JUMP KINETICS, BONE HEALTH AND NUTRITION IN ELITE ADOLESCENT FEMALE ATHLETES

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The relationship between physical force capacity (kinetics), nutritional intake, and lower limb bone health was the focus of the present study. 119 adolescent female athletes across four sub-populations, gymnastics, track and field, water polo and non-active controls, completed a series of jump tasks, bone scans, and a three day food diary. Statistical analysis using two-way analysis of variance was used to compare key measures between groups. Significant differences were identified for bone and jump parameters. Stepwise linear regression analysis identified jump kinetics as best able to predict distal tibial trabecular bone density (r^2 = 44.2%, p = 0.000) and bone strength (r^2 = 28.5%, p = 0.000). Athletes engaging in weight-bearing loading appear advantaged in site-specific markers of bone health.

KEYWORDS: bone, loading, training, nutrition, health, sport

INTRODUCTION: For the aspiring adolescent female athlete the competing demands of growth and development and increasing training hours provides a unique challenge when maintaining overall health. The unique nature and demands of a particular sport may also have both short and longer-term health implications. Sports involving considerable loading of the lower limb through high-impact or repetitive ground contacts (e.g. athletics and gymnastics), can illicit both positive (bone building, strength) and negative (injury risk) outcomes (Nichols et al., 2007). Conversely, water-based sports where the body is frequently unloaded during training has differing outcomes of reduced injury risk (positive), but limited potential for bone building (negative).

Nutrition, in particular caloric and calcium intake, also plays a role in bone building, and overall growth and development (Rogol et al., 2000; Nichols et al., 2007). The increased energy demands of training may place additional stress on the nutritional intake of elite athletes. Research highlights that the nutritional habits of elite athletes may be insufficient to support both growth and the rigors of training (Hawley et al., 1995). Insufficient energy intake coupled with high training demands may negatively impact bone health.

The use of jump tasks to measure general strength and power has been widely utilized in applied sports research (e.g. Bradshaw & Le Rossignol, 2004). Through the measurement of kinetics during functional tasks, an understanding of the typical forces experienced in the daily training environment can be obtained. The relationship between nutritional intake, jump performance and bone health is yet to be established, particularly for the elite adolescent female athlete.

The purpose of the present study was to evaluate the relationship between nutritional intake and jump kinetics with site specific markers of bone health in four distinct sub-populations of adolescent females.

METHOD: One hundred and nineteen adolescent female participants from four sub-populations; high-‘impact’ sports (gymnastics and track and field), low-‘impact’ sport (water polo), and a less physically-active control group (<4 hours of physical activity per week outside of their physical education classes) volunteered for the study (refer to Table 1). All participants were injury free at the time of testing. All procedures were approved by the University Ethics Committee and athlete and parental/guardian consent was obtained prior to participation in the study.

Table 1. Participant age, physical descriptors, daily nutritional intake (from 3 day food diary), and weekly physical activity (PA) for all sub-population groups, reported as mean ± standard deviation.

Group	Participants (n)	Age (yrs)	Height (cm)	Mass (kg)	PA (hrs)	Caloric Intake (kCal)[a]	Calcium Intake (mg)[b]
Gymnastics	26	13.7 ± 1.9	146.6 ± 7.8	39.4 ± 7.3	33.2 ± 2.3	1965.6 ± 651.3	992.3 ± 291.3
Track and Field	34	15.9 ± 1.2	168.8 ± 6.8	58.8 ± 7.5	8.4 ± 3.9	2152.6 ± 445.3	996.5 ± 409.5
Water Polo	31	16.2 ± 0.7	172.1 ± 6.1	67.5 ± 8.0	13.0 ± 5.2	2032.3 ± 668.3	810.9 ± 234.3
Controls	28	14.3 ± 1.1	163.9 ± 5.6	58.4 ± 9.3	1.9 ±1.5	2090.1 ± 560.7	1119.6 ± 826.5

Notes: The recommended daily intake for adolescent females aged 12-18 years in Australia and New Zealand is [a]2245 kCal for caloric intake and [b]1300 mg for calcium intake (http://www.nrv.gov.au). The recommendations are an average and don't account for individual variations in physical activity such as those female athletes engaged in elite training.

All of the participants performed a self-administered warm-up prior to the testing. Two warm-up jumps followed by three trials of a counter movement jump (CMJ), a squat jump (SJ), a standing long jump (SLJ), and drop jump (DJ) from a 70cm box were completed. All jumps were performed in the same order. 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 CMJ and SJ trials and jump as high as possible whilst minimizing ground contact time for the DJs.

All of the jumps were completed on two portable, multi-component force plates (Kistler, 9286A, Switzerland) sampling at 1000Hz. Both force plates were covered with Mondo running track surface material to simulate a 'typical' sporting environment surface. Jump height was calculated by using the impulse-momentum method (Linthorne, 2001). Peak force data was normalized to body weight. Jump height and distance was normalized to standing height.

A Peripheral Quantitative Computed Tomography (pQCT; Stratec XCT 2000, Pforzheim, Germany) scanner was used to assess the non-dominant lower limb for each participant at the 4%, 38% and 66% sites of the tibia measured distally. Trabecular area, density and bone strength-strain index (SSI) were assessed at the 4% distal site using the manufacturer's software. Cortical area, density and bone SSI were assessed at the 38% distal site, and muscle and fat area at the 66% distal site.

Means and standard deviations were calculated for all measures across the four sub-populations using Statistical Package for Social Sciences (SPSS, version 17, Chicago, USA). Analysis of covariance (ANCOVA) controlling for limb length with Bonferroni post-hoc analysis was used to identify differences in bone density, area and SSI. Analysis of variance (ANOVA) with Bonferroni post-hoc analysis was used to identify differences between groups for jump kinetics. Pearson product-moment correlations between jump kinetics and bone parameters provided the basis for a stepwise linear regression model to predict bone area, density and SSI from the jump kinetic data.

RESULTS AND DISCUSSION: Table 2 displays the mean tibial bone results. At the 4% distal tibial site, the high-'impact' sport athletes (gymnasts and track & field athletes) had significantly higher trabecular bone density and SSI values ($p<0.001$). This supports the previously reported positive bone building potential of weight-bearing sports (Nichols et al., 2007). In addition, the track and field group displayed significantly higher cortical bone area and SSI ($p<0.001$) at the 38% distal tibial site than the control group. This finding, in the absence of any significant differences in the other sporting groups, would suggest that the type of loading experienced by the track and field athletes (potentially more vertical compression) may be important in cortical bone development.

Table 2. Mean ± standard deviation for distal tibia bone measures of the non-dominant leg.

Group	Tibia Length (mm)	4% Tibia –Trabecular Bone			38% Tibia – Corticol Bone			66% Tibia	
		Area (mm^2)	Density (mg/cm^3)	Strength (mm^3)	Area (mm^2)	Density (mg/cm^3)	Strength (mm^3)	Muscle Area (mm^2)	Fat Area (mm^2)
Gymnastics	331.9^{ctw} ± 22.6	472.5 ± 44.4	362.0^{ctw} ± 62.1	2180.9^{cw} ± 301.0	237.5 ± 30.9	1096.7^{ctw} ± 37.9	1180.9 ± 234.3	5549.1^{t} ± 923.7	1363.5^{cw} ± 270.6
Track and Field	378.2^{g} ± 21.4	485.7 ± 75.1	293.2^{cgw} ± 54.6	2235.6^{cw} ± 557.7	293.9^{cw} ± 35.7	1140.2^{g} ± 26.1	1643.1^{c} ± 304.5	6606.7^{gw} ± 806.9	2048.4^{cw} ± 499.2
Water Polo	384.3^{cg} ± 22.4	468.3^{c} ± 56.0	231.2^{gt} ± 41.7	1831.6^{gt} ± 423.8	271.7^{t} ± 25.5	1151.2^{g} ± 23.4	1563.9 ± 231.8	5933.9^{t} ± 849.7	3054.4^{gt} ± 1412.9
Controls	366.1^{gw} ± 35.3	501.5^{w} ± 53.4	241.4^{gt} ± 36.4	1665.7^{gt} ± 498.4	242.8^{t} ± 35.6	1135.7^{g} ± 28.4	1322.6^{t} ± 303.4	5971.9 ± 717.6	2637.3^{gt} ± 759.9

Notes: Statistically significant with; c: controls, g: gymnasts, t: track and field, w: water polo. ($p<0.05$ following Bonferroni adjustment for multiple comparisons) All bone measures were covaried for tibial length. 'Estimated' mean values following covariance not reported.

Jump kinetic and performance data is presented in Table 3. Overall, the gymnasts displayed significantly greater peak forces than the water polo (all jumps, $p<0.005$), control (SJ and CMJ, $p<0.001$) and track and field athletes (SJ and SLJ, $p<0.001$). Track and field athletes and gymnasts had significantly better jump performance than the controls and water polo athletes across all tests ($p<0.001$) except for the DJ where only gymnasts showed a significant difference in jump height. Water polo athletes had the lowest peak forces across all groups with the controls displaying the lowest jump heights and distances across all tests. Gymnasts had a significantly shorter contact time (0.240s) for the DJ test than the track and field (0.300s), control (0.333s) and water polo (0.363s) groups.

Table 3. Peak ground reaction forces and jump height/distance as a percentage of standing height (m) for the four jump tasks for all groups, reported as means ±standard deviation. All force measures are vertical with the exception of the SLJ which is a horizontal force.

Group	CMJ		SJ		SLJ		DJ	
	Force (BW)	Height (%)	Force (BW)	Height (%)	Force (BW)	Distance (%)	Force (BW)	Height (%)
Gymnastics	2.5^{w} ± 0.3	0.15^{cw} ± 0.02	2.8^{ctw} ± 0.3	0.14^{cw} ± 0.02	1.2^{ctw} ± 0.1	1.20^{cw} ± 0.10	9.2^{w} ± 1.4	0.10^{cw} ± 0.03
Track and Field	2.3 ± 0.2	0.14^{cw} ± 0.03	2.5^{gw} ± 0.4	0.14^{cw} ± 0.03	0.9^{g} ± 0.1	1.16^{cw} ± 0.11	8.2 ± 1.8	0.08 ± 0.03
Water Polo	2.2^{g} ± 0.2	0.12^{cgt} ± 0.02	2.2^{gt} ± 0.3	0.11^{cgt} ± 0.02	0.7^{g} ± 0.1	0.92^{gt} ± 0.11	7.8^{cg} ± 1.4	0.07^{g} ± 0.03
Controls	2.3 ± 0.3	0.10^{gtw} ± 0.02	2.3^{g} ± 0.2	0.09^{gtw} ± 0.02	0.8^{g} ±0.1	0.90^{gt} ± 0.12	9.3^{w} ± 1.7	0.06^{g} ± 0.03

Notes: Statistically significant with; c: control group, g: gymnastics group, t: track and field group, w: water polo group ($p<0.05$ following Bonferroni adjustment for multiple comparisons).

Regression analysis showed reasonable predictability of trabecular bone density and strength at the 4% distal tibia site with jump kinematics and kinetics able to explain 43.5% ($p=0.000$) and 28.5% ($p=0.000$) of the variance in bone scores respectively. Predictability of cortical bone variance using jump kinetics was not as high with only 14.1% ($p=0.000$) of cortical bone density at the 38% distal tibia site explained by SLJ and SJ peak force. Caloric and calcium intake were not significantly related to any of the bone parameters.

Table 4. Regression analysis using jump kinetics to predict differences in bone area, density and SSI.

Dependent Variable	Model	R^2	P	SEE%	Formula & independent variables
4% Tibia – Trabecular Bone	Area (mm^2)	0.037	0.029	12.2%	451.29 + 388.32 x DJ Height
	Density (mg/cm^3)	0.435	0.000	18.8%	7.94 + 216.51 x SLJ Peak Force + 8.66 x DJ Peak Force
	SSI (mm^3)	0.285	0.000	22.0%	200.84 + 930.89 x SLJ Distance + 3764.27 x DJ Jump Height + 58.13 x DJ Peak Force
38% Tibia – Corticol Bone	Area (mm^2)	0.048	0.015	14.5%	321.17 – 23.55 x SJ Peak Force
	Density (mg/cm^3)	0.141	0.000	2.9%	1216.62 – 19.91 x SJ Peak Force -38.93 x SLJ Peak Force
	SSI (mm^3)	0.080	0.013	21.6%	1907.32 – 504.00 x SLJ Peak Force

CONCLUSION: Elite adolescent female athletes involved in ‘high-impact’ sports (gymnastics and track & field) showed greater trabecular bone density and bone strength as well as increased jumping ability and force production capability compared with ‘low-impact’ (water polo) sporting and control groups. The ability of jump kinetics to predict differences in trabecular density and bone strength at the distal tibia among athletic populations suggests that the ability to produce and routinely deal with higher forces is important for bone development. The type of loading experienced during sports participation appears important for cortical bone development. The repetitive, more vertical and compressive nature of loading on relatively hard surfaces experienced in track and field differs from the repetitive, more rotational nature of loading on predominantly sprung surfaces experienced by gymnasts. This varies with the loading demands of a non weight-bearing sport such as water polo. These demands, as suggested by the differences in kinetic capacity between the groups, appear to have an impact on bone health. However, the exact relationship between force capacity and bone health may be more evident during longitudinal assessment.

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