IS A GYMNAST'S PERFORMANCE AND HEALTH AFFECTED BY VITAMIN D DEFICIENCY?

Elizabeth J. Bradshaw[1], Kylie Thomas[3], Mark Moresi[2], David Greene[2], Wendy Braybon[3], Kate McGillivray[3], and Kylie Andrew[3].

School of Exercise Science, Australian Catholic University, Melbourne[1], and Sydney[2], Australia

Sports Science and Sports Medicine, Victorian Institute of Sport, Melbourne, Australia[3]

This study examined the effect of vitamin D deficiency on bone strength and jumping and competition performance in 38 sub-junior gymnasts. Each sub-junior gymnast completed anthropometry, blood, bone (pQCT), and biomechanical jumping tests, as well as a Tanner survey and 3 day food diary. Vitamin D was not related to bone health, and was not positively related to any biomechanical or competition performance measures. The repetitive, high impact training of gymnastics was most important for bone health.

KEY WORDS: impact, load, blood, pQCT, nutrition.

INTRODUCTION: Vitamin D deficiency is increasingly being recognised as a worldwide epidemic (Hamilton, 2010). Evolving evidence suggests that vitamin D plays a role in an athlete's health, training, and competition performance (Larson-Meyer & Willis, 2010). Gymnasts present a high risk for vitamin D deficiency due to their long training hours indoors. Lovell (2008) identified that 83% of gymnasts training at the Australian Institute of Sport had mild to moderate vitamin D deficiency. The same proportion of gymnasts had clinically confirmed bony stress reactions, including one stress fracture, during the preceding 12 months. A significant number of studies have demonstrated that gymnastics training, at any level, prior to adolescence is positive for bone mineral density (Bass et al., 1998) and strength (Burt et al., 2011; Burt et al., 2012; Greene et al., 2012). However, the relationship between vitamin D, bone health, injury and performance is unknown in gymnastics populations. A threshold exists between optimum loading via gymnastics training that enhances bone health and that which is detrimental, resulting in bone stress injuries. It is unclear from Lovell (2008) whether the bone injury patterns were a result of low vitamin D or training overload. The purpose of this study was to examine the relationship between vitamin D and bone strength, and vitamin D and performance in gymnasts. It was hypothesised that vitamin D was not related to bone strength, jump or competition performance in gymnasts.

METHODS: Thirty-eight gymnasts aged 9-13 years (Age = 11.89 $\pm$ 0.82 years; Height = 1.30 $\pm$ 0.07 m; Mass = 33.58 $\pm$ 4.55 kg) who were injury free at the time of testing, participated in the study. All of the gymnasts were selected to participate in a sub-junior national development camp and compete at the international development levels 6 to 10. All procedures were approved by the Australian Catholic University and the Australian Institute of Sport Ethics Committees and athlete assent and parental/guardian consent was obtained prior to participation in the study.

Anthropometry, Maturation, and Dietary Measures: Each gymnast's height, body mass, limb lengths (foot, humerus, radius, femur, tibia, tibia to floor), and segment widths (shoulder, hip) were measured. Participants completed Tanner staging via self-assessed pubertal rating for pubic hair and breast or genital development, and self-reported menstrual cycle, where appropriate. Calcium (mg), iron (mg), and total energy intake (kJ) was determined using a 3-day (2 weekdays and 1 weekend day) food diary. Instructions regarding completion of a 3-day food diary were provided to all participants by the same investigator (K.T.), and included noting details of any supplements taken (e.g. calcium tablets). Completed diaries were analysed using Foodworks Food Analysis program (Xyris Software 1999, Version 7). All food-related measures (excluding supplements) were calculated as absolute daily intake and expressed as mean values.

Blood and Bone Measures: Blood samples were drawn from an antecubital vein by a qualified phlebotomist. All blood samples were analysed by the Australian Institute of Sport Biochemistry/Haematology laboratory excluding serum D (25-hydroxyvitamin D), plasma calcium and bone studies which were completed by the Australian Capital Territory Pathology laboratory. The nondominant tibia was measured by pQCT (XCT 2000; Stratec Medizintechnik, Pforzheim, Germany) using software version 5.50d. Scans were performed at 4 % (distal site), 14%, 38%, and 66 % (proximal site) of bone length (measured as a relative distance from the distal end of the bone). Volumetric trabecular bone mineral density was measured at the 4 % distal sites after the removal of cortical bone. A contour mode with a threshold of 180 mg/cm^3 was used to separate soft tissue and bone to analyze trabecular bone. A constant default threshold of 711 mg/cm^3 was used to identify and remove cortical bone. Estimates of bone strength index (strength strain index, SSI mm^3) were provided by the manufacturer's software. The precision of repeat measurements in our department is 0.8% to 2.9% at the tibia and radius after repositioning in 8 adults. Repeat measurements were not undertaken with children because of the need to minimize cumulative radiation exposure.

Biomechanical Measures: All of the participants performed a self-administered warm-up prior to the testing. Each gymnast then completed three trials of a squat jump (SJ), countermovement jump (CMJ), as well as rebound jump (RJ) and drop landings (DL) from 82 cm and 120 cm boxes. The gymnasts also completed 10 continuous hops (CH), 10 continuous jumps (CJ10), and 30 s of continuous jumping (CJ30). All hop and jump tasks were performed doubled legged, barefoot, and at a self-selected pace. To minimize the effect of fatigue all participants were given approximately 30 seconds recovery time between each jump, and 1-2 minutes between each jump type. During the SJ, a self-selected starting depth was held for 2 s prior to each jump. The participants were instructed to jump as high as possible in the SJ and CMJ trials, and jump as high as possible whilst minimizing ground contact time for the DJ, CH, CJ10, and CJ30 trials. All of the hop and jump tests, excluding the RJs and DLs, were completed on a uniaxial force platform (Quattro, Kistler, Winterhur, Switzerland, 500 Hz) covered with two 3 cm thick, high density carpeted foam mats. The average result was recorded for each gymnast from the Quattro jump software (version 1.0.9.2). The RJs and DLs were completed on two portable, triaxial force plates (9286A, Kistler, Winterhur, Switzerland, 1000Hz). Both force plates were also covered with high density foam mats (6 cm). Accounting for the force plate and foam mats the resulting drop depths were 72.5 and 110.5 cm respectively for the two boxes. The force-time data was exported from the Bioware software (version 5.0.3.0, Kistler, Winterhur, Switzerland) into a custom-written excel spreadsheet for analysis (e.g. contact time, peak force) where the vertical forces were combined. RJ displacement was calculated using the impulse-momentum method (Linthorne, 2001). Peak force data for all hops and jumps were normalized to body weight (BW). Power measures were normalised to body mass (kg).

Competition Level and Scores: Competition levels and all-around scores for each gymnast in the study were taken from the results of the 2013 Australian Gymnastics Championships held in the days preceding data collection. It should be noted that all gymnasts were given a minimum of a half day rest prior to participating in the training camp.

Statistics: All data was collated and analysed statistically using SPSS for Windows software (SPSS Inc., Illinois, version 21.0). An alpha level of 0.05 was set for all analyses. All data were tested for normal distribution prior to parametric statistics using a Shapiro Wilk test. Means, standard deviations, minimum and maximum are reported for descriptive statistics. Pearson product-moment correlations between all measures provided the basis for a stepwise linear regression model to predict bone strength (SSI), trabecular density, corticol density, competition level and all-around score.

RESULTS: Participant anthropometry, maturation, bone, blood and nutritional results are presented in Tables 1 and 2, and jump performance measures are presented in Table 3. Two of the gymnasts did not complete the blood test. For the remaining 36 gymnasts, 25 gymnasts had a possible vitamin D deficiency (serum D<60 nmol/L = 69%) and two gymnasts had a vitamin D deficiency (serum D<30 nmol/L = 6%). No relationship was identified between vitamin D and the bone measures. However vitamin D was moderately, negatively correlated with RJ73 ($r = -0.361$, $p = 0.039$) and RJ111 ($r = -0.398$, $p = 0.024$) displacement. All of the gymnasts' results were within the laboratories reference ranges for calcium and iron. Calcium had no relationship with any of the anthropometric, dietary, biomechanical or bone measures. However, iron was moderately related to trabecular density (r = 0.401, p = 0.017). Dietary calcium was positively correlated with trabecular density (r = 0.563, p = 0.015).

Table 1: Participant's physical descriptors and bone measures.

Statistics	Anthropometry & Maturation				Tibia			
	Femur Length (cm)	Tibia to Floor Length (cm)	Hip Width (cm)	Tanner Score (n)	Trabecular Density (mg/cm^3)[a]	Cortical Area (mm^2)[c]	Cortical Density (mg/cm^3)[b]	Strength Strain Index (mm^3)[b]
N	37	38	38	38	38	38	38	38
Mean	33.33	39.98	23.14	1.50	344.22	252.60	1079.42	989.11
Standard Deviation	2.31	2.6	1.52	0.65	48.03	36.43	27.36	203.21
Minimum	29.60	36.4	20.50	1.00	233.70	187.50	1033.90	623.10
Maximum	40.20	45.3	26.40	3.00	448.10	326.00	1140.90	1414.30

Notes: [a]4% tibia, [b]38% tibia, and [c]66% tibia.

Table 2: Participant's blood test and nutrition measures.

Statistics	Blood						Food	
	Serum D (nmol/L)	Calcium (mmol/L)	Phosphate (mmol/L)	Iron (umol/L)	Eosinophil Count (n)	Eosinophil (%)	Caloric Intake (kJ)	Dietary Calcium (mg)
N	36	36	36	36	36	36	27	27
Mean	52.31	2.55	1.48	20.05	0.20	0.20	6670.63	778.59
Standard Deviation	17.58	0.06	0.20	6.32	0.20	0.20	1892.09	380.91
Minimum	21.00	2.44	1.01	10.67	0.01	0.01	4258.00	173.39
Maximum	96.00	2.67	1.77	35.52	0.09	0.88	12261.00	1458.99

Table 3: Participant's biomechanical measures

Statistics	Uniaxial Force Platform				Triaxial Force Platforms				
	SJ Displacement (cm)	SJ Take-Off Force (BW)	CMJ Land Force (BW)	CH Average Power (W/kg)	RJ73 Displacement (cm)	RJ73 Take-Off Force (BW)	RJ73 Average Concentric Power (W/kg)	RJ73 peak Concentric Power (W/kg)	RJ111 Displacement (cm)
N	38	38	38	38	38	38	37	38	37
Mean	33.45	2.71	5.12	20.84	15.37	9.19	24.47	38.10	15.15
Standard Deviation	2.71	0.44	0.94	4.59	2.77	1.36	3.41	5.73	2.92
Minimum	29.2	2.02	3.27	13.10	9.97	6.41	15.76	27.53	10.79
Maximum	40.1	3.90	7.20	30.60	23.09	11.93	28.55	52.59	22.99

Notes: SJ is squat jump, CMJ is countermovement jump, and RJ is rebound jump.

Thirty-five of the gymnasts competed in the national competition. Twenty-two (63%) of the gymnasts competed at the International Development Programme (IDP) level 6, nine (26%) gymnasts competed at IDP level 8, and four (11%) gymnasts competed at IDP level 10. The average all-around score from two days of competition was 99.38 ± 1.40 points. Competition level had significant relationships with age (r = 0.703, p<0.001), mass (r = 0.417, p = 0.034), tibia to floor length (r = 0.449, p = 0.024), vitamin D (r = -0.445, p =0.023), and cortical area (r = 0.392, p = 0.048). Competition score significantly correlated with vitamin D (r = -0.350, p = 0.039), CMJ landing force (r = -0.414, p = 0.036), and RJ111 peak eccentric power (r = 0.416, p = 0.048). The results for the linear regression models are summarised in Table 4 and indicate, for example, that femur length and tanner score has a relationship with strength strain index, when combined with the blood measure of eosinophil count and the biomechanical measure of RJ73 peak concentric power (SEE = 0.00%).

Table 4: Linear regression models using all measures

Dependent Variable	R^2	p	Formula & Independent Variables
Strength Strain Index (mm^3)	1.000	<0.001	2235.264 Eosinophil Count (n) -12.177 RJ73 Peak Concentric Power (W/kg) + 46.303 Tanner Score (n) - 0.251 Femur Length (cm) + 1020.797
Trabecular Density (mg/cm^3)	1.000	<0.001	0.993 RJ73 Average Concentric Power (W/kg) + 16.449 Eosinophil (%) + 43.677 CMJ Land Force (BW) + 53.476
Corticol Density (mg/cm^3)	1.000	<0.001	27.011 Tanner Score (n) + 224.233 RJ111 Displacement (cm) + 12.546 Phosphate (mmol/L) - 1.938 CMJ Land Force (BW) + 999.348
Competition Level (n)	1.000	<0.001	0.201 SJ Take-Off Force (BW) + 4.351 Phosphate (mmol/L) - 0.268 Iron + 5.694
Competition Score (n)	1.000	<0.001	0.052 Tibia to Floor Length (cm) + 0.949 RJ73 Take-Off Force (BW) + 2.477 SJ Displacement (m) + 10.868

DISCUSSION AND CONCLUSION: Seventy-five percent of gymnasts in this study had possible or confirmed vitamin D deficiency. This was slightly lower than previously reported levels for Australian gymnasts (Lovell, 2008), however the reference levels used in this study by the laboratory were lower (serum D<60 nmol/L) than those used in the Lovell (2008) study (serum D<75 nmol/L). Vitamin D was not related to any of the bone measures, and was not positively related to any jump performance or competition measures. Despite these findings for vitamin D, the gymnasts in this study had superior bone health (trabecular density) when compared to Greene et al.'s (2012) data on other active and less active populations. This indicates that the gymnasts high impact training, as evidenced from the results for some of the biomechanical jump measures, is most important for their bone health. Further analyses of this data set will examine the relationship between these measures with injury to attempt to identify impact thresholds.

REFERENCES:

Bass, S., Pearce, G., Bradney, M., Hendrich, E., Delmas, P.D., Harding, A., and Seeman, E. (1998). Exercise before puberty may confer residual benefits in bone density in adulthood: Studies in active prepubertal and retired female gymnasts. *Journal of Bone and Mineral Research, 13*, 500-507.

Burt, L.A., Naughton, G.A., Greene, D.A., Ducher, G. (2011). Skeletal differences at the ulna and radius between pre-pubertal non-elite female gymnasts and non-gymnasts. *Journal of Musculoskeletal and Neuronal Interactactions*, *11*, 227-233

Burt, L.A., Naughton, G.A., Greene, D.A., Courteix, D., Ducher, G. (2012). Non-elite gymnastics participation is associated with greater bone strength, muscle size, and function in pre- and early pubertal girls. *Osteoporosis International, 21*, 1277-1286.

Greene, D.A., Naughton, G.A., Bradshaw, E.J., Moresi, M., Ducher, G. (2012). Mechanical loading with or without weight-bearing activity: Influence on bone strength index in elite female adolescent athletes engaged in water polo, gymnastics and track-and-field. *Journal of Bone and Mineral Metabolism, 30,* 580-587.

Hamilton, B. (2010). Vitamin D and human skeletal muscle. *Scandinavian Journal of Medicine and Science in Sports, 20,*182-190.

Larson-Meyer, D.E. & Willis, K.S. (2010). Vitamin D and athletes. *Current Sports Medicine Reports, 9*, 220-226.

Linthorne, N.P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics, 69*, 1198-1204.

Lovell, G. (2008). Vitamin D status of females in an elite gymnastics program. *Clinical Journal of Sports Medicine, 18,* 159-161.

Acknowledgement: This study has been supported by the Australian Institute of Sport, High Performance Sport Research Fund. The authors would like to thank Susie Parker-Simmons for her assistance during the early stages of the project.