ABSTRACT

A Review of the Significance of Calcium & Vitamin D in the Occurrence Stress Fractures

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Stress fractures have historically been a common problem for athletic populations, especially athletic women. Professional ballerinas are specifically harmed by these injuries and many years of research have been spent discovering what factors concerning anthropometrics, lifestyle, and diet correlate most strongly with these occurrences. Early research on this topic focused mainly on calcium intake, due to calcium's obvious role in bone structure and integrity. However, inconsistent findings and statistically insignificant differences in calcium intake between test groups from many research studies demonstrated that there is more to bone health than calcium alone. Current research has shifted to include vitamin D and other nutrients in cooperation with calcium to provide a clearer picture of the dietary factors of bone health. Dancers who experienced stress fractures often exhibited levels of 25-hydroxy-vitamin D below 30 ng/dl, the lower limit of the recommended serum vitamin D range for optimal health, indicating the importance of vitamin D to bone integrity. A critical review of nearly thirty years of research will be conducted to make a conclusion on the significance of calcium and vitamin D in the occurrence of stress fractures and how dietary adjustments can help ballerinas to avoid fractures.

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A REVIEW OF THE SIGNIFICANCE OF CALCIUM & VITAMIN D IN THE OCCURRENCE STRESS FRACTURES

A Thesis Submitted to the Faculty of

Baylor University

In Partial Fulfillment of the Requirements for the

Honors Program

By

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Waco, Texas

May 2015

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ACKNOWLEDGMENTS

I would like to acknowledge Mr. Stanley Wilfong for his assistance with the creation of this thesis, as well as his encouragement and expertise. I would also like to thank Dr. Suzy Weems and Dr. Bill Neilson for their participation in my defense process. Lastly, I would like to thank Baylor University for providing the opportunity to do this project and for the resources to complete it.

DEDICATION

In appreciation to Mr. Stanley Wilfong, Dr. Suzy Weems, and Dr. Janelle Walter

To Lucas

CHAPTER ONE

An Introduction to the Nature of Ballet and Stress Fractures

Introduction

A person's nutritional needs have long been a topic of conversation for doctors, dietitians, the government, and the average person at home. The nutritional needs of athletes and active persons have increasingly become a matter of importance. From Gatorade commercials to protein powder available in every grocery store, people have a high regard for nutrition and its relationship with athletic performance.

When thinking of athletes, football and basketball players and Olympic champions come to mind. Professional ballet is not often considered part of the athletic world. However, ballerinas push their bodies to limits comparable to that of any professional athlete and their nutritional needs are complex. Poor nutrition coupled with a high degree of physical activity can accompany a large number of nutritional and physical disorders and injuries.

The role that vitamins and minerals play in the health of a professional dancer's bones has been a topic long explored by researchers, specifically how calcium and vitamin D intake and body levels correlate with the incidence of stress fractures in female ballet dancers and athletes. Following an introduction to ballet and stress fractures, research on calcium and vitamin D concerning stress fractures will be reviewed and evaluated to determine the relationship between these nutrients and the incidence of stress fractures. With this information a conclusion will be made for the validity of supplementation of these nutrients as a means for stress fracture prevention.

Introduction to Ballet

The athleticism involved in various forms of dance, specifically ballet, is often overlooked in light of more physical team and individual sports. However, dancers train as rigorously as any professional athlete and their bodies often suffer the physical consequences of overuse, as well as the effects of an inadequate diet.

Originating in the Italian renaissance courts, ballet evolved over the years into the style that audiences are accustomed to today. Russian, French, and Italian "schools of thought" concerning technique and execution have formed a very recognizable form of dancing that is viewed today as "Classical Ballet" ("A Brief History of Ballet") Ballet has been made very available to society. Children and adults are able to take lessons at an amateur level for recreation and exercise. Professional performances can be seen at ballet companies, and amateur performances are given through dance schools, colleges, and community groups.

For a young adult female preparing for a career as a professional ballet dancer, the training schedule followed consists of classes in a variety of styles and themes seven hours a day, five days a week. Styles include ballet, jazz, modern, technique, partnering, and character development. This does not include time a dancer may spend on her own at the gym lifting weights, doing additional aerobic exercise, or stretching to increase flexibility. Classroom courses such as nutrition, stress management, and career preparation are also included in ballerina's core curriculum ("Pre-Professional Ballet," 2014).

Energy Systems

Both the aerobic and anaerobic energy systems are involved in ballet dancing, though the aerobic system is mainly used. The slower and more controlled portions of routines and movements, as well as many of the *barre* exercises done at the beginning of a ballet class, are moderate-level activities and allow for methodical breathing. A constant supply of oxygen to the muscles allows for oxidative pathways to be utilized for the creation of energy for the working muscles. However, very long routines, or sets of movements requiring bursts of power, can begin to utilize the anaerobic pathway and the phosphagen system. For example, lifts performed by dancers in partner work require a great deal of physical strength. While the male dancer is the one physically lifting the female for an extended period of time, the female dancer must constantly engage her abdominal and back muscles to assist in supporting her own weight throughout the course of a routine (Hamilton, Hamilton, Marshall, & Molnar, 1992, 267). Additionally, leaps, fast-paced dance combinations, and intricate footwork also require some anaerobic energy. However, these rapid dance moves and quick portions of a are often followed by rest, either with slower dancing or a movement of the dancer off the stage, allowing the aerobic system to resume the majority of the energy-producing tasks as the dancer rests and returns to a lower heart rate and rate of breathing.

Bone and Muscle Groups

Muscular strength and flexibility are important attributes in a dancer. The main muscle groups used by a ballet dancer consist of the "core" and the muscles of the legs and feet. The abdominal, oblique, and back muscles make up the "core" of the dancer.

This core enables the dancer to maintain her posture and balance in the majority of her moves. The muscles of the legs, ankles, and feet are used constantly. The main muscles used by a ballerina include the quadriceps, hamstrings, external hip rotator and gluteal muscles, the gastrocnemius, and the small muscles in the feet (Hamilton, Hamilton, Marshall, & Molnar, 1992, 267). The bones that are under the most pressure in a dancer are the distal tibia and fibula, as well as the calcaneus, metatarsal bones, phalanges of the feet. While the bones are under a great deal of pressure while dancing in a soft ballet shoe, the force on these bones increases when the dancer performs in pointe shoes. However, features of the pointe shoe work to help to reduce certain forces acting on the bones of the foot by offering support and distribution of weight. The specific structure of the pointe shoe is very important for its proper functioning and for the performance success of a dancer.

Pointe Shoes

A pointe shoe is a specific type of footwear worn primarily by female ballet dancers. The shoes consist of the box or the block, the hardened area of the shoe consisting of the wings, vamp, and platform, the outsole, the insole, and the sock. The box is created in a similar manner to papier-mâché, where several layers of a variety of fabrics are held together with a special paste. The box acts to hold and support the foot when upright *en pointe*. The vamp is the front part of the box, over the anterior surface of the foot. The wings go up the side of the foot to hold it tightly and the platform is the flat end upon which the dancer balances. The sock is the fabric of the shoe, which covers the insole. The outsole is on the bottom outside of the shoe. The shoes also contain a

drawstring around the opening, allowing for a customizable fit for the dancer ("Grishko Pointe Shoe Fitting"). The exact dimensions and shapes of the different parts of the shoe vary for different styles. This way, a dancer can choose a shoe that provides the best fit and support for her foot. She can additionally tape her feet with athletic tape to provide a more exact fit and increase soft tissue support, and the end of the box can be padded with cotton, lamb's wool, or gel to provide a softer balancing surface. The ballerina will also sew on her own ribbons and elastic in the style that she prefers, providing additional support, as well as a means for holding the shoe to the foot firmly while dancing.

Anthropometrics and Dietary Patterns of Dancers

Female ballet dancers are typically short in stature, light of weight, and have a naturally slim build. They usually range in height from 5'2" to 5'8" and weigh from 85 to 135 pounds. They tend to have long arms, legs, and necks, short torsos, and small heads (DiPalma, 2011). Historically, this body shape was sought for the aesthetic appeal of the dancer on stage and these physical attributes work positively for the dancer. A short, light-weight ballerina may be lifted more easily by a male partner, who will also likely be slim. She will also have to exert less force to move her own body weight in leaps and her toes and ankles will not have as much weight to support when the dancer is *en pointe*. Pressure is put on dancers by choreographers, directors, and themselves to achieve particular weights and sizes. Features such as well-pronounced muscles and bones, such as the collarbone, are seen as ideal. This can encourage unhealthy or even dangerous eating and exercise practices. The dietary practices of dancers are one of the main factors in many of the disorders and injuries that may occur.

The diet pattern typically followed by dancers includes low total caloric intake and few carbohydrates. By limiting their caloric intake, a low weight and defined muscles and bones are ensured. Due to misconceptions on the unhealthy qualities of carbohydrates, ballerinas tend to limit this important energy-providing nutrient in their diets. Additionally, many dancers avoid dairy due to the high fat content that may be present in milk, cheese, and other dairy products (Sousa, et. al., 2013, p. 119) On top of the few calories consumed, dancers practice many hours a week and will additionally do yoga, Pilates, lift weights, and do aerobic activities in order to maintain optimum strength, flexibility and cardiovascular fitness.

Due to the dietary practices of dancers, as well as the body image they attempt to maintain, they tend to not consume enough calories overall, causing an inadequate intake of carbohydrates, fats, and many vitamins and minerals needed by the body (Constantini, 2010). Problems such as excessive dieting, anemia, and bulimia have often characterized the stereotypical view of a dancer's nutrition (Quintas et al., 2003, p. S58). Historically a lack of nutrition education leads to these behaviors. Today, ballet companies have begun to include nutrition courses as part of professional preparation for their dancers. With theses programs dancers can be educated on the importance of good nutrition, as well as how to follow a healthy diet while maintaining an ideal weight and size.

Many diet-induced injuries and disorders are common in professional female dancers. Due to high levels of activity and low calorie diets, Female Athlete Triad syndrome is quite common. Excessive dieting, bulimia, and anorexia nervosa are also common in this field (Sousa, et. al., 2013, p. 120). Ballerinas also tend to develop bunions, ingrown toenails, sprained joints, and torn ligaments in their ankles, knees, and

hips. Due to the high amounts of stress on a dancers feet and ankles, stress fractures are also extremely common.

Stress Fractures

Stress fractures are tiny cracks in bone that result from overuse. When a muscle becomes fatigued due to repeated use it is no longer able to absorb added shock. This stress load transfers into the bone and can cause the tiny fractures over time. The majority of stress fractures in athletes occur in the feet and lower legs. This is seen very commonly in ballet dancers, especially those who dance *en pointe*. The continuous stress on the toes and ankles can eventually fatigue the supporting muscles and result in a fracture ("Stress Fractures", 2007). Dancers spend a great deal of time practicing and exercising, leaving their muscles without adequate time to heal. These muscles can quickly become overused. The bones that fracture most commonly in dancers, consistent with all athletic stress fractures, are of the distal tibia and fibula, the metatarsals, and the phalanges of the foot (Albisetti, 2010). Along with overuse, low bone density has been hypothesized to lead to a greater likelihood of experiencing a stress fracture (Myburgh, 1990). Women are more likely to have low bone density than men, due to syndromes such as Female Athlete Triad and eating disorders.

Stress fractures are often diagnosed by X-rays. However, due to the fracture's very small size, a CT scan may be necessary to appreciate the fracture. The fracture also may not be identifiable on a scan until a few weeks after the pain associated with it has begun (Bolin, 2001). The most important aspect of stress fracture recovery is rest of the affected area. This will allow for the bone to mend itself. If usual activity or increased

activity is resumed too quickly, the fracture will not heal as quickly. This may lead to a more complicated injury ("Stress Fractures," 2007). Braces or inserts in a shoe may help to keep pressure off the effected area. This presents a problem for athletes, especially dancers. She is required to miss rehearsals or dance at a lower intensity than usual, and performance scheduling cannot be changed. For these reasons, many dancers will continue to practice and perform, even on a fractured ankle, foot, or toe.

Female dancers have a variety of lifestyle habits that contribute to stress fractures. The combination of high levels of repetitive activity, short periods of rest, and poor diet can all contribute to the high likelihood of stress fractures, slow healing, and complications associated with fractures. Large amounts of research have been conducted over time examining the correlations of diet and stress fractures. The earlier research focuses most closely on calcium. More current research has examined calcium intake and levels in coordination with other minerals, such as phosphorus, vitamin D, and fluoride. In this research review, a variety of studies will be analyzed to determine to what extent calcium and vitamin D levels factor into the prevention and treatment of stress fractures, whether or not vitamin and mineral supplementation would be beneficial for dancers to prevent stress fractures.

CHAPTER TWO

The Significance of Calcium

Research concerning stress fractures in ballet dancers and other athletes originally focused on the most apparent variables, such as degree of over-use and calcium intake. Calcium was the targeted as main nutrient of focus for bone health, due to its long-known and extremely important role in development and strength. The low intake of calcium in professional dancers is largely attributed to the overall lack of caloric intake exhibited by this population. The relative importance of calcium, among a side variety of other nutrition-related topics, was and remains to be some of the most important topics of research for stress fractures in ballet dancers. The research examined in this review dates back to 1986.

An Introduction to Calcium

Calcium is an extremely important mineral for the human body. It is the most abundantly found, and is involved in a variety of body processes such as muscle contraction, nerve conduction, vasodilation, and hormone secretion. Calcium is most commonly associated with the structure and strength of teeth and bones. Bones and teeth contain almost ninety-nine percent of the body's calcium, whereas the rest is found throughout the body in muscles, intercellular fluid, and blood. This remaining one percent of calcium in the body, referred to as serum calcium, is very tightly regulated by a variety of hormones and feedback mechanisms, and is not allowed to a wide degree of fluctuation. When there is a deficit of serum calcium, the bones are demineralized to

release calcium back into the bloodstream and to the rest of the body. Conversely, when serum levels are adequately high, bones will reabsorb calcium. This occurs in a constant cycle (*Bone Formation*, Encyclopedia Britannica).

While this cycle of breakdown is extremely beneficial in maintaining adequate serum calcium levels to allow for proper cellular, muscular, and metabolic function, a diet with insufficient calcium intake can quickly lead to bones with low calcium stores. When insufficient calcium is consumed, the body must continue to remodel bone in order to supply calcium to the rest of the body. This insufficient dietary intake will not be able to supply calcium that can be reabsorbed to counteract the necessary breakdown. When breakdown exceeds formation, this can eventually lead to a softening of the bones known as osteoporosis. Weak bones are more highly susceptible to fracture (*Bone Formation*, Encyclopedia Britannica).

Children, whose long bones are undergoing continual growth and development, experience rates of bone formation that exceed rates of breakdown. Females aged approximately eighteen to fifty years old experience bone reabsorption and deposition at relatively equal rates since the bones are no longer growing. Post-menopausal females, however, tend to experience greater breakdown than formation, putting them at a higher risk for osteoporosis. Ballerinas fall into the second category, ranging usually from ages eighteen to thirty. For this age group, the Recommended Dietary Allowance of calcium per day is 1,000 mg. The Recommended Dietary Allowance, or RDA, is developed by the Food and Nutrition Board of the Institute of Medicine of the National Academies. At this level of consumption, the needs of 97-98% of healthy individuals are met without risk of

overdose or harm. Even in the case of pregnancy or lactation this amount is adequate for all body processes and proper integrity of bones (*RDA and AI's*).

The best dietary sources of calcium are found in dairy products such as milk, yogurt and cheese. Not only are there high levels of calcium in these food products, but the mineral is also highly bioavailable for absorption into the body during digestion. Nondairy sources, such as kale, broccoli, spinach, and other vegetables, have significant amounts of calcium, but are much less bioavailable. For those who are lactose intolerant or choose not to consume many dairy products, there are a wide variety of foods that are fortified with calcium, ranging from grain products to fruit juices to tofu (Fink, 2104).

Many people, often post-menopausal women, choose to take calcium supplements to help increase dietary intake. The two main forms of supplements available are calcium carbonate and calcium citrate. Calcium carbonate, which contains 40% elemental calcium by weight, is best taken with food, due to its dependence on stomach acid for absorption. Calcium citrate, which contains 21% calcium, is absorbed equally well with or without food. The percentage of calcium absorbed at once is inversely related to the amount of calcium consumed at one time. The more elemental calcium consumed, the less will be absorbed (Hanzlik, Fowler, and Fisher, 2005). People taking large doses of supplemental calcium should split the supplements into several smaller doses taken throughout the day. While calcium intake is extremely important for the health of bones, weight-bearing exercise, resistance exercises, and avoiding excess alcohol and smoking can all contribute to healthy calcium levels and strong bones.

There are a variety of ways to assess if one's calcium intake is adequate. Blood work can be done to assess serum calcium levels and there are a number of bone mineral

density tests available. The normal serum calcium range is 8.5 to 10.2 mg/dL. The results of bone mineral density (BMD) tests are given as T-scores, which compare the individual's BMD to an optimal BMD. A score of -1.0 or higher indicates normal bone density. -1.0 to -2.5 indicates osteopenia, and lower than -2.5 indicates osteoporosis (Calcium Fact Sheet).

Research Review

There have been many research studies conducted over stress fractures and dietary patterns in ballet dancers. Calcium intake, serum levels, and bone mineral density were the prime topics of the beginnings of research in this area. Several of these studies will be reviewed to create a base of knowledge concerning the nature of the relationship between diet, exercise, calcium intake, bone density and stress fractures.

Women's involvement in professional sports was limited until the 1970s, when greater participation gradually began to be seen. Many professional women's leagues were created and exiting leagues were updated with more equal rules for both men and women (Chase and Dummer, 1992). Due to this late inclusion of females in the athletic performance world, research concerning health conditions, injury, and diet of female athletes was also not conducted until relatively recently. In the 1980s, researchers discovered that young female athletes had bone mineral densities of women two to three times their age. This prematurely decreased bone density was thought to correlate with a greater risk for stress fractures. After this discovery, researchers wasted no time in exploring more variables concerning stress fractures in athletes, including professional ballet dancers.

Study 1: nutrition and the incidence of stress fractures. The first research study that will be reviewed was done in 1990 by Frusztajer, Dhuper, Warren, Brooks-Gunn, and Fox concerning nutrition and the incidence of stress fractures in ballet dancers. This study compared pairs of dancers, one with a stress fracture and one without, to a non-dancing control female, who were matched for age, weight, and height. Body weight and medical history, nutrient intake, eating patterns, menstrual patterns, and bone mineral density were determined for each of the subjects and then compared to determine which variables were most highly associated with the incidence of stress fractures.

Nutrient intake was determined by two 24-hour recall diaries, performed with the assistance of a Registered Dietitian, and through a Walter Willet semi-qualitative food frequency questionnaire. Nutritional supplementation was included in this area of data, determining the magnitude of use as a replacement for a balanced diet. Eating patterns, specifically the presence and severity of eating disorders, were determined through questionnaires, subject interviews, and physical examinations that focused on clinical signs of anorexia and bulimia. Menstrual patterns and history were obtained through interviews with a nurse practitioner, as well as body weight and medical history. Bone mineral content was determined noninvasively at the radius and the lumbar spine, and bone density of the foot, focusing on the first metatarsal, was also performed.

The results of the study showed that despite statistically similar mean caloric intakes in each of the three comparison groups, the dancers who had experienced stress fractures within the past year were more likely to restrict food intake to below 85% of recommended calorie levels. There was an observed avoidance of high-fat dairy foods,

greater consumption of low-calorie food options, and a higher incidence of eating disorders in the stress fracture group. The stress fracture group also showed a trend of continuing reduced dietary intake on weekends, while the non-stress fracture group and non-dancer group exhibited increased caloric intake. Dancer groups took larger quantities of general vitamin supplements. However, it was found that all groups had similar intakes of calcium, phosphorus, and Vitamin D. The results of menstrual patterns of menarche and amenorrhea were statistically similar for both dancer groups. Additionally, the wrist and spine bone density results were similar for all three groups, and the dancer groups exhibited greater density in the first metatarsal.

Study 2: a comparison of nutrition knowledge and attitudes. In the Journal of the American Dietetic Association, "A comparison of nutrition knowledge and attitudes, dietary practices, and bone densities of postmenopausal women, female college athletes, and nonathletic college women," was published in 1992 by Frederick L. and Hawkins ST. This study examined postmenopausal women, college-aged dancers and track athletes, as well as non-athletic college women.

Nutrition knowledge was evaluated by a written exam, where as attitudes and eating patterns were determined by personal questionnaires, 24-hour food recalls, food frequency questionnaires, and an attitude survey. High-calcium foods were of particular focus in the surveys. Additionally the average minutes per week spent exercising was obtained for each subject. Bone density was measured non-invasively at the spine.

The group of college dancers statistically differed from each of the other subject groups in the evaluations of nutrition knowledge and intake of high-calcium foods,

scoring lower than the others. The intake of high-calcium foods correlated significantly with both nutrition knowledge scores and attitude scores. However, the incidence of eating disorders was greatest in the college track athletes, as well as the most amenorrhea. This coordinated with the track athletes additionally reporting the longest amount of time spent exercising each week. Bone density showed no significant difference between all four of the groups.

Study 3: physical activity, body composition, and bone density. In 1995, a study called "Physical Activity, Body Composition, and Bone Density in Ballet Dancers," by Van Marken Lichtenbelt, Fogelholm, Ottenheijm, and Westerterp was published in the British Journal of Nutrition. One of the specific goals of this study was to obtain more precise data concerning the body composition of the dancers, so a four-component (4C) model was used in place of the customary two-component (2C) model. The 4C model uses fat, total body weight, total bone mineral content (BMC) and fat-free dry mass. The stressed importance of the body composition measurements was used in order to help find the relationship between bone mineral density and body composition, which in prior studies was found to have a positive correlation.

Information concerning menstrual patterns, training history, and possible eating disorders was obtained through oral interviewing. Total energy intake and calcium intake was measured by using a seven day dietary record, completed by the subjects after very specific oral and written instructions.

Body composition, using the above 4C method, BMC, site-specific bone mineral density (BMD) and total bone mineral density (TBMD) were all obtained using a variety

of techniques, including the use of dual X-ray absorptiometry, or DEXA. Site-specific BMD was measured at the lumbar spine.

In comparison to a control group, the dancers studied exhibited lower percent body fat, causing a lower body mass. However, there was no statistical difference in the body mass score of dancers with menstrual disorders compared to dancers with normal menses. TBMD was significantly higher in both groups of dancers as compared to the controls, due mainly to increased site-specific BMD in the legs and pelvis. No relationship was found between calcium intake and BMD, rather BMD was significantly related to BMI, as well as with daily period of training, and negatively related with the age of menarche. There was no relationship between TBMD and start of training.

Study 4: stress fractures in female army recruits. The final study to be examined in this chapter was performed in 1997. Cline, Jansen and Melby performed a study, "Stress Fractures in Female Army Recruits: Implications of Bone Density, Calcium Intake, and Exercise." Though this study did not specifically examine ballet dancers, the age of the women and the types of physical stress put on their bodies allows this study to be analogous to the other research and useful for our purpose of identifying the role of calcium in the incidence of stress fractures. In this study, female soldiers with a history of confirmed stress fractures were compared to a group of female soldiers with no history of stress fracture of other orthopedic injuries.

Habitual exercise, sports participation, and food intake were determined by retrospective self-reports and dietary recall questionnaires. Height, weight, BMI, menstrual patterns, and lifestyle factors, such as smoking, were determined through

physical exam and interview performed by a nurse practitioner. Bone mineral density was determined noninvasively at the trochanter, femoral neck, Ward's triangle, lumbar spine, and radius shaft.

Height, weight, and BMI were statistically very similar for both groups. Additionally, caloric and specific-nutrient intake was similar. Calcium intake specifically was no different between the two groups and did not correlate with bone density. Bone density was also not statistically different between the groups, though sports participation correlated with an increased bone density of the hip. Habitual past exercise and leisure activity energy expenditure, however, did tend towards an association with lower stress fracture risk as energy expenditure increased.

Conclusions

The above research projects are just a very select few of the many carried out in the 1990s that laid the foundation for stress fracture and bone density research in ballet dancers. From the research completed, it appears that subjects with longer durations of menstrual disorders have higher frequency of stress fractures. However, calcium intake seems statistically consistent across dancer and control groups, and does not appear to correlate with increased or decreased bone mineral density. Additionally total bone mineral density does not appear to vary between athletic and non-athletic subjects or between those with and without stress fractures, though site-specific bone mineral density increases with increased physical activity. This data lacks a clear picture of stress fracture incidence related to calcium.

While these conclusions have made the need for further research very clear, they have allowed researchers to determine which direction that research should take. A wider variety of variables began to be analyzed, including other significant nutrients for bone health and more accurate measures of intake and body levels of nutrients.

CHAPTER THREE

The Significance of Vitamin D

The study of bone health and the incidence of stress fractures have been more recently connected to the importance of vitamins and minerals other than calcium. Phosphorus, magnesium, and vitamin D have become more recent points of interest. As previous research has suggested, the overall intake of calcium by ballet dancers is consistent with or only slightly lower than the intake of calcium by control groups. The dancers do, however, exhibit overall decreased caloric intake. This reduced intake increases the probability that consumption of other important vitamins and minerals are reduced and body levels are low. This studies that will be reviewed in this chapter examine Vitamin D as a part of the diet and how it correlates with the incidence of stress fractures.

An Introduction to Vitamin D

Vitamin D is a fat-soluble vitamin with a wide range of uses in the body. Vitamin D has been attributed to proper transmission of nerve impulses, absorption of calcium, and has functions in the immune system. It can be obtained through diet, as well as through exposure to sunlight (Fink, 2014).

Only a select few foods contain substantial amounts of vitamin D. The most common naturally occurring sources are fatty fish, such as salmon and tuna contain high amounts of the vitamin. Eggs, mushrooms, and liver also contain the vitamin. However many foods and beverages are now fortified with vitamin D that was not previously

present. Beginning in the 1930s, a fortification program was started in the milk industry, almost completely eradicating rickets, a disease observed in children with inadequate vitamin D intake, characterized by soft brittle bones and bowed legs. Other foods and beverages, including yogurt, margarine, orange juice, and breakfast cereals, are now fortified as well, making the previously hard-to-find vitamin much more attainable in a normal diet (Fink, 2014).

Vitamin D can also be obtained by spending time in the sun. The ultraviolet light reacts to cholesterol found in the skin. A reaction occurs, converting the cholesterol into a pre-vitamin, which is later converted into active vitamin D after reactions in both the liver and the kidneys. Little sun exposure is needed in order to produce adequate amounts of vitamin D, but the exposure must be directly on the skin. Time of day, season, and latitude all effect how much ultraviolet light is able to reach your skin. Additionally, people with darker skin do not absorb as much ultraviolet light because the melanin resent in their skin blocks the absorption. When spending time in the sun, care must be taken to avoid over-exposure, which can lead to skin damage and can predispose to issues such as skin cancer (Ross, et al., 2011). Additionally, caution must be taken to avoid excessive amounts of vitamin D consumption through supplementation. Vitamin D is a fat-soluble vitamin and is stored in fatty areas of the body, such as the liver. Excess can build up and cause damage to organs and various body systems.

The group of focus, female young adults, should consume an average of 600 IU of vitamin D per day. This level is rarely met in the average adult, especially when only dietary intake is considered. Vitamin D status can be assessed through reviews of diet and supplementation (*RDA's and AI's*). However, vitamin D levels can also be tested from

blood, presenting a more complete picture of the status of the vitamin. This test, called the 25-hydroxy-vitamin D test, currently provides the most accurate measure of vitamin D in the body, Normal levels range from 30-74 ng/mL. On average, most people have levels below this range (Holick, 2009).

Considerable vitamin D deficiency can manifest in different ways depending on age. Children with vitamin D deficiency can develop rickets, a condition of soft, thin, brittle bones. In adults this is called osteomalacia, described as a gradual softening of the bones. Groups at risk for low vitamin D levels include breast-fed infants, people with dark skin, older adults and those with limited sun exposure, and people with conditions causing fat malabsorption (Holick, 2009).

Research Review

The following four research studies will be explored to continue to review information on what factors are most involved in the occurrence and prevention of stress fractures. These studies examine first the role of vitamin D in relation to overall bone health and turnover, later turning to the impact on stress fractures in active populations. Vitamin D levels in the body are measured through serum blood tests, usually 25 hydroxy-vitamin D, a precursor to the biologically active form of vitamin D in the body.

Study 1: role of vitamin D and parathyroid hormone in regulation of bone turnover and bone mass. The role of vitamin D and parathyroid hormone (PTH) in bone mineral density regulation was explored in a study performed in 2003 by Szulc, Munoz, Chapuy, and Delmas. Bone dimensions, seasonal variation of bone turnover, bone

mineral density (BMD), and bone mineral content (BMC) of specific sites and the whole body were measured. The subjects were over 800 men of varying ages.

For young men, whose results can potentially mirror those expected for you women, serum 25OHD levels varied with summer and winter seasons, highest in the summertime. However parathyroid hormone (PTH), BMD, and markers of bone turnover did not vary significantly. BMC and BMD were significantly associated with 25OHD levels. It was found, however, that PTH levels also determined BMC and bone thickness.

This data shows the importance of sun exposure in obtaining an adequate amount of vitamin D in the body. In winter months people are more often inside, and less ultraviolet light reaches the skin. This seasonal variation of vitamin D status may be seen to mirror seasonal injury rates, which were not examined in this study.

Study 2: associations between serum 25(OH)D concentrations and bone stress fractures. This 2006 study, performed by a Finnish group, on young adult male military recruits undergoing basic training (Ruohola, et al.). The study was conducted to identify whether vitamin D status is a predisposing factor for the likelihood of stress fractures. The recruits were assessed for stress fractures under homogenous circumstances for physical activity, sunlight exposure, diet. This data was compared with vitamin D status, measured as serum 25(OH)D, age, height, weight, BMI, and physical activity.

Of the 800 young men randomly selected for the trial, 756 completed the study. Those who did not develop stress fractures were used as controls. Though relatively few, 2.9% of the subjects, were diagnosed with stress fractures, these men consistently exhibited a serum vitamin D level significantly below median serum levels. This stood as

the only tested factor to correlate with the occurrence of stress fractures, indicating that low vitamin D levels is a predisposing condition to the development of the injury.

While this study focuses on the opposite gender and differing physical activity from female dancers in the other studies, the similarity of situation makes the study applicable for review. The study had a large sample number and had sufficient control subjects. Further study could be done in order to determine why the young men with fractures had lower vitamin D status, considering the homogeneity of living and training situations experienced by all of the recruits.

Study 3: vitamin D status in professional ballet dancers: winter vs summer. In this study, performed in 2012 by Wolman, et. al., biochemical markers of bone health and injury status was surveyed over a six month period in female professional ballet dancers. The driving thought behind the study was that dancers, who train indoors, have limited sun exposure and are therefore more prone to vitamin D deficiencies. The six-month period was followed in order to see potential differences in vitamin D levels during winter and summer months. Vitamin D was measured as serum 25-hydroxyvitamin D, and parathyroid hormone levels and blood serum bone turnover markers were measured to attain a picture of vitamin D status and bone health. Injuries were also recorded.

The data obtained in the study was analyzed with repeated measure ANOVA and Wilcoxon analyses, as well as Chi-square tests. All of the dancers tested displayed significantly lower serum 25-(OH) D levels in winter months, as well as increased parathyroid hormone and bone turnover markers. Additionally, the occurrence of injuries

to both bone and soft tissue was significantly lower in summer months, correlating with higher vitamin D status and better bone health.

This study was only performed on a small number of dancers exposed to very similar environments, so the sample size makes the results less valid. Additionally there was no control group of non-dancers to give comparison data. Despite the shortcomings of this study, it does represent an aspect of bone health related to vitamin D levels in the body separate from dietary intake.

Study 4: prevalence of vitamin D deficiencies. With increasing studies on the importance of vitamin D in bone turnover, bone mineral density, and bone mineral content, it is clear that vitamin D has importance in the health and stability of bones, especially in athletes and dancers. This study, performed in 2013, examines the prevalence of vitamin D deficiencies in patients with foot and ankle injuries, common to ballet dancers. Over the course of six months, serum 25(OH)D levels were measured in patients with ankle, metatarsal, and stress fractures. Patients with ankle sprains lacking fractures were also measured to serve as control subjects.

The serum testing revealed that the nearly half of the patients exhibiting fractures had serum vitamin D levels that were either low or deficient, and that all fracture patients had significantly lower serum levels than the control patients. Results similar to these have been attained in a wide variety of studies with patients of differing ages, genders, and activity levels.

Conclusion

The continuity of evidence from the studies examined supports the hypothesis that vitamin D is very involved in total bone health and can be a key in the prevention and treatment of stress fractures. Fracture groups consistently exhibit serum vitamin D levels that are either below the range of "normal" or fall into the range of "deficient." The occurrences of stress fractures increased during winter months, correlating with a lowered serum vitamin D level and an increase in bone turnover markers. Total BMD was also found to correlate with vitamin D intake.

This research, however, is still relatively new and is broad in scope. Many of the studies examined focused specifically on men or the elderly. There is the possibility that bone health in women can differ from hormone levels, overall body mass, and lifestyle differences. It has been proven that vitamin D intake, as well as sun exposure, is extremely important in terms of bone integrity and the avoidance of injury. Supplementation of vitamin D and calcium, whether through diet or medications, becomes a topic of question when determining healthful practices for stress fracture avoidance.

CHAPTER FOUR

Preventative Supplementation

This review has examined almost thirty years of research concerning bone health in both active and inactive populations of a variety of ages. While it is clear that calcium is an integral factor of bone health, adequate body levels of vitamin D have been consistently shown to be of great importance in the rate of bone turnover, bone mass, composition, and density. These factors all work together to either predispose or prevent the occurrence of overuse injuries in all populations.

Professional ballerinas are a specific population at risk for stress fractures of the phalanges, metatarsals, tibia, and fibula for a wide variety of reasons. Low body mass, low caloric intake, rigorous training schedules, high-impact weight-bearing activity, and poor diet all contribute to the risk of fractures in this population. Supplementation in the athletic world is a norm that has existed over many years and is becoming increasingly common as health care and nutritional information becomes more attainable for the general population, even without the guidance and advice of a physician or dietitian. With data to demonstrate the need for adequate vitamin D levels to avoid stress fractures, and the role of calcium in bone structure, final studies concerning supplementation will be reviewed to support or negate the possibility of using supplemental vitamin D or calcium to prevent stress fractures.

Support for Supplementation

Without calcium bones are increasingly brittle and thin. However, a specific serum calcium level must be maintained in order for proper muscular contraction and blood coagulation. The surprisingly inconsistent findings for the direct association of calcium intake and stress fractures make it hard to determine to what degree variations in calcium intake affect bones, but does show that there is more involved in bone health than calcium alone.

Athletic populations, including dancers, have shown more supplement use than many control groups interviewed for a variety of studies. Calcium intake was measured to include this supplementation but the details surrounding its use, such as bioavailability, dosage, and time of consumption, were not discussed. These variables can all change how much calcium is actually absorbed by the body and proper supplementation usage can increase the effectiveness of the practice.

Studies have shown both that calcium citrate and calcium carbonate are effective for supplementation. However, when the supplements are taken and how much is taken at once should be considered. Calcium is best absorbed in an acidic stomach, so calcium carbonate is more effectively absorbed with meals (Hanzlik, 2005). Additionally, only about 500 mg of calcium can be absorbed by the gastrointestinal system at once, so taking multiple, smaller doses throughout the day is most beneficial. Due to this, supplements taken with a calcium-rich meal may not necessarily be absorbed. Some side effects such as cramps, bloating, and gas may be experienced with either one supplement form or the other (*Calcium Fact Sheet*).

Unlike the calcium study results, the evidence throughout a wide variety of studies on the direct correlation between serum vitamin D levels, intake, sun exposure, and stress fracture incidence was very consistent. Because of the high correlation between these factors, having adequate to slightly elevated vitamin D levels is a treatment to avoid stress fractures, and to possibly help heal existing fractures. Many people, including ballerinas, may choose to obtain these levels by means of supplementation. This could potentially allow attainment of these levels without having to considerably increase dietary intake of foods and allow them to follow the diet patterns they customarily follow.

As with any organic compound, there are a variety of forms which most be chosen between in order to maximize health benefits and minimize negative effects or uselessness. If supplementation is chosen as a form of intake, both ergocalciferol and cholecalciferol are viewed as equally effective. Vitamin D is a fat-soluble vitamin, so absorption and use will be maximized if the supplement is consumed with a meal. Many people choose to take supplements that combine both calcium and vitamin D. This can be very effective as well, since vitamin D aids in calcium absorption. It is very important, however, to pay attention to the dosage of each multivitamin that is taken to ensure that excessive quantities are not being ingested (Ross, et al., 2011).

A 2008 study (Lappe, et al.) performed with female United States Navy recruits showed the clear benefits of supplemented vitamin D and calcium. The test, conducted as a placebo-controlled, double blind study with numerous test subjects, gave supplemental vitamin D and calcium to a randomly selected group of recruits. The other recruits were given placebo pills. All recruits had the same sun exposure, physical activity, and food

availability. At the end of the trial period, the group that had been given the supplemental calcium and vitamin D had a twenty percent lower incidence of stress fractures.

In 2013 a research review was conducted by Chen, Tenforde, and Fredericson discussed several studies that pointed to the value of therapeutic supplementation of calcium and vitamin D to levels slightly exceeding the usual recommended intakes. These elevated levels, while avoiding side effects, appeared to be beneficial in the prevention of stress fractures in young athletic adult females.

While supplementation can be an excellent option for those who require extra vitamin D in their diets, due to high activity levels or lack of an adequate diet. However, supplementation, if used improperly, can bring vitamin D levels to unhealthy levels in less active individuals.

Support to Avoid Supplementation

Despite some positive results associated with supplementation, there can be discrepancy on the full legitimacy of the need for supplemental pills or powders. Supplementation is an option for some populations in order to maintain adequate vitamin D status and to ensure adequate calcium intake to maintain bone health. While useful for the elderly and those with physical or medical impairments that hinder a normal diet, digestion, or sun exposure, supplements may not be viewed as necessary or recommended for young, healthy populations lacking dietary restrictions. These populations, though conscious of body weight and calorie intake, have the ability to consume diets with adequate quantities of both nutrients.

Many of the studies done on the effects of supplementation on stress fractures have been performed on postmenopausal women. While this is not our population of interest, it can be assumed that similar results could be seen in younger women. However, slightly different results could occur due to the differences in weight bearing activity, sun exposure, diet, and hormone involvement. In 2006 the New England Journal of Medicine published an article on a seven-year study performed on postmenopausal women who were given calcium and vitamin D supplements and watched for the incidence of stress fractures, as well as the occurrence of other side effects of supplementation (Jackson, et al.). At the conclusion of the study, the occurrence of stress fractures did not significantly reduce, despite a slight increase in hip bone density. However, the risk of kidney stones did increase.

A different study, conducted in 2010, was concerned with the use of vitamin D supplements versus vitamin D-fortified orange juice in terms of bioavailability and effectiveness (Biancuzzo, et al.). All subjects in the study were vitamin D deficient at the onset on the study. The double-blind, placebo-controlled study showed that supplemental D2 and D3, both in capsule form, did not have any significant differences in absorption or effectiveness as D2 or D3 fortified orange juice. All subjects receiving vitamin D treatment had statistically identical increases in vitamin D status, as measured by serum 25(OH) vitamin D. This knowledge helps validate that proper diet, including fortified foods and drinks, is just as effective as supplementation.

This information is additionally supported by the studies that showed how much total caloric intake and body mass factored into bone health and the occurrence of stress fractures. Dancers, who tend to be small and light, have historically followed diets low in

calories and fat. Dairy foods are often avoided due to the fat present. This practice has lead to low calcium and vitamin D intakes (Anshel, 2004). The foods that should be consumed for a diet rich in these two nutrients is not particularly difficult or calorie-dense. Dairy products and vegetables contain calcium and many foods are fortified with vitamin D, such as cereal, milk, and fruit juice. Patient education and assistance in proper diet selection would help nutritionally vulnerable populations significantly.

In addition to the fact that adequate levels can be obtained through diet, one must also keep in mind that excessive supplementation, which is possible in uneducated populations or those supplementing without the instruction of a doctor or dietitian, can lead to a variety of health problems and negative side effects.

Clinical studies have observed a wide variety of negative side effects, but the results of these studies have been inconsistent at times. The National Institutes of Health Supplementation Office of Dietary Supplements present some of the more consistent findings that have been collected from a wide variety of studies. Those who take high levels of calcium supplements can experience constipation. Those who consume doses of specifically supplemental calcium exceeding 1000 mg per day may carry an increased risk of myocardial infarctions and cardiovascular disease. These cardiovascular issues can be attributed to increased coagulability of blood, vascular calcification, and eventual stiffening and stenosis of blood vessels. Increased risk and occurrences of kidney stones can also occur with excessive supplementation. Kidney stones are mainly composed of calcium oxalate, so the kidneys would collect the extra calcium circulating in the blood and have the risk of precipitation. Lastly, higher risks of prostate cancer in older men, but this risk does not concern our population of interest (*Calcium Fact Sheet*). Many of the

adverse side effects are described in postmenopausal women or other older populations, but little research has been done on the long-term effects of high supplementation.

Excessive intake of vitamin D has an extremely wide variety of effects, ranging from mild to severe. These side effects are much more well-known than the risks associated with excessively high levels of calcium. Intake of vitamin D exceeding the upper limit of 4000 IU/day can lead to mild to moderate acute side effects, such as fatigue, dehydration, constipation, muscle weakness, dizziness and high blood pressure. Chronic complications of vitamin D toxicity, if left untreated, includes kidney damage, calcification of arteries and soft tissues, and severe heart arrhythmias (Holick, 2009).

The risks associated with supplementation, in addition to the ability to consume enough of each vitamin and mineral through diet alone signifies that supplementation should only be pursued when a proper diet is not possible.

A Stance on Supplementation

Calcium and vitamin D in conjunction are more important than either vitamin or mineral individually in terms of total health and stress fracture prevention. Supplementation should only be used for adequate levels if it is not possible for the athlete to consume them with a proper diet. For the professional ballerina without special health circumstances, a diet rich in nutrients and adequate in calories should be a very effective means for avoidance of stress fractures. While calcium and vitamin D levels have been shown to be very important factors in the prevention of stress fractures, and adequate intake of each will not necessarily prevent a fracture from ever occurring. Repeated trauma and overuse of the joints will invariably predispose dancers to injuries

of this nature. Due to this predisposition, it is even more important for proper diet to be followed in order to minimize the risk of harm. However, since this population is at risk to engage in dieting and tends to avoid dairy products and extra calories, supplementation for both vitamin D and calcium is a reasonable and scientifically sound manner of reducing the occurrence of stress fractures secondary to exercise and overuse.

Conclusion

The research conducted on calcium demonstrates that, though calcium is integral for bone health, varying levels of intake do not correlate strongly with bone mineral density or the incidence of stress fractures. The serum levels of calcium necessary for adequate blood clotting and nerve impulse transmission is in a small window, so serum levels are maintained consistently between fracture groups and control groups. Overall caloric intake seemed to have a much more clear correlation between stress fractures. However, the research concerning vitamin D shows a very clear relationship between low serum vitamin D levels and increased incidence of stress fractures in athletic population. Inadequate intake of vitamin D can be attributed to the poor-quality diet often followed by ballerinas, coupled with minimal sun exposure due to indoor practice and performances. Supplementation should not be required in order to fulfill daily requirements of calcium and vitamin D while meeting RDA calorie requirements. However, dietary practices of dancers are difficult to change due to widespread lack of education and preoccupation with a very slim and characteristic body image. Supplementation, if performed correctly under the care of a dietitian or physician, can be

of great benefit to ballet dancers to promote bone health and help to avoid the occurrence of stress fractures by providing adequate to increased levels of vitamin D and calcium.

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