Whiplash simulation requires an accurate model of actively lengthened muscle

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Vehicle safety systems have successfully reduced traffic accident fatalities [5], but injuries to the neck (whiplash injuries) have remained stubbornly common [8]. Crash simulations are often used to help develop new safety systems and depend on accurate human body models (HBMs) to predict injury. Finite element human body models can accurately predict the head and neck movements of post-mortem-human-subjects [6] but show greater head and neck movements than living participants [7].

During an accident, reflexes cause living participants to activate the muscles of the neck which can be lengthened as the head is moved by the vehicle [1]. Actively lengthened muscle can generate enormous forces over modest length changes [2]. We hypothesize that the large forces developed when the neck's muscles are actively lengthened serve to reduce the movement of the head, but also apply large loads to the structures of the neck.

To test this hypothesis, we have developed simulation of an in-vivo whiplash experiment which we simulate using a finite element model of the head-neck.

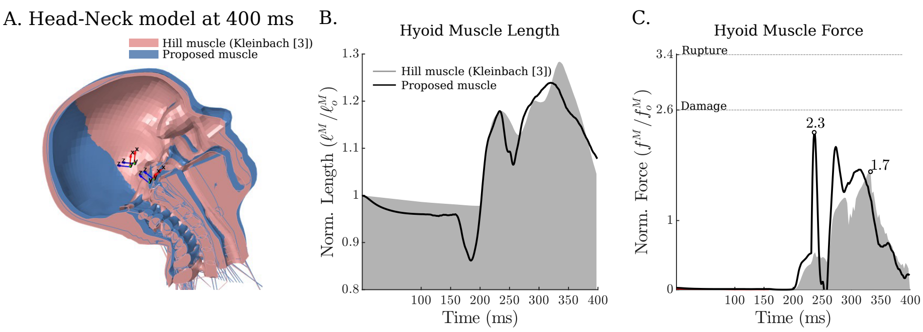

Figure 1: When the in-vivo sled experiment of Sato et al. [9] is simulated using the Hill model of Kleinbach et al. [3] (pink) and a model with a titin element (blue) [4], both simulations produce similar head kinematics (A.), and contractile element strains (B.). In contrast, the proposed model develops higher forces, particularly for the hyoid muscles (C.).

One of the head-neck models is actuated by a Hill-type muscle model [3] and the other is driven by a muscle model [4] we have extended that includes an active titin element. Titin is an enormous elastic protein that develops higher forces during lengthening in an active muscle as compared to a passive muscle.

During a simulation of Sato et al.'s in-vivo sled experiment [9] the kinematics (Fig. 1A) and fiber strains (Fig. 1B) are similar between the two models but the active forces developed the proposed model can be much higher (Fig. 1C) particularly in the hyoid muscles. In both cases, the normalized muscle forces were below the force threshold at which damage is expected [2]. We are currently working to evaluate how the stresses and loads applied to the facet joint capsule, ligaments, and intervertebral disks are affected by these enhanced active forces.

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