Effects of Exercise During Growth on Bone Strength and Morphology

Matthew Q. Salzano[1], Timothy M. Ryan[2], Suzanne M. Cox[3], Stephen J. Piazza[3], & Jonas Rubenson[1,3]
[1]Integrative & Biomedical Physiology, The Pennsylvania State University, University Park, PA
[2]Department of Anthropology, The Pennsylvania State University, University Park, PA
[3]Department of Kinesiology, The Pennsylvania State University, University Park, PA
Email: salzano@psu.edu

Summary

Acceleration-based exercise (*e.g.* running, jumping) during growth in an avian model increases bone strength, and influences bone shape in a way that is suggestive of larger Achilles tendon (AT) moment arms.

Introduction

It is well established that loading stimulus influences bone strength during growth [1]. However, whether bone shape is similarly plastic during growth is less clear, although previous work in mice has shown scapula [2] and femoral head (*i.e.* hip structure) [3] shape changes as a result of exercise during growth. Indirect evidence from human populations suggests that joint structure might be affected by exercise stimulus; sprint trained athletes have been shown to have smaller AT moment arms compared to untrained individuals [4].

The purpose of this study was to test whether loading stimulus during growth influences bone shape in addition to bone strength. Specifically, we hypothesized that additional high-acceleration exercise would result in a decreased hypotarsus width, a proxy for AT moment arm (Figure 1).

Methods

Thirty guineafowl (*Numida meleagris*) were split evenly into exercise (EXE) and sedentary (SED) groups at 4 weeks of age. The EXE group were housed in a large pen to promote running and jumping, while the SED group were housed in small pens to restrict movement. EXE birds were also trained 30 minutes per day, 5 days per week, during which they performed short bursts of high-acceleration running. The SED group received no training. The protocol lasted until birds were 14 weeks of age, when they were sacrificed for morphological analyses.

Specimens were first scanned using dual-energy X-ray absorptiometry to measure bone mineral content (BMC), and bone mineral density (BMD). Right limbs were removed and the tarsometatarsus (TMT) was scanned with a microCT scanner. Bone CT scans were processed in Avizo software. Cross-sectional properties were analysed at 50% diaphysis length in ImageJ with the BoneJ plug-in. To characterize overall bone shape, 159 landmarks and semilandmarks were created in ViewBox. Landmarks were used to calculate simple TMT dimensions related to function. A principal components analysis will be run to determine overall shape differences. T-tests were used to test for significant differences, with $\alpha = 0.05$.

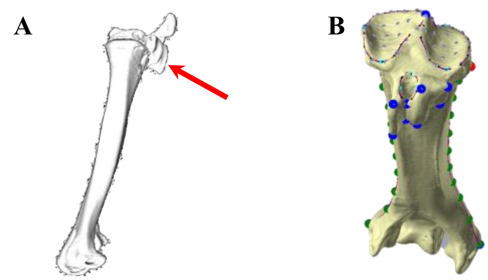

Figure 1. A: Sagittal view of TMT, with red arrow showing hypotarsus. B: Landmarks and semilandmarks for TMT.

Results and Discussion

EXE birds had smaller body mass and shorter TMT compared to SED (Table 1), while whole-body BMC and BMD were not different (not shown). Measures of rigidity (I_{max}, I_{min}, J) and strength (Z_{max}, Z_{min}, Z_{pol}) were significantly greater in EXE (Table 1), indicating stronger bones overall. I_{max}/I_{min} (not shown) was not significantly different, suggesting no difference in diaphysis cross-sectional shape. EXE also had wider hypotarsi (AT insertion) in the A-P direction (Table 1), suggesting a larger AT moment arm, contrary to the findings in human sprinters [4].

Conclusion

Acceleration-based training during growth has the capacity to alter not only bone strength, but also bone shape. The wider hypotarsus in EXE birds may increase the AT moment arm, possibly an adaptation for increase elastic energy storage.

This study was supported through NIH Grant R21AR071588.

References

[1] Strong WB et al. (2005). *J Pediatr*, **146**(6): 732-7.
[2] Green DJ et al. (2012). *J Exp Zool B Mol Dev Evol*, **318**(8): 621-38.
[3] Plochocki JH et al. (2006). *Anat Rec A Discov Mol Cell Evol Biol*, **288**(7): 776-81.
[4] Baxter JR et al. (2012). *Proc Biol Sci*, **279**(1735): 2018-24.

Table 1: Variables of size, strength, and shape that show significant ($p < 0.05$) differences between groups. Significantly larger measures are bolded. † indicates normalization to body mass. * indicates normalization to leg length. # indicates normalization to leg length x body mass.

	Body Mass (kg)	TMT Length (mm)	† CSA (mm^2/kg)	# I_{max} (mm^3/kg)	# I_{min} (mm^3/kg)	# J (mm^3/kg)	# Z_{max} (mm^2/kg)	# Z_{min} (mms^2kg)	# Z_{pol} (mm^2/kg)	Hypotarsus Width
EXE	1.29	74.35	**11.43**	**0.63**	**0.34**	**0.97**	**0.19**	**0.13**	**0.27**	**0.0555**
SED	**1.38**	**76.28**	10.66	0.55	0.31	0.86	0.17	0.11	0.24	0.0501