Modeling Bone Growth in High-Performance Tennis Players

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Purpose

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[2,3].

In addition, it is unclear as to which are the dominant variables that shape bone growth, muscular loading, impact forces during play or biological factors. We hypothesize that we can model this bone hypertrophy using a finite element growth model and that simulation gives further insight into the interplay between load and biological response.

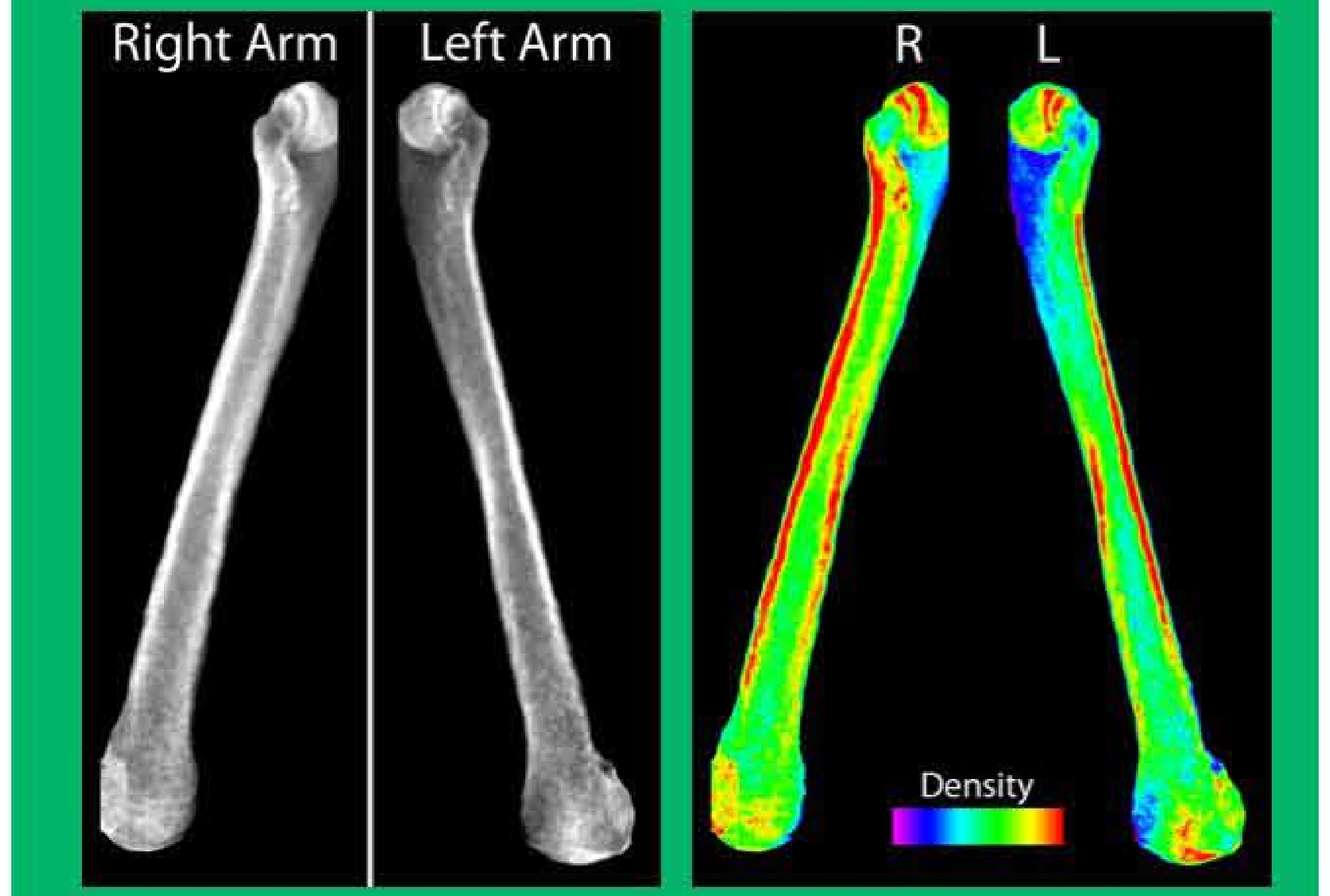

Figure 1: Variation in humerus density in left and right arm of professional tennis player: Bone mass density 1.107g/mm^2 (left) and 1.369 g/mm^2 (right).

Methods

Figure 2: Observation of serve posture suggests that humerus remains aligned with shoulders throughout serve: Humerus rotation is identified as most critical motion influencing bone growth in tennis players.

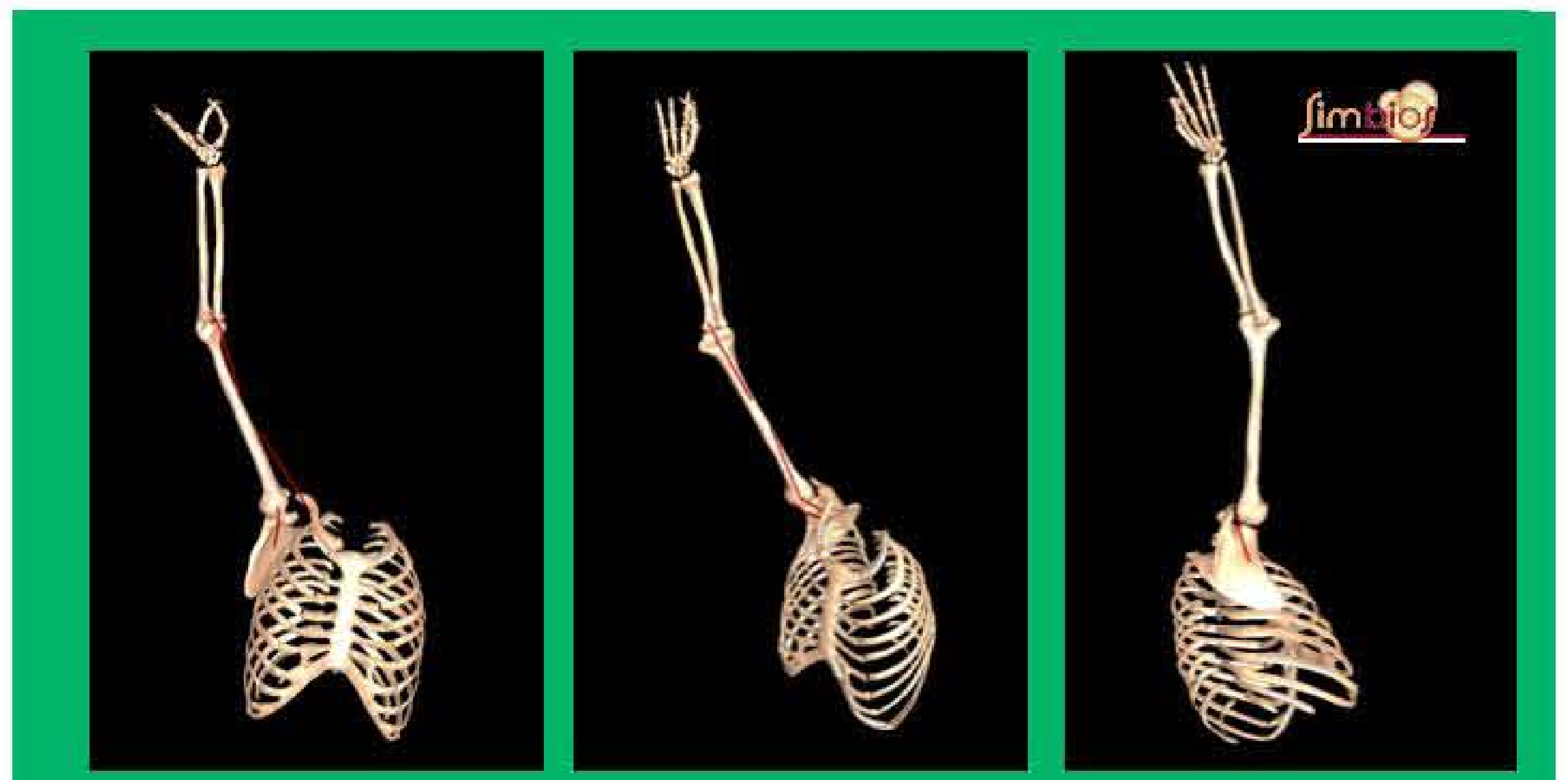

Figure 3: Critical serve posture at moment of raquet-ball contact.

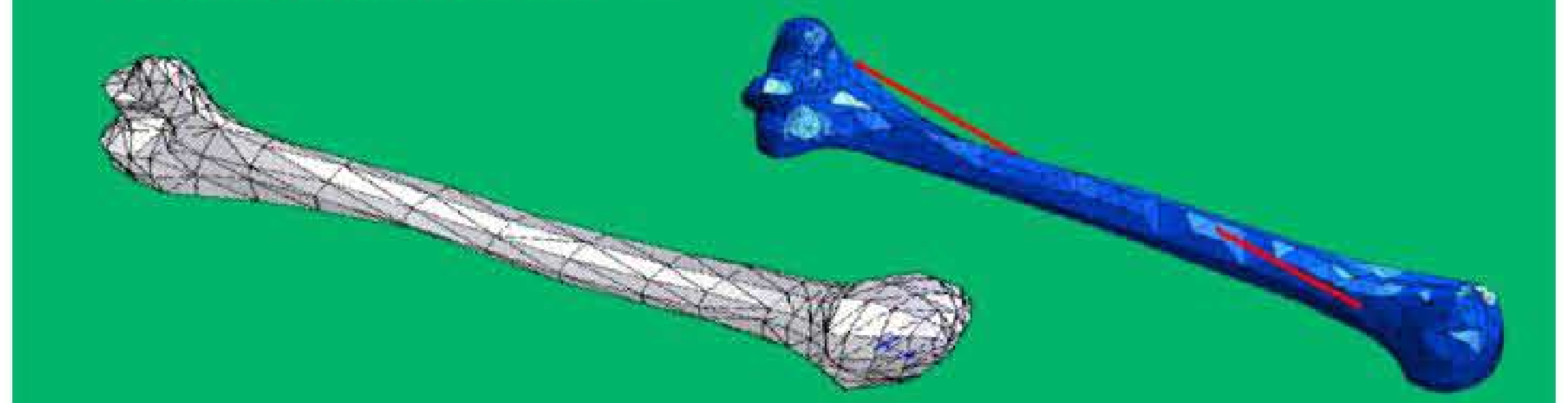

Figure 4: Meshed humerus in OpenSim (left) and finite element mesh (right) with 1182 nodes and 4362 linear tetrahedral elements, muscle forces approximated with OpenSim.

The humerus was chosen for our study because it is the least complex of the arm bones. We investigated various loading scenarios and found tennis players to be excellent subjects because they show asymmetrical bone growth, and bone size in the non-dominant arm can be used as a control. We hypothesize that peak loading conditions occur during the high-speed serve. Based on video observation of tennis serves, we determined a posture for peak humerus stress. From this, approximate muscle forces were calculated with OpenSim. These forces were applied as external loads in a finite element growth model developed in class.

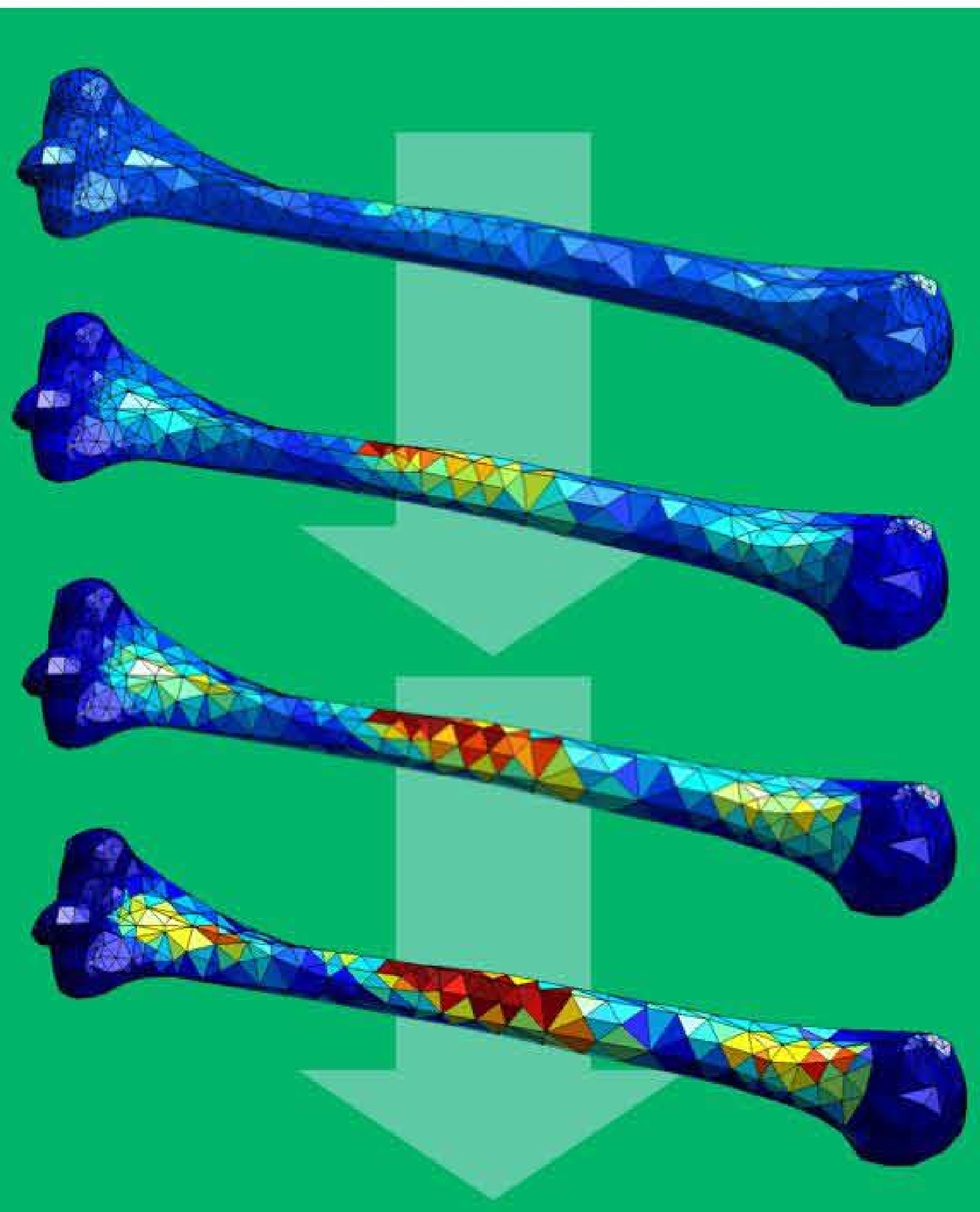

Figure 5: Density changes with increasing number of load cycles.

Results

A three dimensional finite element model of the human humerus has been generated. Three dimensional muscle force vectors, muscle attachment points and boundary conditions for the finite element simulation have been determined based on video analysis with the help of OpenSim. The finite element simulation based on strain energy driven bone growth reveals pronounced twisted increase in bone density in the dominant right arm. The results of the simulation of Figure 6 are in qualitatively good agreement with the bone mass density scans displaced in Figure 1.

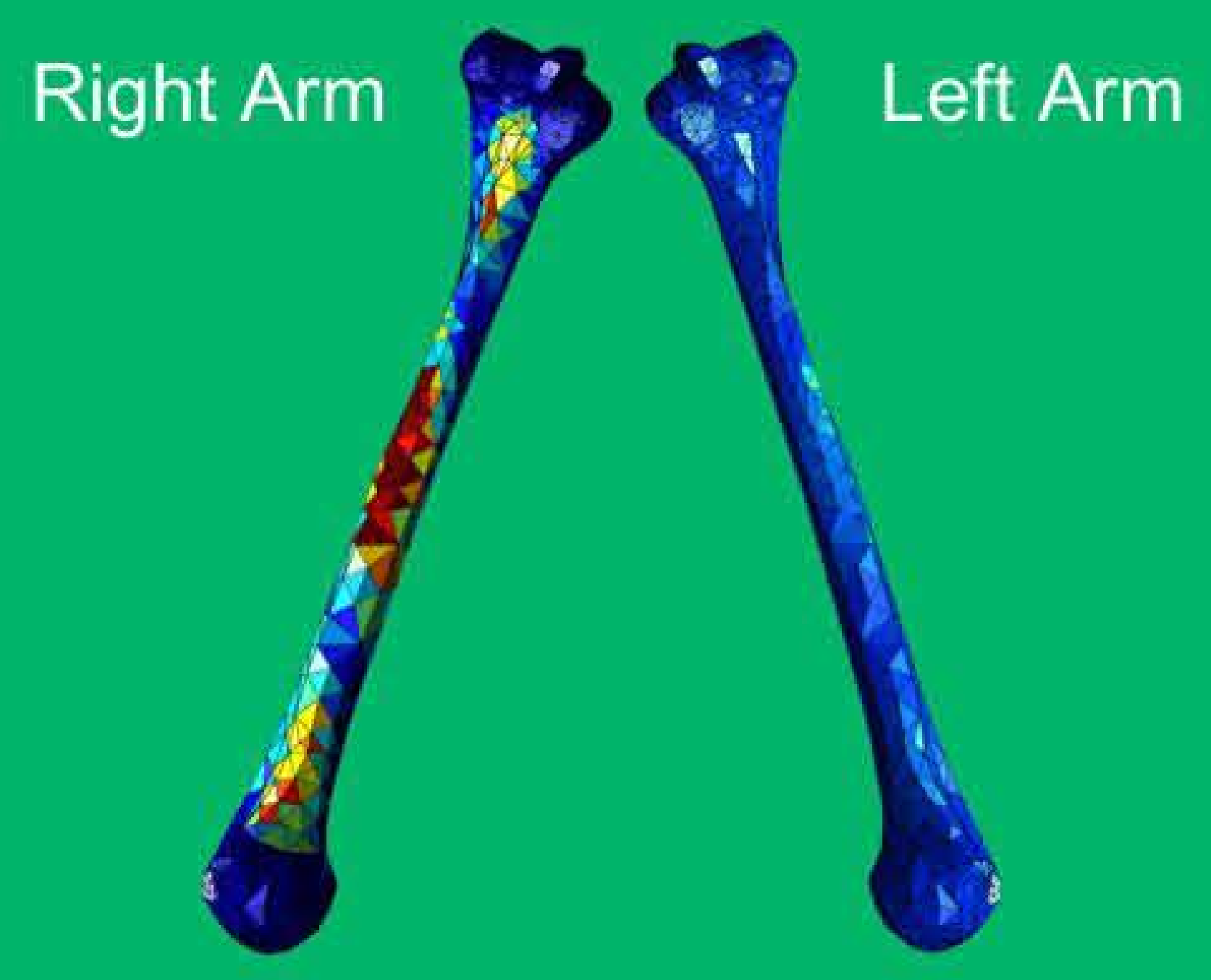

Figure 6: Variation in humerus density in left and right arm of professional tennis player: Finite element simulation.

Conclusions

The encouraging results of our study 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.

References

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http://biomechanics.stanford.edu/mechanics_of_growth https://simtk.org/home/simgrowth