AN EXAMINATION OF THE ROLE OF VITAMIN D, BONE MINERAL DENSITY, AND PERCIEVED EXERTION ON THE PREVELANCE OF STRESS FRACTURES IN DIVISION I CROSS COUNTRY ATHLETES

by

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ABSTRACT

Background: Stress fractures of the lower extremity are common injuries among athletes of all levels, especially elite distance runners; however, the potential risk factors are highly debated.

Objective: To identify whether bone mineral density (BMD), Vitamin D levels, and perceived exertion are prospectively associated with stress fractures risk among NCAA Division I collegiate cross country runners.

Design: Retrospective Cohort Study

Methods: A total of 17 athletes between 18 and 23 years old were recruited. Questionnaires assessed injury rate, menstrual and training history, nutritional knowledge, supplementation, and perceived exertion. Bone mineral density (BMD) of total body and legs were assessed using dual X-ray absorptiometry (DEXA). Vitamin D levels were collected via a serum blood test performed prior to the 2015 season. Among the 17 athletes who completed the questionnaire, DEXA scan, and vitamin D test, 10 sustained a stress fracture diagnosed by magnetic resonance imaging, giving an incidence rate (95% confidence intervals) of 58 % of the study population sustaining a stress fracture during the 2015 season.

Results and Conclusions: BMD and vitamin D showed no statistically significant correlations to stress fracture rates in the population. However, training load was shown to have an indirect effect on stress fracture rates, indicating that there may be a psychological component related to the increased risk for stress fractures. Further research on this population with a larger sample size and examination of more contributing factors could be used to confirm the findings of this study.

Introduction

Stress fractures of the lower extremity account for up to 25% of sport related injuries seen in clinics each year, especially in the running population.[1,3,5,6] While the prevalence of stress fractures is significant, the etiologic process is widely contested in the literature. Some categorize stress fractures as an overuse injury caused by repetitive, submaximal loading that accelerates bone remodeling.[3] Others have theorized causes including repetitive stress at the insertion point of a muscle, an initial prolonged focal impaired perfusion of the bone, or a cross-sectional area of decreased bone strength.[10] That being said, most literature acknowledges that when osteoblastic activity lags behind osteoclast activity, this leaves the bone susceptible to microfracture, therefore indicating a stress fracture.[3,11,14]

Researchers have proposed and studied numerous risk factors related to stress factors, including previous injury, gender, irregularity of surfaces, inadequate strength, or poor flexibility.[14] This study is intended to examine the relationship of bone mineral density (BMD), Vitamin D, and training load on the risk for developing a stress fracture in Division I cross country runners.

Review of Literature

Bone Mineral Density

The gold standard for testing BMD is the dual energy x-ray absorptiometry (DEXA), which uses two beams with different energy levels to measure relative bone density.[3] Total body measurements were taken, but results of the pelvis, lumbar spine, and lower leg were ascertained for the comparison. On top of measuring bone density, most studies also looked at bone geometry, looking at the girth of bones, especially in the lower limbs.[3,4,10]

Increases in BMD are usually correlated to weight bearing exercises like running. Surprisingly, Mudd et al. found a decreased BMD in Division I female collegiate cross country runners. When compared to other female division I athletes (softball, soccer, track and field, field hockey, and rowing), the long-distance runners had lower BMD than collegiate swimmers, who were predicted to have the lowest due to the non-weight bearing nature of swimming.[4] Mudd et al. predicted that this decrease in BMD was related to the calcium intake, disordered eating, or insufficient energy intake that may have been related to improper education or lack of knowledge. Mudd also examined the influence amenorrhea on BMD and found no significant correlation to decreases in BMD, which was also confirmed by a similar study performed by Robinson et al, who implemented a study comparing gymnasts and cross country runners with the same occurrence of amenorrhea. Both studies found similar prevalence of amenorrhea in multiple athletic populations, but still significant differences in BMD.[4,10] Studies examining different populations did find a higher correlation of amenorrhea and BMD decrease.[4,13] This would confirm the indication by Mudd et al., which stated the BMD is heavily affected by sports participation. [4]

While the BMD of female runners may be relatively low, in most cases Division 1 male cross country runners seem to have normal to high BMD when compared to other athlete groups. This is most likely related to the decreased prevalence of disordered eating/energy intake. While the majority of males have normal bone density, it is important to look for the risk factors for decreased BMD that are seen in females.

While Mudd stated that the BMD of women may be affected by exercise, Lauder et al. found that the risk for stress fractures was also related to BMD.[11] In a study looking the BMD of 190 women, mainly military recruits (which have similar physical demands to Division I collegiate athletes), and their risk for stress fractures, Lauder et al. found that there was a strong correlation between stress fracture and high exercise intensity. Women who experienced stress fractures were found to have 50% greater intensity level of exercise than their counterparts. On top of increased intensity levels, Lauder found that the women who exercised more than 10 hours a week had a 50% increased chance of suffering a stress fracture, compared to 11.4% risk for moderate activity levels (5-10 hours).[11] This evidence once again supports the claims of Mudd et al. While levels of intense exercise can increase BMD, they can also have adverse effects that can lead to stress fractures. This highlights the importance of the indirect effect of increased exercise (through increased BMD) with its detrimental direct effect of increased stress fractures.

Participating in weight-bearing exercise, especially at the NCAA Division I level, should increase the BMD and lean body mass of these athletes, which could contribute to a decreased risk for stress fractures.[3] That being said, many of these athletes who endure extreme amounts of vigorous activity do not fuel their body properly, which affects their BMD contradictory to what you would expect of someone who participates in that level of exercise.[4] This is an important anomaly to address when utilizing BMD, but the effects of disordered eating on BMD will not be specifically addressed in this review.

Vitamin D and Calcium

Calcium is a vital part of bone health that is needed for bone mineralization that works with vitamin D to maintain calcium homeostasis and bone remodeling.[13] While these are well recognized nutritional factors in the risk for stress fractures, this risk has been challenged in the literature. That being said, vitamin D deficiency is relatively common. Vitamin D is most commonly acquired through sun exposure, but most people do not get enough, causing the need for supplementation through dietary sources.[9] In order to reap the benefits of vitamin D, there must also be adequate amounts of calcium, which is one reason that they are often examined together.

While the epidemic of vitamin D deficiency and insufficiency has ignited a push for fortified foods in local grocery stores, its correlation to the risk for stress fractures is still up for debate. While calcium and vitamin D are often grouped together, recent research has shown that vitamin D has more of an effect on bone health, but this evidence is inconsistent across populations and age groups.[10] Larson-Meyer et al. conducted a study on athletic populations that found that adequate vitamin D levels aid in bone health, immune function, inflammatory modulation, and optimal muscle function. In the same study, Larson-Meyer found that while the population as a whole suffers from vitamin D deficiency, vitamin D concentration varies widely in athletic populations with higher concentration during the summer months. The best concentration was found in athletes in high-altitude areas of the United States, with the lowest residing in the Middle East and Finland.[9]

It is important to note the environmental influences of vitamin D. Unlike BMD and calcium, vitamin D is very dependent on the environment of play. In order to compensate for lack of vitamin D acquired from UVB rays, some athletes reported taking a vitamin D supplement that may result in higher, but not optimal vitamin D concentration.[9]

Vitamin D is also affected by body fat. While collegiate distance runners customarily have low body fat, for other populations with a more standard body composition, it is important to note (to note what?). Newer research suggests that increased adiposity could increase one's risk for low levels of vitamin D.[9] In individuals of a normal weight, vitamin D is stored in subcutaneous fat and released in times of low concentration (typically in the winter months). However, in individuals with excess subcutaneous fat, vitamin D stores are significantly deeper within the tissue inhibiting the conversion of stored vitamin D.[9] More studies should be conducted to examine individuals with extremely low body fat, to find if the risk for deficiency could be related to their lack of vitamin D storage. This could be important for a more athletic population, especially one as rigorous as Division I collegiate cross country.[9]

In a study of 5000 military recruits, Lappe et al. found that participants who received a supplement of calcium and vitamin D had a 20% decreased risk for stress fractures compared to the control group.[13] This is one of the only studies that examined supplementation of calcium and vitamin D in a large population. Lappe et al. correlated the decrease in risk for stress fracture with the activity of decrease in Parathyroid Hormone (PTH) secreted by the body therefore decreaseing the breakdown of the bone.[13] That being said, as in all of the studies examined in this review, stress fractures may also be influenced heavily by gender, amenorrhea and previous injury.

Methods

Procedures

Participants were recruited via the athletic trainer and the primary researcher. Participants first completed a written informed consent prior to the commencement of this study, detailing the objectives of the study and the potential risks. Approval for all procedures was obtained from the Departmental Review Board at Texas Christian University before commencing the study. Seventeen (9 females and 8 males) NCAA Division I cross country runners between the ages of 18 and 23 participated in this study. The participants completed a subjective questionnaire with information pertaining to training load, supplementation, exercise habits, nutritional knowledge, and menstrual health (females only). Participant information was then collected from their

Preparticipation Exam (PPE) on file with the TCU Sports Medicine and Athletic Training Department.

The information collected from the PPE included results from the participants' DEXA scans and serum blood draw results. BMD is measured using a dual x-ray absorptiometry (DEXA) densitometer. The participant is supine on a padded exam table for 15-20 minutes while an x-ray scanner passes over the body. Blood draws are taken prior to the beginning of the competitive season and test for serum vitamin D levels. Potential risk of participating in this study is decreased due to the fact that both the DEXA and blood draw are collected as a routine measure, even without participation in this study.

The participants tracked their training load and perceived exertion via Run 2 Win. This application allowed the participants to log their mileage and perceived exertion, as well as leave any comments about their run. The data is then compiled in an online database that is accessible to each individual runner and the researcher through a login.

All suspected stress fractures were documented in the participant's medical file. This study examined retrospective data from August 2015 to December 2015 (cessation of regular season of cross country competition).

Data Analysis

Participants were assigned an ID # (de-identified) when information was compiled using an Excel spreadsheet. Data included sex, age, BMD (DEXA), vitamin D results, physical exertion, training load, history of lower extremity injury, and diagnosis of stress fractures. This data was analyzed via the SPSS software to determine if the independent variables (BMD, vitamin D, and perceived exertion) were correlated with stress fractures (dependent variable).

Descriptive statistics for each variable including group mean and standard deviations were also calculated. T-tests were utilized to examine the relationship between BMD and vitamin D levels and stress fractures. (I don't think a logistic regression was ever utilized—this was just suggested in your DRB, but I didn't get the impression that this was calculated. The demographic questionnaire was used as additional information to describe or support potential trends. SPSS software was utilized to determine

Results

Participants

Of the total sample of 17 athletes, 10 suffered stress fractures (7 females and 3 males), while the other 7 (without stress fractures) were used as controls. This resulted in an injury rate of 58%, which is higher than reported rate in the literature which range between 10-25% of all running related injuries.[1,3,5,6] Table 1 presents summary statistics for the sample, stratified by the presence or absence of stress fractures.

Table 1: Participant Statistics by the Presence of a Stress Fracture

	Bone Injury	N	Mean	Std. Deviation
Age (years)	No	7	21.4871	1.60317
	Yes	10	20.6410	.60491
Weight (lbs)	No	7	141.1714	8.50837
	Yes	10	128.5400	14.30246
Height (in)	No	7	68.1429	2.68816
	Yes	10	66.1200	4.01104
Hematocrit (%)	No	7	43.5000	4.24303
	Yes	10	41.7300	3.94942
Hemoglobin (g/dL)	No	7	14.4714	1.50301
	Yes	10	13.8000	1.31403
Ferritinn (g/ml)	No	7	59.0000	24.95329
	Yes	10	52.7000	42.67461

Comparisons of the two groups revealed no statistically significant differences between the injury and noninjury group with respect to age, weight, height, hematocrit, hemoglobin, and ferritin. Any differences between the mean values were small and not significant and were mostly correlated to a large variance in the values, shown by the large standard deviations (σ).

Perceived Exertion

Perceived exertion served as a subjective measure of overall training load for the participants. As shown in Figure 1, 56% of the participants (injury and noninjury group) reported that they believed their training program was more strenuous than other NCAA Division I programs. With that in mind, fewer participants (40%, n=10) in the injury group reported that they believed their program was more strenuous compared to the noninjury group (70%, n=7). These results suggest that awareness of needed rest or training load may help prevent injury in this population, as well as supporting the claim that there could be a psychological component related to injury rate in this population.

Table 2 presents descriptive information of the participants in regards to selected characteristics and training habits. These were self-reported on the demographic questionnaire. There was a large variance in values that indicated no direct correlations contributing to increased risk for stress fractures between ethnicity, vitamin C and iron supplementation, extra workouts, or oligomenorrhea (unusually infrequent periods). Both groups reported (injury 60%, n=10. noninjury 42%, n=7) unexpectedly high numbers of withholding reporting injury symptoms in order to compete. This finding suggests that there may be a significant psychological component that is contributing to the high injury rate in this population.

Figure 1: Perceived Exertion of all Participants

Table 2: Descriptive Questionnaire Information

Ethinicity	**Injury**	
	caucasian	80%
	black	10%
	hispanic	10%
	noninjury	
	caucasian	85%
	black	0%
	hispanic	15%
Ideal Weight	**injury**	60%
	noninjury	71%
Vit. C Supplementation	**Injury**	30%
	noninjury	42%
Iron Supplementation	**injury**	40%
	noninjury	57%
Oligomenorrhea	**injury**	0%
	noninjury	14%
Extra Workouts	**injury**	20%
	noninjury	28%
Not reporting injuries to	**injury**	60%
compete	**noninjury**	42%

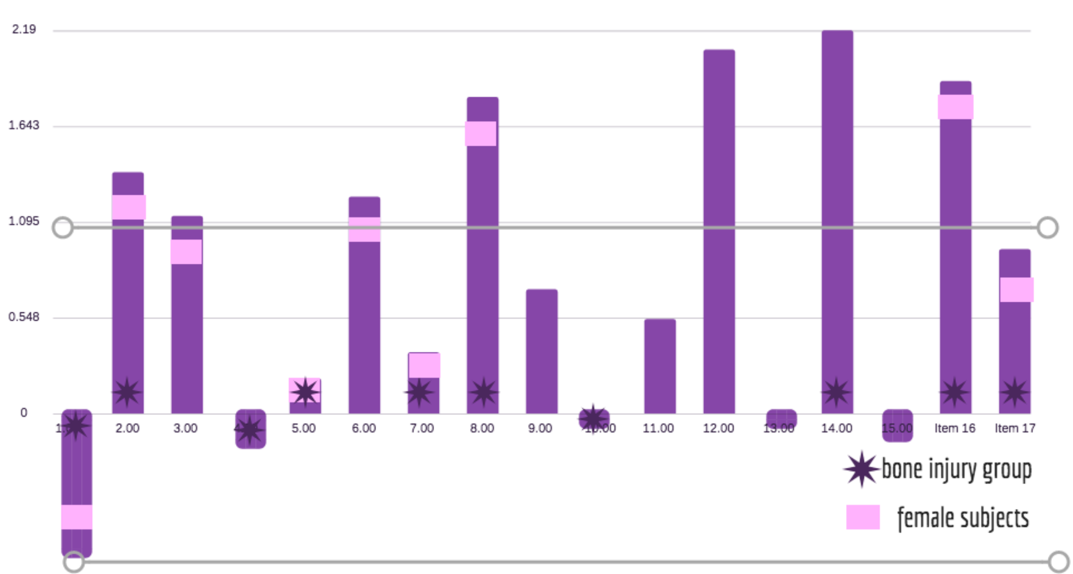
BMD

Dual energy X-ray absorptiometry (DEXA) was used to measure BMD and bone mineral content of the total body and legs, as well as percent fat. For all anatomical locations, BMD *Z*-scores were calculated using the US adult male and female reference database according to age, sex, and ethnicity. It is important to note that these z-values represent the normal values for a normal non-athletic population. The BMD results from the DEXA scan (Table 3) revealed no statistically significant relationship between BMD and stress fracture ($p = .09$). Interestingly, the predicted values of BMD were expected to be much higher ($>1\sigma$) than the z-score norms due to the stresses placed on bones during running, but most values (of both injury and noninjury groups) fell within 1σ (indicated by the grey lines in Figure 2), which may indicate that there are other factors limiting the increase in bone mineral density that was expected and observed in other studies that examined BMD in an athletic and non-athletic population.[3,6,11]

Table 3: Injury vs. Noninjury BMD Data

	Bone Injury	N	Mean	Std. Deviation
Bone Mineral Density (full)	No	7	1.2529	.08281
	Yes	10	1.1700	.06976
Bone Mineral Density (legs)	No	7	1.4257	.11928
	Yes	10	1.3290	.11396
Percent body fat	No	7	16.0000	3.37145
	Yes	10	20.3400	6.74606

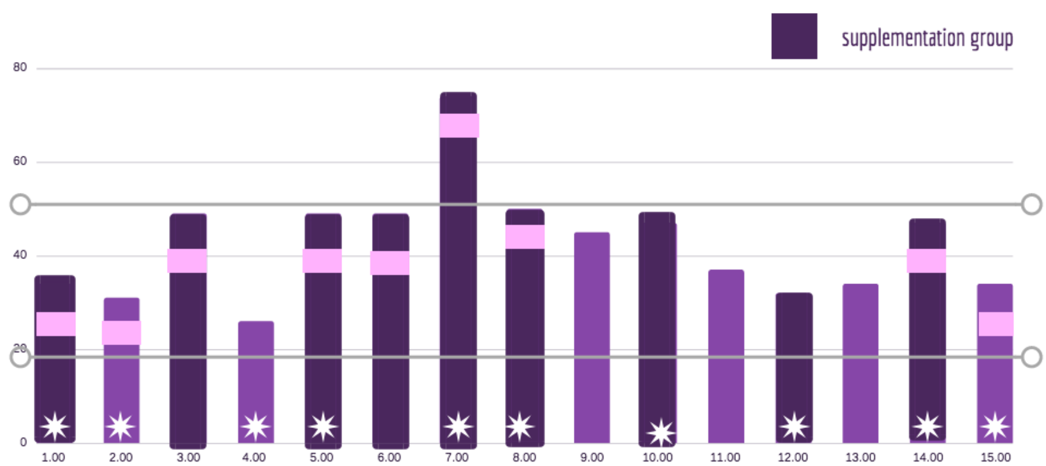
Figure 2: BMD z-scores



Vitamin D

Although numerous studies have recorded a high prevalence of vitamin D insufficiency in the general population worldwide, very few of the studies have examined this in the athletic population, especially long distance runners.[1,5,7,8] Most studies found that normal serum vitamin D levels fall between 20 and 50 ng/dL, as shown by the grey boundaries in Figure 3. Figure 3 indicates participants who supplemented vitamin D with darker bars and pink bars designating female participants.

Figure 3: Serum Vitamin D Levels



As seen in Figure 3, there were no statistically significant differences in vitamin D serum levels between the injury and noninjury groups. The data had a large σ (12.653 ng/dL), confirming the suggestion by Jackson et al. that there is a large variance in normal vitamin D levels within a population.[12] It is also important to note the difference in need between males and females. As seen in Figure 3, females prophylactically supplemented vitamin D much more readily (70%, n=10) than males (33%, n=6). This prophylactic supplementation is often recommended to offset the increased need for vitamin D in females, when compared to males.[1] Table 4 shows the data extrapolated by sex to see the difference in levels between sexes, but still the lack of statistical significance between the injury and noninjury group.

Table 4: Vitamin D Serum levels by Gender

	Bone Injury	N	Mean	Std. Deviation
Vitamin D levels Male	No	3	38.6667	5.68624
	Yes	3	35.0000	10.81665
Vitamin D levels Female	No	2	49.0000	.00000
	Yes	7	45.5714	14.84203

Discussion

To our knowledge, this is the first study to examine the relationship between vitamin D, BMD, and perceived exertion in NCAA Division I cross country athletes. While this did cause some challenges when comparing our finding to previous research, our most significant finding was the strong correlation (56%) between perceived exertion and injury rate. This was directly related to the high percentage (67%) of athletes reporting withholding pertinent symptoms relating to injuries in order to compete. This is what makes this study stand apart, as we looked at the psychological component of stress fractures as they relate to perceived exertion.

Oftentimes, injuries are written off as strictly physiological issues, but with more research, injuries seem to have more of a psychological component than previously believed. The Kubler Ross Stress Model is a model used to describe the grief response using five stages: denial, anger, depression, bargaining, and acceptance.[15] While grief isn't always the first thing you think of when you think about injuries, this model fits a very normal psychological response to injury, especially if you are dealing with athletes who are withholding information in order to compete. This pushes them into the denial or even bargaining stage. They have taken an "ignorance is bliss" approach to their training, which is likely contributing to this 58% injury rate.

Stress fractures are a chronic injury that occur over time, so neglecting to address the early symptoms could lead to further injuries explained by sports psychologist John Taylor, PhD who was once a sub-three-hour marathoner, who said "By denying you're injured, you can exacerbate the injury. What once was a minor tweak could turn into a major injury."[15] Laker et al. found similar findings in a study that examined division I cross country runners where the athletes failed to report their symptoms until 2-3 weeks after the initial onset, This lead to an increased injury rate of 44% (n=25).[4] Laker at al. also found that those who were experiencing symptoms without reporting them were more susceptible to overtraining in an attempt to offset the detraining effects they were scared of suffering by resting. This relates directly to the bargaining stage of this model where the athlete becomes resistant to rest even if they are aware of the damage that they are doing to their body. It is interesting to note that the participants of this the current study, suffered a majority of their injuries (80%, n=10) during the middle of the season, which is often the time of highest training load and increased training intensity.

With regards to the results pertaining to BMD, we found that all patients fell within the normal range with no statistically significant correlation to stress fracture rates. However, the overall BMD levels were much lower than expected. In 1930, Hans Selye proposed the General Adaptation Syndrome, which was originally intended to explain hormonal response to stress, but in the 1960's was utilized to explain the body's' stress response to exercise. The model is composed of three stages including alarm, resistance, and exhaustion stage. We expect runners to spend most of their time in the resistance stage where the body is making adaptations to the stresses being exerted on it, such as increased BMD, increased vitamin D and calcium uptake and cardiovascular training adaptations. All of those are beneficial to the athlete, but may not be able to be achieved if there is not proper rest post-stress. If there isn't adequate rest time taken, athletes may fall into the exhaustion stage that will counteract those beneficial adaptations mentioned above.

Wolff's law explains the expected adaptations seen in the resistance stages as "every change in the function of a bone is followed by certain definite changes in its internal architecture and its external conformation".[10] This suggests that, although these athletes fell within normal limits for the non-athletic population, these athletes may be lacking adequate response to the stresses that would normally give them the bone strength to withstand the stresses of running 50+ miles per week. Similarly, Mudd et al. and Lauder et al. found that army recruits and runners who exercised at a higher intensity had a lower BMD than those who exercised at a lower intensity, again counteracting the explanation set forth by the Hans Selye.[4,11] Similar to this study, neither Lauder et al. or Mudd et al. found statistically significant values that could utilize BMD as a predictor for stress fractures. Overall, more research related to normal values for this population would relieve some of the uncertainty about the relationship between BMD, bone health, and stress fracture rates in a Division I cross country runners.

Vitamin D supplementation, although widely utilized, is readily contested in the literature for its contribution to bone health and decreasing the risk for stress fractures, which is supported by the results of this study. With such a vast range of vitamin D levels in this population, there were no statistically significant findings. These results could lend well to an exploration of dietary vitamin D versus supplementation in an exercising population. Similar to BMD, we expected this sample to require more vitamin D than the normal population, but there has been no recommended dietary allowance (RDA) set for an active population, so we could not make comparisons with established reference data. The increased demand for vitamin D in order to build bone may directly influence the BMD of these athletes, which could account for the variance of BMD values.

While the body intends to respond to the stresses of exercise by adapting, if it doesn't have the proper building materials it may not be able to fully compensate for the adverse effects of stress. Although all the participants reported they believed they adequately fueled their body, perhaps they lacked knowledge about the increased needs due to the stresses of their sport. Lappe et al. mentions that previous recommendations for vitamin D intake may not be suitable for the present day since as a population. Americans are spending more time indoors, therefore decreasing the amount of vitamin D they receive from their environment which may increase the need to supplement vitamin D in their diet. Although this study did not directly look at the serum levels of calcium, it is still a vital part of bone health, that works directly with vitamin D. Therefore, further studies that examine the influence of these factors and how they may contribute to the risk for stress fractures would be beneficial, especially in the athletic population.

Conclusion

Our results revealed a significant correlation between perceived exertion and stress fractures, which emphasizes the role of the psychological effects of injury. While BMD and vitamin D did not present any statistically significant findings as predictors for stress fractures, this should not discount their importance to the overall health of the athlete. Our results suggest that some risk factors associated with stress fractures and BMD are, in large part, preventable and that careful attention should be directed at educating patients about avoidable risk factors including nutrition, over training, and adequate rest. Finally, optimal training programs should balance the beneficial *indirect* effect of increased exercise with its detrimental *direct* effect on stress fractures.

Resources:

1 Sonneville KR, Gordon CM, Kocher MS, Pierce LM, Ramappa A, Field AE. Vitamin d, calcium, and dairy intakes and stress fractures among female adolescents. Arch Pediatr Adolesc Med. 2012;166(7):595-600.

2 Frusztajer NT, Dhuper S, Warren MP, Brooks-gunn J, Fox RP. Nutrition and the incidence of stress fractures in ballet dancers. Am J Clin Nutr. 1990;51(5):779-83.

3 Nattiv A, Kennedy G, Barrack MT, et al. Correlation of MRI grading of bone stress injuries with clinical risk factors and return to play: a 5-year prospective study in collegiate track and field athletes. Am J Sports Med. 2013;41(8):1930-41.

4 Mudd LM, Fornetti W, Pivarnik JM. Bone mineral density in collegiate female athletes: comparisons among sports. J Athl Train. 2007;42(3):403-8.

5 Hamilton B, Grantham J, Racinais S, Chalabi H. Vitamin D deficiency is endemic in Middle Eastern sportsmen. Public Health Nutr. 2010;13(10):1528-34.

6 Laker SR, Saint-phard D, Tyburski M, Van dorsten B. Stress fractures in elite cross-country athletes. Orthopedics. 2007;30(4):313-5.

7 Cannell JJ, Hollis BW, Sorenson MB, Taft TN, Anderson JJ. Athletic performance and vitamin D. Med Sci Sports Exerc. 2009;41(5):1102-10.

8 Mccabe MP, Smyth MP, Richardson DR. Current concept review: vitamin D and stress fractures. Foot Ankle Int. 2012;33(6):526-33.

9 Larson-Meyer DE, Willis KS. Vitamin D and athletes. *Curr Sports Med Rep*. 2010;9(4):220-226.

10 Robinson TL, Snow-Harter C, Taaffe DR, Gillis D, Shaw J, Marcus R. Gymnasts exhibit higher bone mass than runners despite similar prevalence of amenorrhea and oligomenorrhea. *J Bone Miner Res.* 1995;10:26–35

11 Lauder TD, Dixit S, Pezzin LE, Williams MV, Campbell CS, Davis GD. The relation between stress fractures and bone mineral density: evidence from active-duty Army women. Arch Phys Med Rehabil. 2000;81(1):73-9.

12 Jackson RD, Lacroix AZ, Gass M, et al. Calcium plus vitamin D supplementation and the risk of fractures. N Engl J Med. 2006;354(7):669-83.

13 Lappe J, Cullen D, Haynatzki G, Recker R, Ahlf R, Thompson K. Calcium and vitamin d supplementation decreases incidence of stress fractures in female navy recruits. J Bone Miner Res. 2008;23(5):741-9.

14 Newman P, Witchalls J, Waddington G, Adams R. Risk factors associated with medial tibial stress syndrome in runners: a systematic review and meta-analysis. Open Access J Sports Med. 2013;4:229-41.

15 Wiese-Bjornstal, D. M., Smith, A. M., Shaffer, S. M., & Morrey, M. A. An integrated model of response to sport injury: Psychological and sociological dynamics. *Journal of applied sport psychology*, 1998 s*10*(1), 46-69.