INTRODUCTION:
Bone alters its mass and shape to respond to its loading environment. High magnitude loads and strain rates produce microdamage in bone tissue. The existence of damage in bone tissue stimulates a remodeling and adaptive response. Skeletal adaptation is highly specific to loading circumstances. With exercise, bone changes are dependent on load magnitude and direction, and the number of load cycles. Adaptations include geometric and bone mineral density changes. Successful adaptation allows the bone to resist injury under subsequent loading conditions.

During periods of intense training, the equilibrium between accumulation of microdamage in bone tissue and bony adaptation can become perturbed. Bone cells that remove microdamage leave bone temporarily porotic, weakening the structure. In situations where there is a high density of microdamage, the subsequent damage removal can leave the bone more porotic than normal damage repair situations. Without training modifications, more damage can develop in the tissue, and propagate into macrocracks and possibly fracture in the bone.

Elite athletes undergo intense and sometimes excessive training to maintain a competitive edge. To achieve successful adaptation, it is crucial to establish a training regimen that does not overwhelm the tissue with microdamage and provides adequate time for damage repair. Because different levels of exercise intensity will affect the ability of biological processes to adapt bone material to intensive loading circumstances, we hypothesized that exercise history affects bone tissue material properties in diaphyses of Thoroughbred racehorse humeri.

METHODS:
Eighteen humeri were collected, post-mortem from 18 Thoroughbred racehorses. A cortical core (n=18) was harvested from the caudal diaphysis of the humerus and monotonically compressed to failure. Material properties were calculated from force versus displacement data and specimen geometry (from a previous study).

For each horse in the study, lifetime high-speed exercise history information was collected (Bloodstock Research Information Services). Exercise events included races and timed high-speed works. Data were reduced to horse-level exercise history variables. Variables included cumulative distances, distance rates, and layup information. Exercise rates included distance rates and event frequencies. Active periods were defined as periods when horses were actively racing and training. Layups were defined as periods greater than 60 days in length without a high-speed event.

The relationship between material properties and all exercise history variables were examined using both univariate and multivariate (stepwise) regression analyses. The univariate analysis was used to examine relationships between individual variables and to screen variables for inclusion in the stepwise analysis. Significance was set at p<0.05 and exercise history variables were included in the stepwise analysis if p<0.20. The purpose of the stepwise analysis was to generate robust models that predicted bone material properties based on exercise history variables. Some horses (n=5) did not have complete exercise histories, and were subsequently removed for the multivariate analysis. Variables were entered into the model if p<0.20 and were retained if p<0.10 and the variable increased the coefficient of determination (R²) by at least 10%.

RESULTS:
Modulus was positively related to the number of career races; career works; race, work and total (race + work) distance; average work and event distances; accumulated distance in the second, third and fourth month together; and total distance the last four and six months preceding death. Modulus also had a positive relationship with the number of career and active days.

Yield strain had a negative relationship with days per furlong for active periods. Yield strength was positively related to average event distance and days between races for active periods. Yield strain energy density (SED) was negatively related to the percentage of career spent in layup, the frequency of races during active periods, and days per furlong for a career. Yield SED was also positively related to the frequency of works for a career and days between races for active periods.

Ultimate strain was positively related to number of layups and negatively related to days per furlong for active periods. Ultimate strength was positively related to average event distance, average race and work distance, and distance accumulated in the second month, third and fourth month together, and distance in the last four months prior to death. Ultimate SED, post-yield strain and post-yield SED were not significantly related to any exercise history variables.

For the stepwise analysis, models were generated for modulus, yield and ultimate strength, yield SED and ultimate strain only (Table 1).

DISCUSSION:
In this study we found that modulus had a number of significant relationships with the examined exercise history variables, particularly those related to distance accumulations. Similarly, ultimate strength was related to a number of distance accumulation variables. Yield SED had relationships with the frequency and distribution of events over time.

The results from the multivariate analysis indicate that some material properties are influenced more than others by exercise history, including modulus, strength, yield SED and ultimate strain. The most influential factors appear to relate to distance accumulations and the distribution of that distance over time.

Statistical significance represents consistency among the data. It does not indicate or represent biological relevance. Thus, less significant variables may result in greater changes to bone material properties than highly significant variables.

Many of the analyzed exercise history variables have a strong relationship with each other. Those that entered into the stepwise regression models may be only slightly more significant than others. Other variables may be easier to control during training.

Many positive relationships existed between material properties and exercise variables. There is likely a limit to the benefits of distance accumulations. Large loads are generated in bone during high speed events and may lead to microdamage accumulation. Excessive microdamage has the potential to lead to fracture due to the bone’s inability to successfully repair itself.

This study provides a general understanding of bone behavior in the presence of intense exercise. Future studies in this area should use larger sample sizes and complete exercise histories (including non high-speed events)

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