

The effect of disuse on muscle lever systems in a rapid-growing avian bipedal model

Matthew Q. Salzano, Stephen J. Piazza, and Jonas Rubenson

The Pennsylvania State University, University Park, PA, USA
email: salzano@psu.edu, web: <http://sites.psu.edu/biomechanics/>

INTRODUCTION

It is well accepted that today's youth exhibit an increasingly sedentary lifestyle compared to previous decades. Previous studies have shown skeletal changes with decreased physical activity in children, including reductions in bone mass and bone mineral density relative to active children [1]. However, how a sedentary lifestyle during childhood affects musculoskeletal structure and function remains unclear. In particular, it is unknown if the muscular lever system (muscle moment arms) is affected by a lack of activity during development. Disuse remodeling of the muscle lever system during childhood may impart functional and locomotor alterations into adulthood.

Previous work indicates that smaller plantarflexor moment arm lengths are related to running ability in humans [2], permitting more effective force production during rapid limb movements. In contrast, disuse may lead to larger moment arms that are well suited to economical static weight support as opposed to an optimization for minimizing muscle excursion and velocities. Hence, we hypothesized that disuse during development in an animal model will result in larger extensor moment arms compared to animals provided with exercise stimulus during growth.

METHODS

This study utilized guinea fowl as a model animal due to their bipedal locomotion, fast growth (approx. 4 months to skeletal maturity), and their clear bony protuberances on the tibia and metatarsus for muscle attachments that can serve as a proxy for knee and ankle extensor moment arms. Guinea fowl were split into an exercise control group (n=15) and sedentary (disuse) group (n=15) at 4 weeks of age. Control birds were housed in joined

dual-circle floor pens (1.85 m in diameter each) containing perches that allowed for ample locomotion and opportunities for perching. Sedentary birds were all housed in small square floor pens (~ 1 m²) to limit locomotion. All birds were given food and water *ad libitum*.

In addition to the increased pen size, the exercise control group were motivated to locomote using an automated boom that swept through the pen for 10 minutes per hour for 12 hours each day for a period of 10 weeks. The exercise control group were also manually exercised for 30-40 minutes per day for 5 days per week over the ten-week period to simulate movement loads similar to those in natural environments (Fig. 1.).



Figure 1. Example of automated exercise protocol for control group.

At 14 weeks of age, both groups were sacrificed. Specimen were x-rayed to obtain images of the skeleton. X-ray images were analyzed using OsiriX software (example in Fig. 2) for bone dimensions including the lengths of the tibia, tarsometarsus, the proximal, middle, and distal phalanges of the third digit, and the radius and ulna. We also measured the articular widths of the ankle and knee joints. Both the tibia and tarsometatarsus have bony protuberances on their proximal ends that act as sites of attachment for extensor muscles. The width

of these two bones at these sites served as approximations of extensor moment arms at the knee and ankle joints.

RESULTS AND DISCUSSION

The masses of the two groups were similar initially (4 weeks-old), but the sedentary group were significantly heavier by week 6 and throughout the remaining experimental phase (Fig. 3).

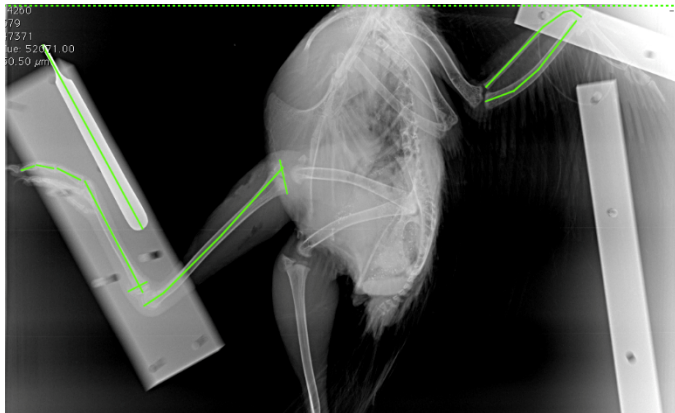


Figure 2. Example X-ray showing measurement lines for analysis.

Bone measurements are presented in Table 1. Preliminary results from a subsample of the animals (n = 5 in the control and disuse groups) indicate that the exercised control birds and sedentary group have similar bone lengths. These findings are in agreement with previous work showing no difference in bone length with hypoactivity in chickens [3]. Bone lengths were consistent across both leg and wing bones. The most pronounced difference in bone geometry was the width of the tarsometatarsal head, which was approx. 7% greater in the sedentary group (p = 0.16). The tarsometatarsus head incorporates the bony protuberances on which the gastrocnemius muscle attaches and thus the increase in tarsometatarsus width serves to increase the moment arm of this ankle extensor muscle.

Table 1: Average bone lengths and widths for each group presented as means ± SD in millimeters.

	Tibia Length	Tibia Width	Tarsometatarsus Length	Tarsometatarsus Width	Basal Phalanx	Middle Phalanx	Distal Phalanx	Ulna	Radius
Control	115.24 ± 1.54	17.57 ± 1.41	73.59 ± 1.25	11.84 ± 0.90	16.54 ± 0.92	11.86 ± 0.61	10.03 ± 0.89	74.06 ± 2.92	75.15 ± 2.14
Disuse	116.99 ± 2.36	17.98 ± 0.96	74.49 ± 1.33	12.53 ± 0.43	16.77 ± 1.12	12.15 ± 0.71	10.23 ± 0.58	74.98 ± 2.56	75.98 ± 2.82

These results provide preliminary support for our hypothesis that disuse results in a remodeling of muscle moment arms. Larger extensor moment arms accompanying sedentary behavior may reflect an optimization for economical weight support. However, the increased moment arms may result in sub-optimal force generating capacity of the muscle during more rapid limb movements. Force generating capacity may be compromised because greater muscle moment arms cause muscle fibers to be shorter and to shorten faster, reducing force due to the force-length-velocity characteristics of muscle.

Future work will involve more detailed measurements of muscle moment arms and musculoskeletal geometry using microCT, MRI and detailed muscle dissections.

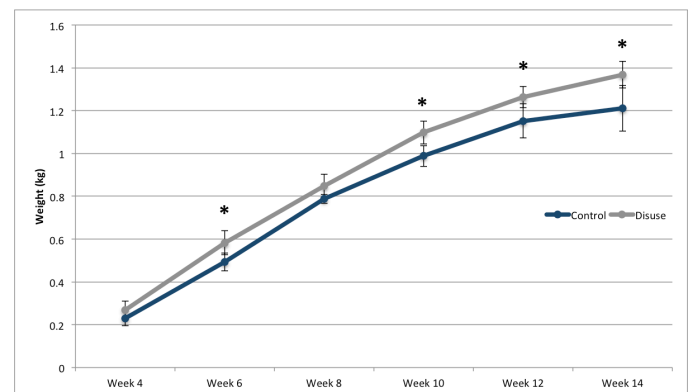


Figure 3. Weight growth curves. *p<0.05.

REFERENCES

1. Heidemann M, et al. *BMC Pediatr* **13**, 32, 2013.
2. Baxter JR, et al. *Proc Biol Sci* **279** (1735), 2018-2024, 2012.
3. Aguado E, et al. *PLoS One* **10**(1), 2015.

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