THE PHENOMENON OF TWISTED GROWTH: HUMERAL TORSION IN DOMINANT ARMS OF HIGH PERFORMANCE TENNIS PLAYERS

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INTRODUCTION:

It is well known that exercise-induced loads cause bone hypertrophy in the dominant arm of tennis players; this phenomenon has been documented by numerous studies of players who began play at pre-pubescent ages.[1] However, the details that describe the processes of growth and remodeling that accompany this observation are unknown.[2]

Motivated by athlete college tennis players who reported chronic pain in their dominant shoulder, we aim to predict humeral growth in the stroke arm in response to high performance sport specific mechanical loads.

We hypothesize that the critical load scenario that initiates bone growth and remodeling is related to maximum external shoulder rotation associated with maximum pre-stretch of the internal rotators. We model bone hypertrophy using a finite element growth model, and that simulation gives further insight into the interplay between load and biological response.

METHODS:

To test the hypothesis that peak loading conditions relevant to growth and remodeling occur during serve, we first performed video analysis of an elite-level college athlete. Based on the individual images during a serve, we identified several postures to determine critical humerus muscle forces. In particular, we focused on maximum external shoulder rotation and ball impact (Fig. 1). These postures were reproduced using an upper limb musculoskeletal model[3] in the OpenSim[4] modeling environment to determine muscle moment arms, muscle forces, and lines of action. Estimated muscle forces were then applied as external forces in a finite element analysis to predict changes in bone density in response to loading.[5] The calculated density profiles were qualitatively compared to bone mass density measures of the study subject (Fig. 2).

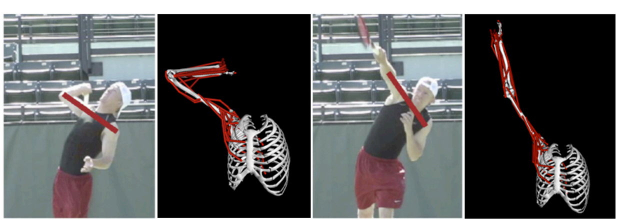

Fig. 1 Serve images and corresponding simulations for postures of assumed maximal bone loading: maximal external rotation (A and B) and ball impact (C and D)

RESULTS:

The dominant torsional loading experienced during the maximal external rotation phase of the tennis serve resulted in pronounced inhomogeneous torsional growth. In regions where the stress was greatest, there was a significant increase in bone density, whereas in areas of low stress we observed bone resorption. The density profiles predicted with the finite element analysis based on the loading from this point in the serve are in qualitatively good agreement with the observed density pattern for the subject. In contrast, loading during ball impact does not produce bone density patterns that are consistent with x-ray observations.

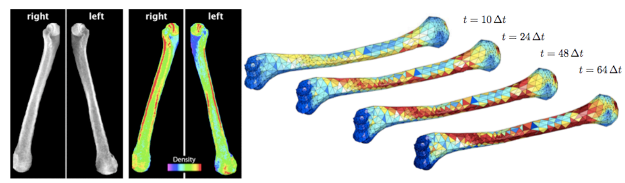

Fig 2. X-rays of left and right arms of a competitive tennis player (A and B) showing a 24% higher bone mass density in the right humerus. Longitudinal growth: Time sequence of density adaptation in maximum shoulder rotation loads agrees with observed density changes (C).

CONCLUSION:

These results provide additional insight and improved understanding of complex phenomena associated with torsional growth along the humeral shaft. This method of predicting bone growth using musculoskeletal modeling and finite element growth models could be of equal benefit to high performance athletes and patients with degenerative bone diseases. Based on patient-specific studies, optimized training strategies can be developed to promote bone growth.

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