Finite Element Analysis (FEA) Reveals Increased Force Used by the Forelimbs in the Sabertooth Cat, *Smilodon fatalis*

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Introduction

The sabertooth cat, *Smilodon fatalis*, was a carnivorous predator that lived during the Ice Age, or Pleistocene Epoch 2.5 million to 11,000 years ago. Unlike modern cats that kill their prey with a suffocating bite to the windpipe, sabertooth cat teeth were too fragile for this method of prey-killing. Sabertooth cats were known to have muscular forelimbs to hold prey down before delivering a fatal bite to the neck viscera with their large saber canines.

Morphological specimens were measured and analyzed using finite element analysis technology, an engineering technique that utilizes the material properties of solids to simulate stress and strain in the material of interest. Bone tissue of the humerus was used to compare the stress and strain potential of the sabertooth cat, *S. fatalis*, to living large cats.

Figure 1. Differences in skeletal morphology between *Smilodon* and a lion. *Smilodon* have more robust humeri.

Question: How do the humerus biomechanics infer similar or differing killing behavior between *Smilodon* and extant large cats?

Hypothesis: Because of their differing morphologies, we expect to find biomechanical differences between *Smilodon* and extant large cats.

Methods

We CT scanned the humerus of each study species (Figure 2A). From those CT scans, we created heterogeneous finite element models (FEM) (Figure 2A). FEM predict how strain will propagate through an object when forces are applied. Heterogeneous FEM are built with more than one material property (e.g. material stiffness) and have been shown to be more life-like than homogeneous FEM. On each FEM we mapped muscle attachment sites that simulate holding down prey with the forelimb (Figure 2B). These muscles included the triceps, anconeus, and pronator teres. We then applied scaled muscle forces for each species (Figure 2B) by multiplying the muscle attachment area (mm^2) by 0.3, the maximum tension mammalian muscle fibers can produce. Lastly, we added scaled extrinsic forces to the distal humerus that pulled laterally to simulate struggling prey (Figure 2C).

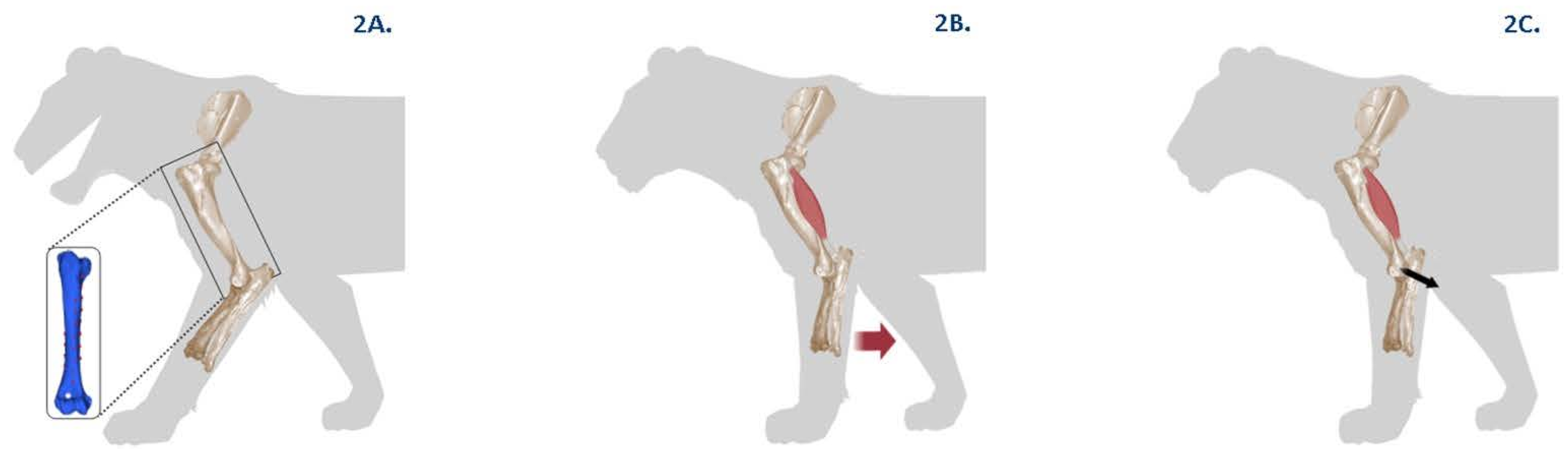

Figure 2. The construction of biomechanical models. **2A)** Heterogeneous finite element models of the skull and humerus produced from CT scans. **2B)** The addition of scaled forces for each muscle attachment site to replicate extension of the forelimb (red arrows). **2C)** Incorporating external forces to simulate struggling prey (black arrows).

Results

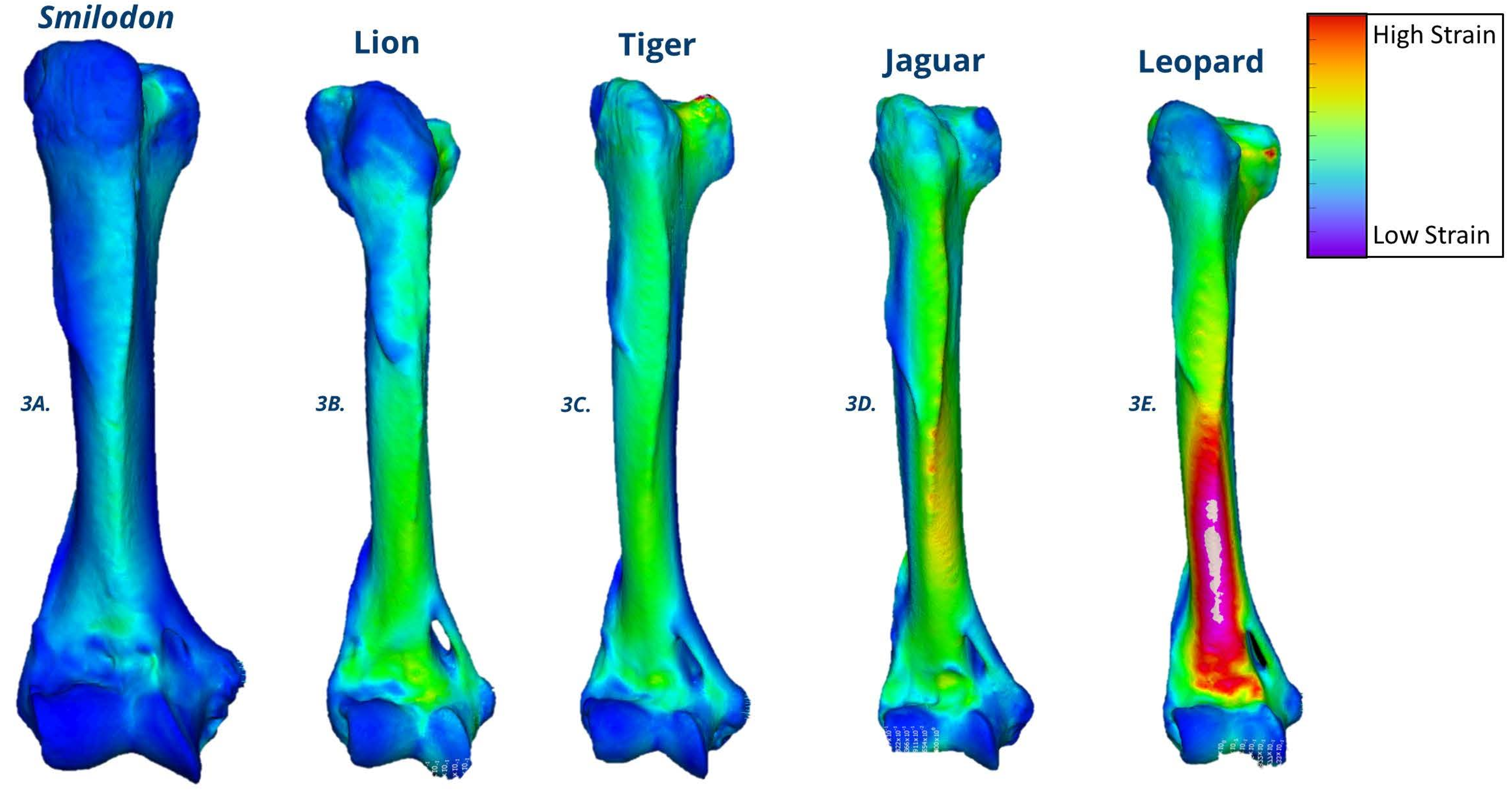

Figure 3. Biomechanical finite element model results. **3A)** *Smilodon* humerus (LACM 492), **3B)** lion humerus (FMNH 49340), **3C)** tiger humerus (LACM 51573), **3D)** jaguar humerus (UCLA 183), **3E)** leopard humerus (LACM 31068).

Conclusion

Biomechanical results were analyzed by comparing Von Mises strain values from a series of reference points between each finite element model. Von Mises strain was used because it is a combination of tensile and compressive strain. Reference points are along a transect where no forces were applied.

***Smilodon's* humerus is more resistant to forces than extant large cats.**

***Smilodon's* humeral strain pattern most resembles the lion.**

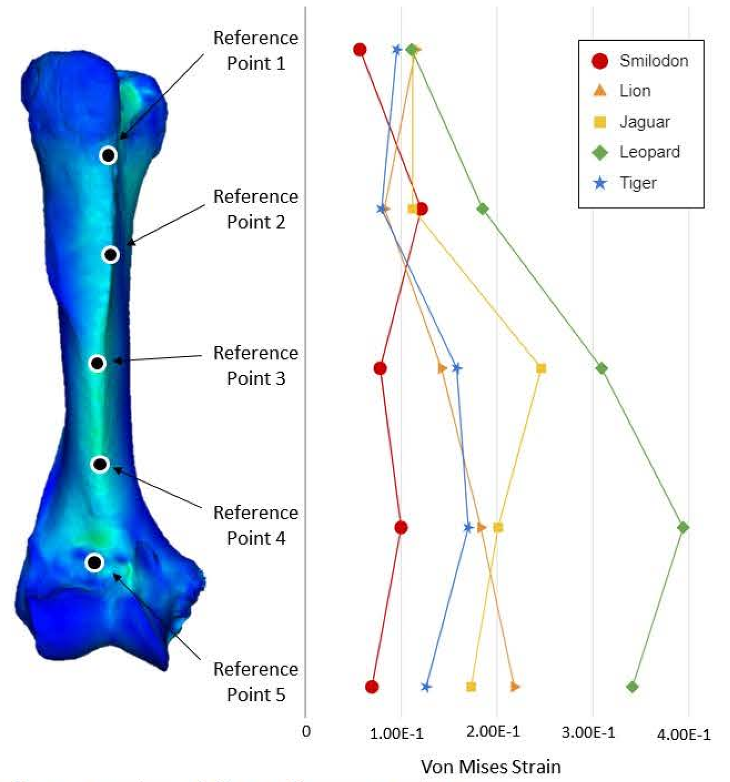

Figure 4. Von Mises strain values from a series of five reference points on the anterior surface of the humerus taken from proximal to distal.

***Smilodon* likely would have relied on their forelimbs more during prey acquisition and processing than extant large cats because of their resistance to forces.**

Utilizing their mechanically strong forelimbs would have helped *Smilodon* protect their sabers during prey acquisition and processing.

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