

Development and Validation of a Multi-body Dynamics Model of the Pro-Neck-Tor Helmet

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Abstract

The Pro-Neck-Tor (PNT) helmet was developed to reduce the incidence of cervical spine injuries during head-first impacts. It consists of an inner- and outer-shell that are connected by an internal guide mechanism. In an impact the mechanism deploys and guides the inner shell and head relative to the outer shell, such that the neck moves into flexion or extension. This increases the impact duration while moving the cervical spine out of an aligned posture. Experimental results have demonstrated that this reduces the compressive loads exerted on the spine.

The deployment mechanism is intended to induce flexion in impacts slightly posterior to the vertex of the head, and extension in slightly anterior impacts. However, the ability of the mechanism to automatically select the correct deployment mode, based on impact location and dynamics, has not yet been optimized. Therefore, the purpose of this work was to develop a multibody dynamics model of the Hybrid III head and PNT helmet that can be validated experimentally, and allows us to assess the functionality of the deployment mechanism.

A multi-body model of a head and helmet in a drop tower was constructed using MSC Adams (MSC Software, Santa Ana, CA). The occipital condyles were modeled as a revolute joint to allow the head to rotate in flexion and extension. This joint was fixed directly to a carriage mass, which was limited to superior-inferior translation, to control the direction and magnitude of the load applied to the head and PNT selector mechanism. The angle of the impact platform was varied to simulate anterior-to-vertex, perpendicular, and posterior-to-vertex impacts. The contact parameters were tuned using force-time data from experimental drop tests to a horizontal surface.

The model simulates a physical drop tower apparatus that was configured to validate the model. Five experimental drops were conducted at each impact angle, and helmet kinematics were measured from high speed videos using 2D image analysis software (TEMA, Image Systems, Sweden). The kinematic behaviours of the virtual and physical systems were then compared. Agreement between the model and experiment, based on the motion of the outer helmet shell, was strongest for the perpendicular, and anterior-to-vertex impact conditions. For these conditions, the peak angular velocity of the simulated outer helmet shell was within 7% of the average experimental peak, while the peak angular position was within 22% of the experimental results. The quantitative agreement for the posterior-to-vertex impact

condition was not as strong (40% difference in peak angular velocity); however the gross kinematic behaviour of the inner shell and deployment mechanism showed good qualitative agreement.

The deployment mechanism demonstrated the capability to select an appropriate deployment mode in various impact scenarios. Flexion was induced in posterior impacts, while extension was induced in axial and anterior impacts. According to the model, the deployment direction is governed by the moment balance resulting from the forces at the deployment pins and the occipital condyles. This supports our understanding of the deployment mechanism, and brings us closer to predicting the behavior of the helmet in any impact.