BIOMECHANICS OF IMPACT LOADING OF GOAT SKULL (*CAPRA HIRCUS*) USING CT IMAGE BASED FINITE ELEMENT MODELING

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INTRODUCTION

Intrasexual male combat is a critical determinant of social status and reproductive success within the order bovidae. Horn on horn collisions between male goats (*Capra hircus*) at speeds up to 2.5 m/s can pose a serious risk of brain and spinal cord injuries. Kitchener (1988) modeled these horn collisions in Big Horn rams (*Ovis candaensis*) as concentrated quasi-static forces using curved beam theory and reported peak stress at the base of the horns, ignoring the role of inertia and wave propagation on different components.

Dynamic loading however might suggest otherwise. Jaslow and Biewener (1995) studied *in vitro* strain patterns of a goat skull during drop tests that supported Kitchener's findings. However, their study measured strain at a limited number of sites around the horn base and the skull.

Figure 1: Male goat (*Capra hircus*) skull showing skull. (Keratin sheath removed from left horn).

Horns are composed of an inner bone core covered by an external keratin sheath (Figure 1). Keratin is not as stiff or strong as bone but has differing material properties, most notably, a ten-fold increase in work of fracture compared to bone (Bertram and Gosline 1987). We present a finite element analysis of the dynamic response of this composite structure to impact loading.

METHODS

The 3D finite element model (Figure 2) was constructed using ABAQUS/Explicit (Abaqus, Inc., Providence, RI) based on 2.5mm thick computed tomography (CT) scan images using a method developed by Dumont, Piccirillo, and Grosse (2005). The bone core and keratin sheath were assigned appropriate Young's modulus, density, and yield stress values. The surface interactions between the two parts were modeled as frictionless and infinite friction. The model was composed of 20,500 3D stress hex-

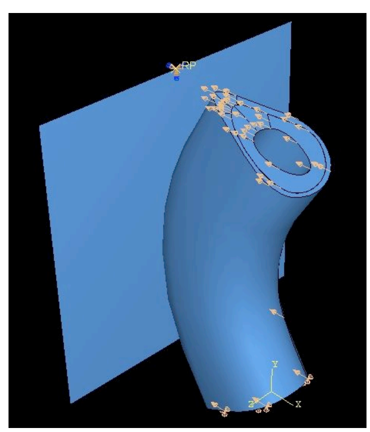

Figure 2: Simplified 3D Model

dominated elements using mid-axis symmetry. The horns were set to impact a rigid wall given an initial horizontal velocity.

RESULTS AND DISCUSSION

Our initial findings disagree with predictions based on Kitchener's (1987) analysis utilizing quasi-static beam theory. Our model shows that maximum stress occurs near the site of the point of impact, a few millimeters below the surface (Figure 3) and not at the base of the horn. In addition, we found that the stress magnitude at the base of support was greater on the cranial (front) surface and than the caudal (rear) surface of the horn bone core (Figure 4).

Finally, there is a 5-fold increase in stress in the keratin sheath impact site compared to the bone horn core. This is a phenomenon that has not been addressed in previous studies. We believe that the role of keratin under dynamic loading needs further attention.

It should be noted that several assumptions were made in the development of this model. We modeled bone as isotropic material although cortical bone is known to be orthotropic. We did not attempt to model adhesion between the keratin and bone, as

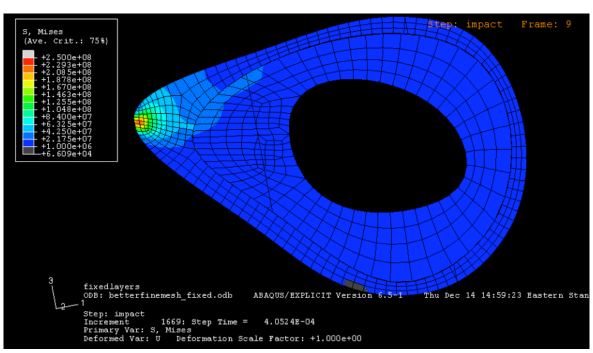

Figure 3: Cross section of horn at the point of contact showing von Mises stress 400 μs after initial contact with the wall.

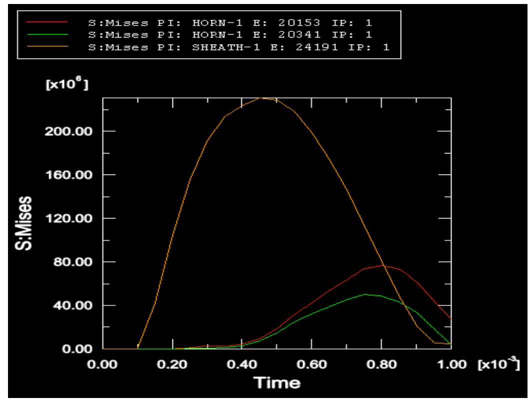

Figure 4: Time varying von Mises stress patterns during impact. Keratin element (orange), cranial bone (red) and caudal bone (green) at the base.

we are unaware of any studies investigating this. In the future, we plan to incorporate materials testing of horn samples to further refine our model.

SUMMARY

We found that maximum stress in the FEM developed here occurs in the keratin sheath at the site of impact. In the base of the bone horncore, the maximum von Mises stresses on the cranial surface exceed the maximum von Mises stresses on the caudal surface.

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