to increase bone mass in premenopausal women has been studied by several researchers. Snow-Harter and colleagues (Snow-Harter, Bouxsein, Lewis, Carter, & Marcus, 1992) conducted an 8-month study of the effects of resistance training on spine and hip BMD in college-aged women. The resistance training protocol consisted of 14 exercises designed to stress the major muscles of the upper and lower body and was completed three days per week. Training intensity at the beginning of the study was 65% 1RM and was progressively increased to 85% 1RM by the end of the study. In comparison to the non-exercise control group, the resistance training group significantly increased (1.2%) lumbar spine BMD. However, hip BMD was unchanged.

2.6 Aerobic Exercise and Bone Adaptation

Cross-sectional studies show in general that exercise modalities requiring high forces and/or generating high impacts have the greatest osteogenic potential. Exercise involving high impacts, even a relatively small amount, appears to be the most efficient for enhancing bone mass (Guadalupe-Grau, Fuentes, Guerra, & Calbet, 2009). A study done by Bassey and colleagues (Bassey, Rothwell, Littlewood, & Pye, 1998) examining a 6 month study investigating the effects of jump training on femoral neck, femoral trochanter, and lumbar spine BMD. 55 premenopausal were randomly assigned to a jumping group or non-jumping control group. The jumping program consisted of 50 maximal double-leg jumps (5 sets X 10 jumps) six days per week. Ground rection forces (GRF's) were sampled throughout the study with a force plate and determined to be, on average, three times body weight. At the conclusion of the study, the jump group significantly increased BMD of the femoral trochanter (2.8%) and femoral neck, with no change in the lumbar spine. Similar results have been reported by other researchers employing high GRF exercise interventions (Friedlander, Genant, Sadowsky, Byl, & Glüer, 1995). Interestingly, these researchers also only found significant increases in hip BMD but not lumbar spine, suggesting that high GRF activities may result in site-specific bone adaptations.

From cross-sectional studies, differences in bone mass between exercising and non-exercising adults are generally less than 10%, but do not account for exercise history which may be very important, and often fail to consider important confounding variables. There is sufficient longitudinal data to demonstrate that moderate to intensive training can bring about modest increases of about 1–3% in bone mineral density of men and premenopausal women (Forwood & Burr, 1993).

In another cross-sectional study aimed to investigate bone mass in females participating in aerobic-type training. Twenty-three females (age 24.1±2.7 years) participating in aerobic exercise for about 3 hours/week were compared with 23 age-, weight- and height-matched sedentary females. Areal bone mineral density was measured in total body, head, whole dominant humerus, lumbar spine, right femoral neck, Ward's triangle, trochanteric, in specific sites in right femur diaphysis, distal femur, proximal tibia and tibial diaphysis, and bone mineral content (BMC) was measured in the whole dominant arm and right leg, using dual energy X-ray absorptiometry. The aerobic workout group had significantly higher BMD in total body (3.7%), lumbar spine (7.8%), femoral neck (11.6%), Ward's triangle (11.7%), trochanteric (9.6%), proximal tibia (6.8%) and tibia diaphysis (5.9%) compared to the non-active controls. In young females, aerobic workout containing alternating high and low impact movements for the lower body is associated with a higher bone mass in clinically important sites like the lumbar spine and hip, but muscle strengthening exercises like push-ups and soft-glove boxing are not associated with a higher bone mass in the dominant humerus. It appears that skeletal adaptation is site-specific to the activity of loading (Alfredson, Nordström, & Lorentzon, 1997).

2.7 Athletic Population and Bone Adaptation

Studies involving recreational as well as elite athletes have provided valuable information regarding the relationship between types of sports activities/mechanical loading and bone adaptation. Athletes that partake in resistance training have a higher BMD (Karlsson et al., 1993). Resistance athletes show an increase in both bone resorption and formation markers indicating that there is a high level of bone remodeling occurring. Sedentary individuals exhibit an increase in bone resorption markers without an increase in bone formation markers (Shackelford et al., 2004). The mechanical loading imposed by specific sports activities is accompanied by site-specific enhancement of BMD (Fehling et al., 1995). Skeletal tissue appears to be particularly responsive to dynamic loading as opposed to static loading (Martyn-St James & Carroll, 2006). In order to elicit a significant osteogenic response, sports-related mechanical stimuli are most effective when the threshold intensity is exceeded. As a result, sports involving high-impact and odd-impact motion, such as volleyball, hurdling and squash have a more pronounced effect on BMD than lower impact sports such as running, swimming and diving (Egan et al., 2006). In a recent study assessing BMD of the lumbar spine and proximal femur in a high number of young male and female athletes performing different top level sports, the highest BMD values were found in power/combat athletes and in team sport athletes in both genders (Hagmar, Berglund, Brismar, & Hirschberg, 2012).

Fig. (1). Bone mineral densities of the lumbar spine (BMD L2-L4) of the different groups (mean ± standard deviation).

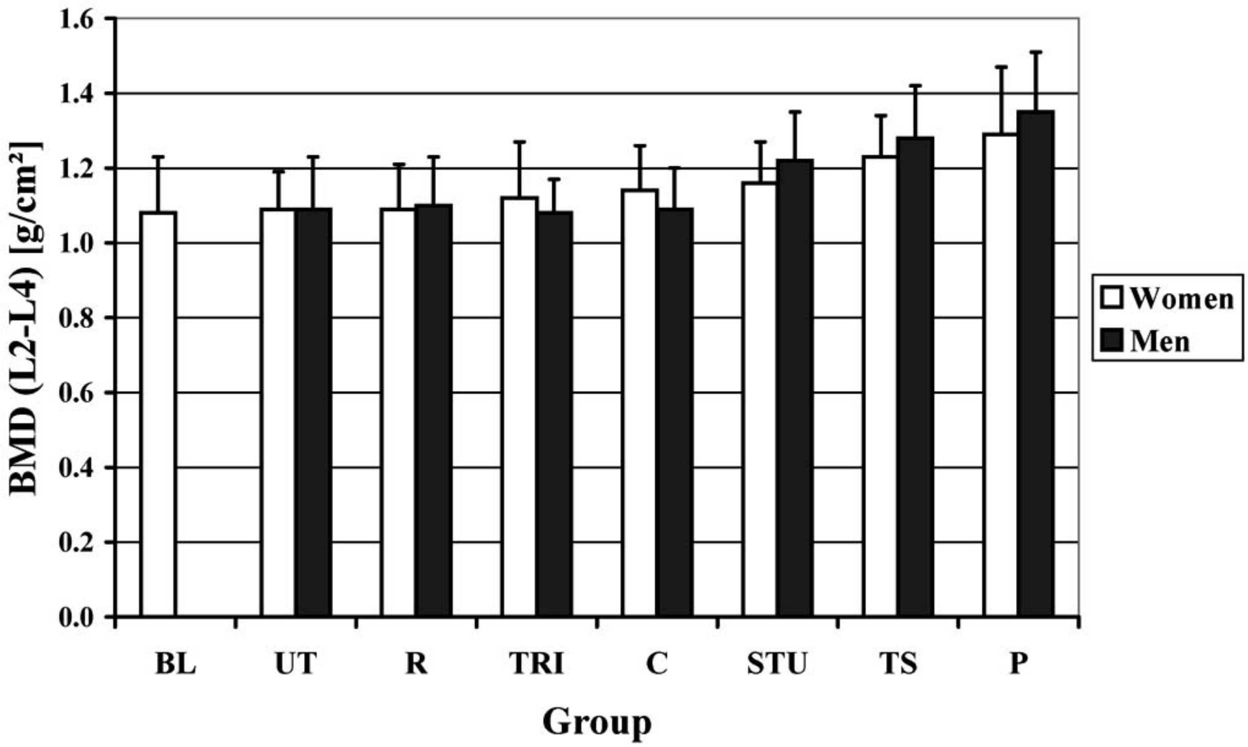


Fig. (1). Bone mineral densities of the lumbar spine (BMD L2-L4) of the different groups (mean ± standard deviation).

BL=Ballet dancers; UT=Untrained controls; R=Runners; TRI=Triathletes; C=Cyclists; STU=Sport Students; TS=Team sport athletes; P=Power/Combat athletes.

These results suggest that activities involving high GRF’s placed upon the skeleton in multidirectional planes of movement are most osteogenic to the skeleton.

Because of the recent growth in cheerleading, especially with males, there have been no studies that examine the bone mineral density and bone adaptation in this special population.

CHAPTER 3

METHODS

3.1 Participants

Twelve male members of the Wichita State University cheer team and 12 age, height, and weight-matched recreationally active male control subjects volunteered for the study. All participants gave written informed consent prior to testing. All methods and procedures were approved by the Wichita State University Institutional Review Board (Appendix). Subject inclusion and exclusion criteria were as follows:

Inclusion:

- Male collegiate-level cheerleader or weight/age/height-matched male controls
- Free of cardiovascular disease or taking any medication known to affect bone metabolism
- Controls were recreationally active (exercising 2-4 days/week)

Exclusion:

- Use of any medication that could affect bone metabolism
- Weight $\geq$ 300 lbs
- Controls who exercise less than 2 or more than 4 times a week
- Regular use of tobacco products

3.2 Research Design

3.2.1 Procedure

Once consent had been obtained, subjects were instructed of the pre-scan protocol which included limiting food intake at least 4 hours in advance, to refrain from heavy workouts 24 hours prior to a scan, arrive hydrated, and to wear appropriate clothing as to not interfere with the DXA scan. All testing for this study was performed in the Human Performance Laboratory located within the Department of Human Performance Studies at Wichita State University. Upon arrival, subjects filled out a Health Status and History questionnaire (Appendix). Subjects were then asked to provide a urine sample to test hydration status. After hydration was confirmed, subjects were measured for height and weight and underwent a DXA scan of the whole body, Lumbar spine, and right and left hip.

3.2.2 Questionnaire

All subjects filled out a Health Status and History questionnaire to identify subject demographics including age, years of cheerleading, exercise training characteristics, and information pertaining to the exclusion/inclusion criteria.

3.2.3 Anthropometric Measures

Height was measured to the nearest 0.1 centimeter (cm) with use of a standard wall-mounted stadiometer. Body mass was obtained to the nearest 0.1 kilogram (kg) with a calibrated digital physician's scale.

3.2.4 Dual Energy X-ray Analysis

All participants had DXA (Hologic, Discovery Series, Bedford, MA) scans to assess areal bone mineral density (BMD) of the whole body, dual proximal femur (femoral neck, trochanter, and total hip) and AP lumbar spine (L1-L4). A whole body scan was performed to obtain bone free appendicular lean mass (AppLM), total bone free lean body mass (LM), total fat mass (FM), and percent body fat (%BF). Quality assurance testing (QA) was performed each day according to the manufacturer's procedures to ensure that the DXA was operating properly. QA testing consisted of scanning a phantom spine block of known density to determine precision of the measured density. The DXA's software automatically determines if the QA scan passes or fails. For the whole body scan, the participants laid supine on the DXA table with arms close to the sides and within the table's scan area. Tape was placed around their feet to ensure that the legs remained still and relaxed. For the AP lumbar spine scan, the legs were lifted and set on a foam block, such that the there was a bend in the knee, and the angle created by the thighs and the scanning bed was 45-90 degrees. The technician ensured that the iliac crests were even, and the lumbar spine was resting flat on the scanner bed. The scanner arm was centered with the torso as marked by the participant's navel, and placed approximately 5 cm below the navel to ensure that the iliac crests as well as the T12 vertebra were visible on the scan. The subjects' arms were crossed and rested behind the head and the scan was started. For the dual femur scans, participants' legs were internally rotated and secured in place to ensure proper exposure of the femoral neck and the femur was positioned parallel to the scanning boundary. The scan began just below the pubic symphysis, centered on the thigh being scanned, and finished 3 to 4 sweeps above the head of the femur. All scans were performed by the same trained technician with day to day technician precision ranging from 0.38 – 1.1% for the sites of interest. Analyses of all scans were performed according to the manufacturer's specifications.

3.3 Data Analyses

Data are reported as mean ± SD for all dependent variables. Statistical analyses were performed using SPSS for Windows version 20.0 (IBM, Armonk, NY). Mean differences between groups for all dependent variables were determined using the independent-samples t-test. An alpha level of 0.05 was used to reject the null hypothesis.

CHAPTER 4

RESULTS

4.1 Subject Characteristics

Participant characteristics are presented in Table 4.1. A total of twenty-nine individuals were recruited (12 cheer/17 recreationally-active). The participants consisted of 12 collegiate male cheerleaders and 12 recreationally-active as the control group. The 12 individuals in the control group that were most closely matched (age,weight, and height) to the cheerleaders were used for comparison. All twenty-four participants in this study were between the ages of nineteen and twenty-seven. There were no significant differences in age, height, weight, and BMI between the 2 groups. However, the exercise minutes per week between t he groups were significantly different.

TABLE 4.1. SUBJECT CHARACTERISTICS FOR CHEER AND CONTROL GROUP

	Participants	
Variables	Cheer (N=12)	CON (N=12)
Age (yrs)	22.58 ± 2.31	22.67 ± 1.67
Height (m)	1.80 ± .07	1.81 ± .06
Weight (kg)	86.81 ± 9.54	86.19 ± 7.51
BMI	26.93 ± 3.36	26.35 ± 2.36
Ex_Min_Wk	111.25 ± 46.33	65.42 ± 27.59
Experience	2.92 ± 2.15	
Day_Ex_Wk		3.67 ± .65

Values expressed as Mean ± SD; BMI: Body Mass Index; Ex_Min_Week: Exercise Minutes per Week; Day_Ex_Week: Days of Exercise per Week

4.2 Body Composition

Body composition data for each group are presented in Table 4.2. The male collegiate cheerleaders' appendicular lean mass and total lean mass were significantly greater (33.56 ± 3.37 and 72.22 ± 6.56 kg) compared to CON (29.57 ± 2.73 and 66.19 ± 5.09), $P<0.05$. The cheerleaders also had a lower percentage of body fat and total fat mass (13.1 ± 4.48% and 11.66 ± 5.10kg) compared to CON (18.92 ± 4.53% and 16.30 ± 4.66kg), $P<0.05$.

TABLE 4.2. BODY COMPOSITION FOR CHEER AND CONTROL GROUPS

	Participants		
Variables	Cheer (N=12)	CON (N=12)	P Value
%BF	13.01 ± 4.48	18.92 ± 4.53	0.005
Fat Mass (kg)	11.66 ± 5.10	16.30 ± 4.66	0.029
AppLM (kg)	33.56 ± 3.37	29.57 ± 2.73	0.004
Total LM (kg)	72.22 ± 6.56	66.19 ± 5.09	0.02

Values expressed as Mean ± SD; App: Appendicular; LM: Lean Mass

4.3 Bone Mineral Density

BMD measures for both cheerleaders and CON are presented in Table 4.3. Although there were no statistically significant differences in any of the BMD variables between cheerleaders and CON, P>.05, the average Z-scores at clinically significant sites ranged from 0.3 to 1.3 standard deviations above the age and ethnicity-related population norm, as defined by the World Health Organization. Average z-scores are presented in Table 4.4.

TABLE 4.3. BONE MINERAL DENSITY FOR CHEER AND CONTROL GROUPS

	Participants		
Variables	Cheer (N=12)	CON (N=12)	P Value
SpineBMD	1.16 ± .12	1.08 ± .137	0.182
SpineBMC	80.75 ± 9.68	76.52 ± 15.01	0.421
LHTotBMD	1.17 ± .06	1.11 ± .13	0.128
LHTotBMC	48.26 ± 5.08	46.93 ± 7.17	0.605
LHFemBMD	1.10 ±.09	1.06 ± .18	0.514
LHFemBMC	6.11 ± .54	6.11 ± 1.13	0.991
LHTrcBMD	.86 ± .06	.81 ± .08	0.064
LHTrcBMC	11.62 ± 1.31	10.87 ± 2.04	0.299
RHTotBMD	1.17 ± .08	1.11 ± .10	0.095
RHTotBMC	47.82 ± 5.07	46.64 ± 6.04	0.610
RHFemBMD	1.12 ± .12	1.05 ± .18	0.262
RHFemBMC	6.10 ± .72	5.94 ± 1.01	0.668
RHTrcBMD	.87 ± .05	.81 ± .07	0.053
RHTrcBMC	11.55 ± 1.44	11.12 ± 1.80	0.524

Values expressed as Mean ± SD; BMD: Bone Mineral Density; BMC: Bone Mineral Content; LH: Left Hip; Tot: Total; Fem: Femoral Neck; Trc: Trochanter

TABLE 4.4. Z-SCORES FOR CHEER AND CON GROUPS

	Participants		
Variables	Cheer (N=12)	CON (N=12)	P Value
Spine	.392 ± 1.04	-.091 ± 1.31	0.337
LHTot	.867 ± .48	.518 ± .93	0.263
LHFem	1.15 ± .71	1.1 ± 1.39	0.836
RHTot	.85 ± .60	.51 ± .70	0.22
RHFem	1.30 ± .94	.95 ± 1.33	0.476

Values expressed as Mean ± SD; LH: Left Hip; RH: Right Hip; Fem: Femoral Neck; Tot: Total

CHAPTER 5

DISCUSSION

To the best of the author’s knowledge, this is the first study to measure BMD and body composition characteristics in male competitive cheerleaders. Numerous studies have documented the effects of exercise or sport on BMD. The findings in this study are similar to other studies that have examined elite or collegiate players involved in high-repetitive preferential loading on the spine and hip, such as gymnasts and dancers.

Cheerleading is a strenuous sport requiring the cheerleaders to perform stunts, jumps, motions, and tumbling while yelling at the top of their voices, and all of this is done without any type of breaks. Collegiate cheerleaders do not get a break during the game, nor do they get a break during timeouts or in between quarters. In fact, these are times when the cheerleaders are required to perform even harder to gain the crowd’s attention. Competitive cheerleaders do not get a break either; they give every ounce of their energy to their two minute and thirty second routine. While this may not sound difficult, it requires extreme physical and mental strength. In cheerleading every squad member must be able to stunt, jump, and tumble. All of these activities are things that can require substantial amounts of strength.

College cheerleading is one of the most distinctive types of cheerleading as it is the only type of cheerleading that involves both side-line cheering and also competitive cheer. Unlike All Star cheer, whose main goal is to compete in as many competitions as possible, colleges are only allowed to compete at one national competition, either that of the National Cheerleading Association (NCA) or that of the Universal Cheerleading Association (UCA). These two organizations even require the squads competing to sign a form stating that they will only compete at that particular competition and no others for the entire year.

Cheerleaders put a lot of strain on every muscle and bone in their bodies. Cheerleading is a unique sport because it is one of the only ones that has practices year-long. Because of this, cheerleaders devote many, many hours of hard work and practice which helps develops extreme strength and muscular endurance.

5.1 Collegiate Cheerleaders and Body Composition

The present study revealed that male collegiate cheerleaders exhibit significantly greater lean mass characteristics and decreased fat mass characteristics compared to their age, height, and weight-matched controls. This is not surprising because of the frequent rigorous amount of training that the cheerleaders participate in. In addition to the mandatory practices, many cheerleaders additionally supplement their training with weightlifting to enhance performance. The analysis of body composition and its relationship to sports performance is part of the science of anthropometry, or human body measurement. Anthropometric studies are conducted in an attempt to determine the precise elements of body composition that contribute to sports performance (Stefanović et al., 2012). Research has demonstrated correlations between body composition and performance in sports as diverse as badminton, weightlifting, basketball, volleyball, judo, gymnastics and marathon running.

Among the more commonly measured elements of body composition are overall body weight, or mass, and the relative percentages of body fat and lean, or non-fat, tissue. In certain sports, such as football, high amounts of body mass, including both lean and fat tissues, are advantageous, while in other sports such as endurance running it is important to be very lean, which cuts down on wind resistance and reduces the amount of energy they require to move their body mass.

5.2 Collegiate Cheerleaders and BMD

No statistical differences in BMD were found between the groups. However, the z-scores at the clinically relevant bone sites of interest ranged from 0.3 to 1.3 standard deviations above the population normative BMD values. These results suggest that the physical demands that male competitive cheerleaders undergo may indeed result in favorable bone adaptations to the skeleton. It should also be noted that our study was limited by the number of male competitive cheerleaders in our sample, and therefore, our statistical power was not high enough to detect significant differences in the BMD variables between the two groups.

5.3 Conclusion

From this study, it can be concluded that male collegiate cheerleaders had greater side-to-side appendicular and lean mass and lower fat mass and & percentage of body fat compared to the control group. Therefore, the type of exercise and conditioning that the cheerleaders participate likely have an overall positive affect on the body.

5.4 Recommendation for Future Study

This study raised further questions about understanding the true effect of cheerleading on BMD, as well as the need for published peer-reviewed literature on the sport of cheerleading at the collegiate level. For further research into the effects of cheerleading on BMD, it would be suggested to investigate more specifically the mechanical loading on the male cheerleaders by possible breaking them into categories. Because cheerleading encompasses so many characteristics of different sports, there is a diverse range of body composition. There are male cheerleaders who focus more on stunting and basing and therefore have a bigger frame compared to others who might focus more on tumbling and have a smaller frame. In addition, this author would recommend expanding this study by adding more variables that may or may not be influencing the BMD and body composition of the male cheerleader to determine if cheering alone is enough activity to induce an osteogenic effect on bones. Such variables would include analyzing the nutrition of the cheerleaders. Nutrition is known to have an influence on BMD. Weightlifting regimens would be another variable to look at. It may include a control group of cheerleaders who only practice with no supplemental workouts and an experimental group that cheer and includes supplemental workouts. These variables would be tested in a longitudinal study so that observations could be about the cheerleaders over an expanded period of time.

Another recommendation would be to expand this type of research on cheer and BMD to determine if cheer has an effect on forearm BMD. Analyzing BMD of the forearm could be used to determine the effect of the single-arm stunting. Further research on cheerleading and BMD would be beneficial to determine the osteogenic effect of cheer on BMD. This could be used to encourage the popularization of the sport of cheerleading at a younger age when building BMD is most critical.

References

References

Alfredson, H., Nordström, P., & Lorentzon, R. (1997). Aerobic workout and bone mass in females. *Scandinavian Journal of Medicine & Science in Sports, 7*(6), 336-341.

Ali, N. S., Shonk, C., & El-Sayed, M. S. (2009). Bone health in men: influencing factors. *American Journal of Health Behavior, 33*(2), 213-222.

Andreoli, A., Monteleone, M., Van Loan, M., Promenzio, L., Tarantino, U., & De Lorenzo, A. (2001). Effects of different sports on bone density and muscle mass in highly trained athletes. *Medicine Science and Sports Exercise, 33*(4), 507-511.

Bassey, E. J., Rothwell, M. C., Littlewood, J. J., & Pye, D. W. (1998). Pre- and postmenopausal women have different bone mineral density responses to the same high-impact exercise. *Journal of Bone and Mineral Research, 13*(12), 1805-1813.

Boskey, A. L., & Posner, A. S. (1984). Bone structure, composition, and mineralization. *The Orthopedic clinics of North America, 15*(4), 597-612.

Brunader, R., & Shelton, D. K. (2002). Radiologic bone assessment in the evaluation of osteoporosis. *American Family Physician, 65*(7), 1357-1364.

Burr, D. B. (1997). Muscle Strength, Bone Mass, and Age-Related Bone Loss. *Journal of Bone and Mineral Research, 12*(10), 1547-1551.

Caetano-Lopes, J., Canhao, H., & Fonseca, J. E. (2009). Osteoimmunology--the hidden immune regulation of bone. *Autoimmune Rev, 8*(3), 250-255.

Carter, D. R., Bouxsein, M. L., & Marcus, R. (1992). New approaches for interpreting projected bone densitometry data. *Journal of Bone and Mineral Research, 7*(2), 137-145.

Clarke, B. (2008). Normal Bone Anatomy and Physiology. *Clin J Am Soc Nephrol 3: S131–S139*.

Cummings Sr, B. D. B. D. M. (2002). Clinical use of bone densitometry: Scientific review. *JAMA, 288*(15), 1889-1897.

Cummings, S. R., Nevitt, M. C., Browner, W. S., Stone, K., Fox, K. M., Ensrud, K. E., . . . Vogt, T. M. (1995). Risk factors for hip fracture in white women. Study of Osteoporotic Fractures Research Group. *N English Journal of Medicine, 332*(12), 767-773.

Dawson-Hughes, B., Harris, S. S., Krall, E. A., & Dallal, G. E. (1997). Effect of calcium and vitamin d supplementation on bone density in men and women 65 years of age or older. *New England Journal of Medicine, 337*(10), 670-676.

Egan, E., Reilly, T., Giacomoni, M., Redmond, L., & Turner, C. (2006). Bone mineral density among female sports participants. *Bone, 38*(2), 227-233.

Fehling, P. C., Alekel, L., Clasey, J., Rector, A., & Stillman, R. J. (1995). A comparison of bone mineral densities among female athletes in impact loading and active loading sports. *Bone, 17*(3), 205-210.

Flynn, A. (2003). The role of dietary calcium in bone health. *Proceedings of the Nutrition Society, 62*(04), 851-858.

Forwood, M. R., & Burr, D. B. (1993). Physical activity and bone mass: exercises in futility? *Bone and Mineral, 21*(2), 89-112.

Friedlander, A. L., Genant, H. K., Sadowsky, S., Byl, N. N., & Glüer, C.-C. (1995). A two-year program of aerobics and weight training enhances bone mineral density of young women. *Journal of Bone and Mineral Research, 10*(4), 574-585.

Guadalupe-Grau, A., Fuentes, T., Guerra, B., & Calbet, J. L. (2009). Exercise and bone mass in adults. *Sports Medicine, 39*(6), 439-468.

Hadjidakis, D. J., & Androulakis, II. (2006). Bone remodeling. *Academy of Science*, 385-396.

Hagmar, M., Berglund, B., Brismar, K., & Hirschberg, A. L. (2012). Body composition and endocrine profile of male olympic athletes striving for leanness. *Clinical Journal of Sport Medicine, 28*, 28.

Hind, K., & Burrows, M. (2007). Weight-bearing exercise and bone mineral accrual in children and adolescents: A review of controlled trials. *Bone, 40*(1), 14-27.

Kanis, J. A., Black, D., Cooper, C., Dargent, P., Dawson-Hughes, B., De Laet, C., . . . the National Osteoporosis Foundation, U. A. (2002). A new approach to the development of assessment guidelines for osteoporosis. *Osteoporosis International, 13*(7), 527-536. Karlsson, M. K., Johnell, O., & Obrant, K. J. (1993). Bone mineral density in weight lifters. *Calcified Tissue International, 52*(3), 212-215.

Kohrt, W. M., Barry, D. W., & Schwartz, R. S. (2009). Muscle forces or gravity: what predominates mechanical loading on bone? *Medicine of Science and Sports Exercise, 41*(11), 2050-2055.

Korhonen, M. T., Heinonen, A., Siekkinen, J., Isolehto, J., Alen, M., Kiviranta, I., & Suominen, H. (2012). Bone density, structure and strength, and their determinants in aging sprint athletes. [Article]. *Medicine and Science in Sports and Exercise, 44*(12), 2340-2349.

Levasseur, R., Sabatier, J.-P., Potrel-Burgot, C., Lecoq, B., Creveuil, C., & Marcelli, C. (2003). Sympathetic nervous system as transmitter of mechanical loading in bone. *Joint Bone Spine, 70*(6), 515-519.

Little, K. D., & Clapp, J. F., 3rd. (1998). Self-selected recreational exercise has no impact on early postpartum lactation-induced bone loss. *Medicine of Science and Sports Exercise, 30*(6), 831-836.

Marshall, D., Johnell, O., & Wedel, H. (1996). Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fractures. *Bone Mineral Journal, 312*(7041), 1254-1259.

Martyn-St James, M., & Carroll, S. (2006). Progressive high-intensity resistance training and bone mineral density changes among premenopausal women: evidence of discordant site-specific skeletal effects. *Sports Medicine, 36*(8), 683-704.

Martyn-St James, M., & Carroll, S. (2010). Effects of different impact exercise modalities on bone mineral density in premenopausal women: a meta-analysis. *Journal of Bone Mineral Metabolism, 28*(3), 251-267.

Miller, R. K., & Washington, K. (2011). Chapter 55: Competitive Cheerleading. *Sports Marketing*, 263-264.

Mohan, S., & Baylink, D. J. (1991). Bone growth factors. *Clinical Orthopaedics and Related Research*(263), 30-48.

Nilsson, B. E., & Westlin, N. E. (1971). Bone Density in Athletes. *Clinical Orthopaedics and Related Research, 77*, 179-182.

Olsen, B. R., Reginato, A. M., & Wang, W. (2000). Bone Development. *Annual Review of Cell and Developmental Biology, 16*(1), 191-220. doi: doi:10.1146/annurev.cellbio.16.1.191

Otto, F., Thornell, A. P., Crompton, T., Denzel, A., Gilmour, K. C., Rosewell, I. R., . . . Owen, M. J. (1997). Cbfa1, a candidate gene for cleidocranial dysplasia syndrome, is essential for osteoblast differentiation and bone development. *Cell, 89*(5), 765-771.

Papachroni, K. K., Karatzas, D. N., Papavassiliou, K. A., Basdra, E. K., & Papavassiliou, A. G. (2009). Mechanotransduction in osteoblast regulation and bone disease. *Trends in Molecular Medicine, 15*(5), 208-216.

Rahimian, M. M. (2004). Assessment of Bone Mineral Density (BMD) in dominant and non dominant arms of female in racquet and non-racquet sport. *In Australian Association for Exercise and Sports Science, Exercise & Sports Science Conference: From Research to Practice April 13th - 16th April 2004, Brisbane, Australia, Australian Association for Exercise and Sports Science, 2004, p.1.* Australia.

Robling, A. G., Duijvelaar, K. M., Geevers, J. V., Ohashi, N., & Turner, C. H. (2001). Modulation of appositional and longitudinal bone growth in the rat ulna by applied static and dynamic force. *Bone, 29*(2), 105-113.

Robling, A. G., Niziolek, P. J., Baldridge, L. A., Condon, K. W., Allen, M. R., Alam, I., . . . Turner, C. H. (2008). Mechanical stimulation of bone in vivo reduces osteocyte expression of Sost/sclerostin. *Journal of Biology Chemistry, 283*(9), 5866-5875.

Rodan, G., & Martin, T. J. (1981). Role of osteoblasts in hormonal control of bone resorption—A hypothesis. *Calcified Tissue International, 33*(1), 349-351.

Shackelford, L. C., LeBlanc, A. D., Driscoll, T. B., Evans, H. J., Rianon, N. J., Smith, S. M., . . . Lai, D. (2004). Resistance exercise as a countermeasure to disuse-induced bone loss. *Journal of Applied Physiology, 97*(1), 119-129.

Shields, B. J., & Smith, G. A. (2009). Cheerleading-related injuries in the united states: a prospective surveillance study. *Journal of Athletic Training, 44*(6), 567-577.

Smathers, A. M., Bemben, M. G., & Bemben, D. A. (2009). Bone density comparisons in male competitive road cyclists and untrained controls. *Medicine Science and Sports Exercise, 41*(2), 290-296.

Snow-Harter, C., Bouxsein, M. L., Lewis, B. T., Carter, D. R., & Marcus, R. (1992). Effects of resistance and endurance exercise on bone mineral status of young women: A randomized exercise intervention trial. *Journal of Bone and Mineral Research, 7*(7), 761-769.

SooHoo, S., Sell, K., & Reel, J. J. (2005). Cheerleading. *Berkshire Encyclopedia of World Sport, 1*, 301-306.

Stefanović, N., Ćirić, I., Pavlović, S., Kundalić, B., Bubanj, S., Petković, E., . . . Antić, V. (2012). Evaluation of some anatomical and anthropometric characteristics of the chest based on the analysis of digital images of the anterior aspect of trunk in top athletes *Acta Facultatis Medicae Naissensis* (Vol. 29, pp. 43).

Suominen, H. (2006). Muscle training for bone strength. *Aging Clinical and Experimental Research, 18*(2), 85-93.

Trussel, A., Muller, R., & Webster, D. (2012). Toward mechanical systems biology in bone. *Annals of Biomedical Engineering, 40*(11), 2475-2487.

Turner, C. H. (1999, Oct 1999). *Mechanical loading effects on bone cells.* Paper presented at the *[Engineering in Medicine and Biology, 1999. 21st Annual Conference and the 1999 Annual Fall Meetring of the Biomedical Engineering Society*] BMES/EMBS Conference, 1999. Proceedings of the First Joint.

Turner, C. H., & Robling, A. G. (2003). Designing exercise regimens to increase bone strength. *Exercise Sport Science Review, 31*(1), 45-50.