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MULTIBODY DYNAMIC ANALYSIS OF WHIPLASH

Mohamed T. Z. Hassan, Mo Gabriel Shi, S. A. Meguid(*)
Mechanics and Aerospace Design Laboratory, University of Toronto, Canada
(*)*Email:* meguid@mie.utoronto.ca

ABSTRACT

Whiplash is the most common injury resulting from motor vehicle collisions. In this work, an analytical multibody dynamics model was developed to study the head-neck response of motor vehicle occupants during rear impacts. The head and the cervical spine were modeled as rigid bodies connected through 1 degree of freedom viscoelastic rotational joints to simulate the motion of each intervertebral level. Due to the nonlinear viscoelastic behavior of the soft tissues of the neck, the stiffness of each cervical intervertebral joint was calculated as a function of the joint's angle of rotation relative to its adjacent rigid body. The equations of motion of the rigid links model were derived using Lagrange's principle, where the kinetic energy term accounted for both linear and rotational components, and the damping was addressed through Rayleigh dissipation function. This results in a system of 8 second-order differential equations permitting motion with 8 degrees of freedom. The input to the system is in the form of an acceleration profile applied at the T1 vertebra to simulate a rear impact.

Keywords: Whiplash, strategies, car safety, multibody dynamics, analytical modelling.

INTRODUCTION

According to the World Health Organization, road traffic crashes is the top cause of death worldwide for people aged 15-29 [1]. Besides death, motor vehicle crashes may result in disabilities and/or chronic injuries. In rear impacts, the neck is the most frequent site of injury, with more than 80% of injuries suffered in rear impacts being cervical whiplash. Although there have been great efforts in enhancing motor vehicle safety in the previous decades, the high number of injuries/fatalities indicates that there is still room for further improvements. In order to provide better protection for motor vehicle occupants, it is crucial to study the occupant's response during crashes. Three main approaches are utilized to evaluate how the occupant responds in various impact scenarios. The first is conducting experimental studies on volunteers, post mortem human surrogates (PMHS) or anthropomorphic test dummies (ATDs) such as the BioRid II. The second approach to study the human response is through the use of multibody dynamics. In these models, the bones were modeled as rigid bodies connected through different types of joints, and the soft tissues were modeled as viscoelastic elements. These multibody dynamics models studied the occupant's response to different crash scenarios. Many models focused on the head/neck region while some other efforts modeled the entire human body. Finally, the finite element (FE) method has been extensively utilized to produce biofidelic models of the human body to be used under different types of loading for both male and female occupants, such as the Global Human Body Model Consortium (GHBMC) and Virtual Vehicle Safety Assessment (ViVA) models. In the current work, we are concerned with developing and validating an analytical multibody dynamics model that can capture the head kinematics during rear impacts.

SAMPLE RESULTS AND CONCLUSIONS

The head and the neck were modeled as rigid bodies connected using viscoelastic 1-degree of freedom (DOF) revolute joints allowing rotation in the sagittal plane as shown in Figure 1. This system can be analyzed using Lagrange's principle as given by:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_k}\right) - \frac{\partial L}{\partial q_k} + \frac{\partial R}{\partial \dot{q}_k} = Q_k \qquad (1)$$

where L is the Lagrangian given by $L = T - V$, $\dot{q}_k$ is the generalized velocities, q_k is the generalized coordinates, Q_k is the generalized forces and R is the Rayleigh dissipation function given by:

$$R = \frac{1}{2} c_1 \dot{\theta}_1{}^2 + \frac{1}{2} \sum_{i=2}^{8} c_i \left(\dot{\theta}_i{}^2 - \dot{\theta}_{i-1}{}^2\right) \qquad (2)$$

where c_i is the joint damping coefficient and $\dot{\theta}_i$ is the absolute angular velocity. The kinetic energy of the system T is:

$$T = \frac{1}{2} \sum_{i=1}^{8} I_i \dot{\theta}_i^2 + \frac{1}{2} \sum_{i=1}^{8} m_i \left(\dot{x}_i{}^2 + \dot{z}_i{}^2\right) \qquad (3)$$

where I_i is the mass moment of inertia of the body, m_i is the mass of the body, $\dot{x}_i$and $\dot{z}_i$ are the horizontal and vertical velocities, respectively. The potential energy of the system V is given by:

$$V = \sum_{i=1}^{8} \int_0^{\phi_i} \phi \, k_i(\phi) \, d\phi \qquad (4)$$

where ϕ is the relative angle of rotation between two adjacent bodies and $k_i(\phi)$ is the variable joint stiffness given by:

$$k(\phi) = ABe^{B\phi} \qquad (5)$$

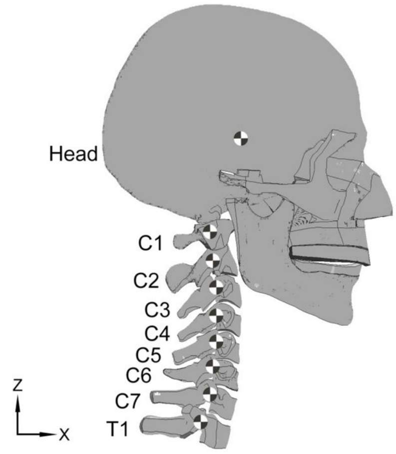

Fig. 1 - Illustration of the multibody dynamics model

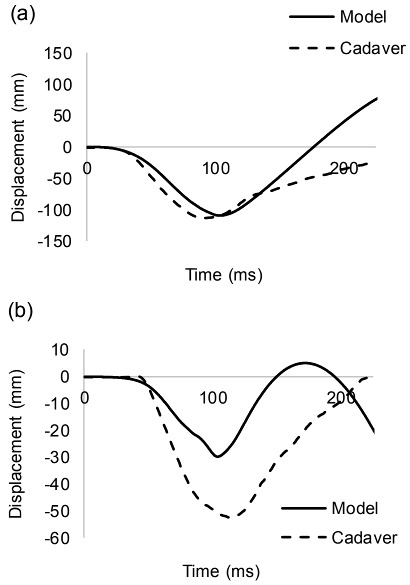

Fig. 2 - Head displacement with respect to T1 vertebra: (a) horizontal and (b) vertical.

where A and B are constants determined for each intervertebral level. To simulate a rear impact, an acceleration profile is applied to the T1 vertebra. Figure 2 shows the resulting head displacement of the model compared to cadaver response for the same impact. The model response agrees with that of the cadaver. Our results indicate that the peak head displacements (maximum neck extension) occur during the first 100 ms after impact which is followed by the rebound phase. The deviation between the model and cadaver may be attributed to the 1 DOF joints used and the constant damping coefficients assigned to the joints.

ACKNOWLEDGMENTS

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REFERENCES

[1] "Global Status Report on Road Safety 2015 Summary," Geneva, 2015.