Responses of Scapular Size and Shape to Exercise and Selective Breeding for High Activity in *Mus*

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Introduction

Chronic exercise produces a variety of osteological responses, including increased bone diameter and mass. In addition, selection that acts on locomotor behavior may lead to evolutionary changes in bone sizes and shapes.

To compare these potential effects, a previous study measured hindlimb bones of house mice selected (S) for high voluntary wheel running (21 generations) and non-selected controls (C) that were housed for 8 weeks either with or without wheel access (Kelly et al. 2006). With body mass as a covariate, femora and tibiafibulae showed significantly greater diameters and masses in response to both wheel access and selection, but there were no bone length differences in either group. Additionally, S mice with the mini-muscle phenotype (50% reduction in hindlimb muscle mass) had longer, thinner hindlimb bones, but no differences in bone mass. The ratio of metatarsal to femur length (MT/F), a classic indicator of cursoriality, showed no differences.

We used these same mice to examine the potential responses of scapular size and shape to selection and exercise. The scapula was chosen because (1) it serves as the site of origin for many of the muscles responsible for forelimb propulsion and (2) is landmark-rich, thus allowing application of geometric morphometric techniques, which are a powerful tool for the detection of differences in multivariate shape.

Methods

MICE:

N = 80 adult males, same as used in Kelly et al. (2006):
4 lines selected (S) for high voluntary wheel running; 4 controls (C)

-Within each line, mice were separated into two experimental groups for a duration of 8-9 weeks.
Active: housed with wheels
Sedentary: housed without wheels

-Euthanized (at 85.6 days average age), then skeletonized and photographed.

LANDMARKS:

-Photographs digitized using tpsdig, 14 landmarks (Figure 1) following Swiderski (1993), Taylor & Slice (2005) and Morgan (2009)

-Linear measurements (SB and MLS) were extracted from the landmark data (Figure 1) using morphotools and following Kimes (1981) and Taylor (1997).
Calculated SB/MLS = ratio of scapular breadth to maximum length.

ADDITIONAL MEASUREMENTS:
-Scapula mass; scapula centroid size (tpsRelw); ratio of scapula mass to centroid size (SM/CS); and body mass.

UNIVARITE ANALYSES:
-Two-way ANCOVA in SAS PROC MIXED with replicate line nested within linetype (Selected or Control) as a random effect; body mass as a covariate.

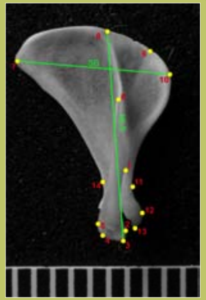

Figure 1. Landmarks and linear measurements.

Results

SCAPULAR SIZE:

S mice are **significantly smaller** than C in body mass, and wheel access **significantly reduced** body mass in both groups.

With body mass as a covariate, **no differences** exist between the S and C lines in scapular mass, centroid size, or SM/CS.

Activity (wheel access) **significantly increased** scapular mass and SM/CS in both groups, such that scapulae became heavier relative to centroid size.

Conversely, S mice with the mini-muscle phenotype had **significantly larger** centroid sizes and **smaller** SM/CS ratios relative to all other mice.

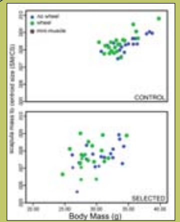

Figure 2. Scapular size.

Results

SCAPULAR PROPORTIONS:

With body mass as a covariate, **no differences** between the S and C lines or between the activity groups in relative scapular width (SB/MLS) exist.

S mice with the mini-muscle phenotype had **significantly narrower** scapulae (reduced SB/MLS).

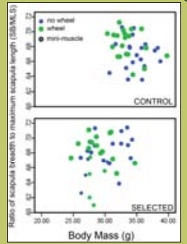

Figure 3. Scapular proportions.

Results

MULTIVARIATE SCAPULAR SHAPE :

With body mass as a covariate, S and C lines **significantly differ in multivariate shape**.

Activity caused **significant shape** differences within both linetypes (S and C), with **no significant interaction** between linetype and activity.

S mice with the mini-muscle phenotype had **significantly different** scapular shapes from all other mice.

Multivariate shape analyses employed a limited shape space (8 relative warps [RW] rather than the generated 24) to perform a two-way MANCOVA in SAS PROC MIXED with line nested within linetype (Selected or Control) as a random effect and body mass as a covariate. Because of the nature of this model and the fact that the df for the nested term must be equal to or greater than the number of dependent variables, shape data were treated as repeated measures with a variable that identified each warp (B. Schaalje and M. Belk pers. comm). Interactions between the warp variable and the fixed effects (linetype, activity, mini-muscle) indicated shape differences.

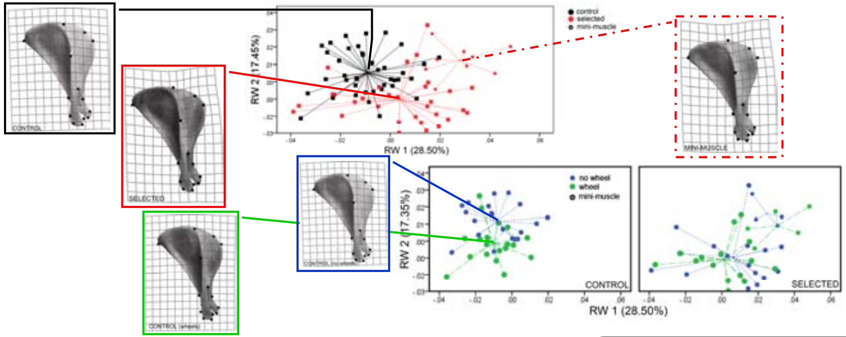

Figure 4. Scapular shape differences. Deformation grids were superimposed over images of individuals closest to the mean of each group. Thus landmark correspondence is not exact.

Conclusions

Both selective breeding for high voluntary wheel running and chronic access to running wheels led to significant alterations in multivariate scapular shape.

Geometric morphometric analyses detected shape differences between the S and C lines that were not apparent in univariate analyses, including analyses of shape based on ratios of linear measures.

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Abstract

Various studies on rodent long bones show that chronic exercise produces a variety of osteological responses, including increased bone diameter and mass. Studies of skeletal responses to voluntary exercise in flat bones, such as the major girdle elements (e.g. scapula), are scarce, but show that scapular shape is also responsive to different types of exercise. A previous study used hindlimb bones of house mice selected (S) for high voluntary wheel running and non-selected controls (C) to examine responses to 8 weeks of wheel access and breeding for high activity (J. Morphology, 2006, 267:360-374). With body mass as a covariate, long bones showed significantly greater diameters and masses in response to both wheel access and selection. Additionally, S mice with the mini-muscle phenotype (50% reduction in hindlimb muscle mass) had longer, thinner long bones, but no differences in bone mass. Employing the same mice, we used geometric morphometrics to generate quantitative descriptors of scapular shape, centroid size, and a series of linear measurements from which we calculated ratios previously used to quantify scapular proportions. As previously reported, S mice were smaller in body length and mass than C, and access to wheels reduced body mass in both S and C mice. ANCOVA showed no differences between the S and C lines in scapular mass, centroid size, ratio of scapular mass/centroid size (SM/CS), or relative width. However, wheel access significantly increased scapular mass and SM/CS in both groups. Finally, S mice with the mini-muscle phenotype had significantly narrower scapulae, larger centroid sizes, and a smaller SM/CS.

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