10th April, 2006.

Dear Members of the Sporting Injuries Committee,

Please find outlined below a summary of findings from the research project titled, "Exercise type, musculoskeletal development and injury risk factors in elite adolescent athletes". The summary consists of abstracts from papers published in peer-reviewed journals between 2004 and 2006.

2004 - D.A Greene, G.A Naughton, J.N. Briody, A. Kemp, H. Woodhead & N. Farpour-Lambert. Musculoskeletal health in elite male adolescent middle-distance runners. *Journal of Science and Medicine in Sport*, 2004; 7:3:373-383.

**Abstract**

The impact of high training volumes on musculoskeletal adaptations of male adolescents is poorly understood. We compared bone mineral content (BMC) of total body, lumbar spine and proximal femur using Dual X-ray Absorptiometry (Lunar Prodigy□, GE Medical Systems, Madison WI) in elite level (n=20), male adolescent middle distance runners (mean 16.8 years, range 14 – 18 years) and age-matched (n=20) controls. Athletes averaged 14 hours of physical activity per week and controls reported participating in physical activity an average of 2 hours per week. Total body mass was 10.97 kg less in athletes than controls (p=0.005). Within the total body mass difference, fat tissue mass of athletes was 10.93 kg less in athletes than controls (p= 0.001). Multiple regression analysis identified total body lean mass and total body fat mass as the strongest predictors of total body BMC ($R^2$ 0.71). After adjusting for lean tissue mass per kg of body weight (p=0.07), no difference in BMC was detected. Lower limb muscle strength and macronutrient intakes were also measured but no between group differences were found. The number of weeks of training and/or competition missed through injury was not associated with total body BMC ($R^2$=0.19) among athletes. Our results imply high training volumes in middle distance running are not detrimental to musculoskeletal health and are associated with positive body composition profiles in elite adolescent male athletes.

2005 - D.A Greene, G.A Naughton, J.N. Briody, A. Kemp, H. Woodhead & N. Farpour-Lambert. Bone geometry and musculoskeletal health in female adolescent middle-distance runners. *Pediatric Exercise Science*, 2005,17,377-389.

**Abstract**

The musculoskeletal consequences of repetitive mechanical loading in adolescent female middle distance runners are unclear. **Purpose**: The study compared tibial bone geometry and total body and regional bone mineral content in elite female adolescent middle distance runners and age-matched controls. **Methods**: Mid distal tibial bone geometry using Magnetic Resonance Imaging (1.5 Tesla Phillips INTERA, Netherlands) and total body, lumbar spine, proximal femur and tibial bone mineral content (BMC) using Dual X-ray Absorptiometry (Lunar Prodigy™) were compared in elite, female adolescent middle-distance runners (*N* =20, age: 16 ± 1.7 yr) and age-matched controls (*N* =20, 16 ± 1.8 yr). **Results**: Athletes and controls differed in bone geometric values for distal tibial mid-slice cortical (P = 0.003) and medullary cavity (P = 0.035) cross-sectional area (CSA). Mid distal tibia total muscle (P = 0.03) and dorsi flexor muscle compartment CSA (P = 0.02) were greater in athletes than controls. Athletes displayed greater unadjusted BMC than control participants in dominant (4.77g ± 1.36, P = 0.001) and non-dominant (3.91g ± 1.46, P = 0.011) proximal femurs, dominant femoral neck (0.5 g ± 0.18, P = 0.01) and dominant tibia (4.14 g ± 2.04, P = 0.05). Total body BMC per kg fat mass was also greater in athletes. Hours of activity averaged 8.9 ± 2.1hr.wk$^{-1}$ in athletes and 2.0 ± 0.07 hr.wk$^{-1}$ in controls. **Conclusion**: Differences in tibial bone geometric properties, total body and regional BMC, and muscle CSA are associated with high training volumes of middle distance running. Within the limits of the cross-sectional design, results imply mechanical loads may be beneficial to musculoskeletal health in adolescent females.

2005 - Greene D.A., Naughton G, Briody J, Kemp A, Woodhead H, and Corrigan, L. Bone strength index in adolescent females: Does physical activity make a difference? *British Journal of Sports Medicine,* 2005; 39:9:622-627.

**Background:** Bone Strength Index (BSI) combines bone mineral and bone biomechanical properties to measure resistance to bending. This index may have greater clinical significance than more the frequently described markers of bone mineral content (BMC), areal density or geometry alone and in turn, may show a stronger relation to fracture risk. The BSI index is the product of volumetric cortical bone mineral density (BMD) and cross-sectional moment of inertia (CSMI) within a region of interest (ROI). Calculations combine Dual X-ray Absorptiometry (DXA) and Magnetic Resonance Imagining (MRI) technologies and provide a useful, non-invasive measure of *in vivo* bone strength.

**Objectives:** (i) To compare BSI in adolescent female middle-distance runners and age-matched controls (ii) To examine factors predictive of BSI in adolescent females.

**Methods:** Twenty adolescent female middle-distance runners (mean (SD) age 16 ± 1.7 yr, physical activity 8.9 ± 2.1 hr.wk$^{-1}$) and twenty female controls (age 16 ± 1.8 yr, physical activity 2.0 ± 0.07 hr.wk$^{-1}$) were recruited. To calculate BSI, a ROI representing 10% of the mid distal tibia was analysed for DXA-derived bone mineral and was combined with bone geometry and biomechanical properties taken MRI assessments. Potential predictors of BSI were also examined.

**Results:** Independent t-tests showed the distal tibia of athletes was greater than controls for BMC ($p=0.028$), cortical BMC ($p=0.002$), volumetric cortical BMD ($p=0.004$), cross-sectional moments of inertia ($p=0.005$) and BSI ($p=0.002$). The strongest predictor of BSI was hours of physical activity per week ($R^2 = 0.46$).

**Conclusions**: Athletes habitually exposed to high training loads displayed greater BSI at the distal tibia than controls. Our results further confirm BSI as a significant and discerning marker in musculoskeletal health in adolescent females engaged in high and low mechanical loading.

2006 - Greene, D.A. Adaptive skeletal responses to mechanical loading during adolescence – A review. *Sports Medicine* (in press)

**Abstract**

Adolescence, defined as the period between puberty and maturity, provides a "window of opportunity" for positive skeletal adaptations to mechanical loading unlike any other period in life. The purpose of this review is to examine the adaptive skeletal responses to mechanical loading in highly-active adolescent populations. Age-related bone loss highlights the importance of accumulating sufficient bone mass during formative years. Adolescents who regularly engage in weight-bearing mechanical loading appear advantaged in site-specific markers of bone mass. The positive influence of physical activity on bone mineral accrual during growth has been extensively studied however, few studies have examined skeletal responses to mechanical loading during adolescence. Weight-bearing physical activity, particularly high-impact sports such as gymnastics, is recognized as being more osteogenic than weight-supported activities. Unilateral loading activities such as tennis or squash provide a direct comparison of skeletal response without sampling bias or genetic confounding. Intervention and longitudinal studies show evidence of positive skeletal adaptations however, sustainability of skeletal advantages remains unclear. The review will provide a brief overview of the material properties of bone and present evidence from cross-sectional, intervention, and longitudinal studies across peri-, and post-pubertal growth phases. New technology regarding structural assessment of bone will also be discussed.

2006 - Greene D.A., Naughton G, Briody J, Kemp A, Woodhead H. Assessment of bone strength at differentially–loaded skeletal regions in adolescent middle-distance runners. *Journal of Science and Medicine in Sport* (in press)

**Abstract**

Bone adaptations to loading extend beyond mineral accrual to geometric markers of bone strength. Available technology and regional differences in cortical bone dictate how bone strength is reported. Examination of bone strength at two differentially-loaded skeletal sites using hip structure analysis (HSA) and bone strength index (BSI) is under explored in adolescent sporting populations.

**Purpose:** (i) to examine HSA at the femoral neck and BSI at the distal tibia between adolescent middle-distance runners and age- and gender-matched controls (ii) to examine factors predictive of HSA and BSI within each gender.

**Methods:** Four groups of 20 adolescents aged 14 to 18 years comprised of male and female middle-distance runners, and male and female controls. Distal tibial BSI was calculated using data from dual energy x-ray absorptiometry (DXA) and magnetic resonance imaging (MRI). Calculations for femoral neck strength were acquired from DXA-derived HSA software.

**Results:** Female athletes displayed greater distal tibial BSI than controls ($P$=0.002) but femoral neck bone measures did not differ. In males, no group differences were found at the distal tibia or femoral neck. In females, the strongest predictors of distal tibial BSI were hours of physical weekly activity and total muscle cross-sectional area (CSA) (58.3%), and neck of femur CSA accounted for 64.6% of the variance in a marker of femoral neck HSA. In males, total muscle CSA explained 43.5% of variance in BSI at the distal tibia, and femur length and neck of femur CSA explained 33.4% of variance at the femoral neck.

**Conclusions**: Exposure to similar high training loads may advantage female adolescent athletes, more than male adolescent athletes compared with less active peers in bone strength at the distal tibia.

We would like to take this opportunity to sincerely thank the New South Wales Sporting Injuries Committee for their financial support.

Yours sincerely,

Dr David Greene Associate Professor Geraldine Naughton