A Mathematical Model of an Improved Neck for a Rear-End Impact Dummy

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ABSTRACT

A mathematical model of a new rear-end impact dummy neck, consisting of seven cervical vertebrae as well as the upper most thoracic element (T1) connected by hinge joints, was implemented using MADYMO. The motion of the T1 was prescribed using displacement data obtained from volunteer tests. The stiffnesses of the joints were progressive and supplemented by two muscle substitutes. The model was validated against volunteer test data at 7 km/h speed change. The response of the model agreed with the volunteer test results in displacement and acceleration of the head relative to the upper torso. This study showed that a combination of elastic stiffness and damping in the muscle substitutes, together with a progressive joint stiffness, resulted in a head-neck response close to that of the volunteer tests.

INTRODUCTION

Neck injuries in rear-end car collisions are increasing. Von Koch et al. (1994) reported that neck injuries account for 50% of all traffic injuries with long term consequences. Rear-end collisions account for about 25% of these injuries (Temming, 1998). Nygren et al. (1985) found that the use of head-restraints decreased the risk of neck injury in a rear-end collision by no more than 20% on average. These findings call for improved methods for assessing such protective devices.

The most essential component when testing the protective performance of seats and head-restraints is the crash dummy. The currently best available dummy for low speed rear-end collision testing is the Hybrid III supplemented by a RID-neck (Svensson and Lövsund, 1992) or a TRID-neck (Thunnissen et al., 1996). These two dummy necks have been shown to improve the head angular response in rear-end collision testing but some problems still remain with the design of the dummy. The Hybrid III has a completely rigid thoracic spine that does not replicate the straightening of the spine nor the vertical motion of the head and T1 that occur in volunteer tests (Scott et al., 1993 and Ono and Kanneoka, 1997). The RID-neck does not give an adequate retraction (rearward translation displacement of the head relative to T1) response (Geigl et al., 1995) and the same problem is probably prevalent for the TRID-neck.

The aim of the present study was to develop a MADYMO-model of the basic design concept of the new rear-end impact dummy neck and to use the model to find a useful combination of stiffness properties that would yield a neck response similar to that found in a volunteer study by Davidsson et al. (1998b).

METHOD

A mathematical dummy neck model was developed based both on the design of a new rear-end impact dummy (Davidsson et al., 1998a) and on a model presented by Jacobsson et al. (1994). The neck model was implemented using MADYMO 2D, restricting the motion to the sagittal plane. This restriction was not a problem since the new rear-end impact dummy was also restricted to sagittal motion. The geometry of the head and neck system of the model (and of the new dummy) was based on a drawing (Fig. 1) of a seated 50th percentile male (Robbins et al., 1983) and consisted of seven cervical elements and one thoracic element (T1) connected by hinge joints. The range of motion for the cervical spine is based on the range of motion in volunteers and cadaver tests reported in the literature (Kapandji, 1974, White & Panjabi, 1978) and adjusted to allow a realistic retraction-protraction. Motion studies of the cervical spine demonstrate that with retraction of the head, a greater range of upper cervical flexion is obtained than by simply flexing the head and neck (McKenzie, 1990). The total range of motion was chosen to be 100 degrees in extension and 41 degrees in flexion from the neutral position defined from a seated posture including a lordos of the cervical spine. The lordos of the neck was adapted to the arc of a circle. The radius of the curvature was found to be 190 mm with a sector of 37 degrees (Fig. 1). The stiffnesses of the joints were chosen to be progressive (Linder et al., 1998) and were complemented with two string muscle substitutes, one on the posterior side and one on the anterior side of the neck. The muscle substitutes were attached to the skull base and to the T1 and guided through all the other vertebrae (C1-C7) (Fig. 2). The muscle substitutes of the model were connected in parallel to a spring and a damper. The anterior muscle substitute was connected to a spring with a linear stiffness of 30 kN/m and a damper with a constant damping coefficient of 4 kNs/m, and the posterior muscle substitute was connected to a damper with a linear stiffness of 200 kN/m and a damper with a constant damping coefficient of 15 kNs/m. The angular and linear motion of T1 was prescribed based on volunteer test data (Davidsson et al., 1998b).

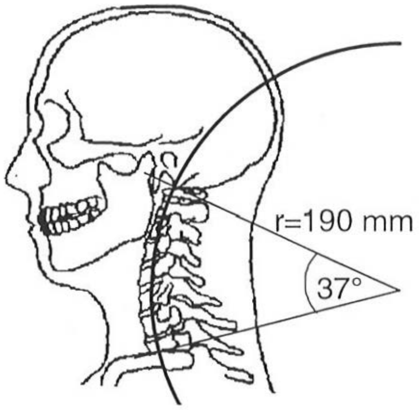

Figure 1. Drawing of the head and the neck of a seated 50^{th} percentile male (Robbins et al., 1983) with the chosen radius of the new dummy neck model included.

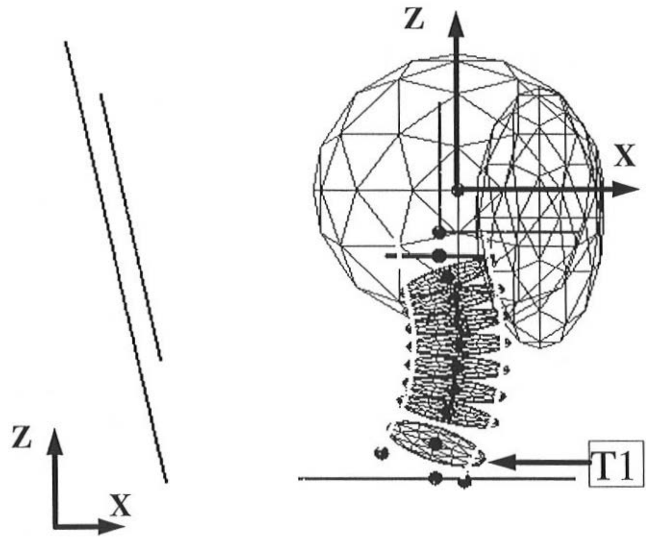

Figure 2. The mathematical neck model and the co-ordinate system used for the output parameters.

The total mass of the neck corresponded to the mass of a Hybrid III neck (Backaitis and Mertz, 1994). The motion of the T1 was prescribed for all degrees of freedom. The model included a headrest and upper seat frame representing the lab-seat used in the volunteer tests. The lab-seat was designed to resemble the seat stiffness of a modern European car.

RESULTS AND DISCUSSION

The model response had good agreement with the volunteer test results in linear and angular displacement as well as acceleration of the head both in terms of peak values and time history. The response of the neck model is shown in Figure 3 together with the response corridors of the volunteer tests. The corridor is represented by plus/minus one standard deviation of the average response of the volunteers, N = 5 (Fig. 3).

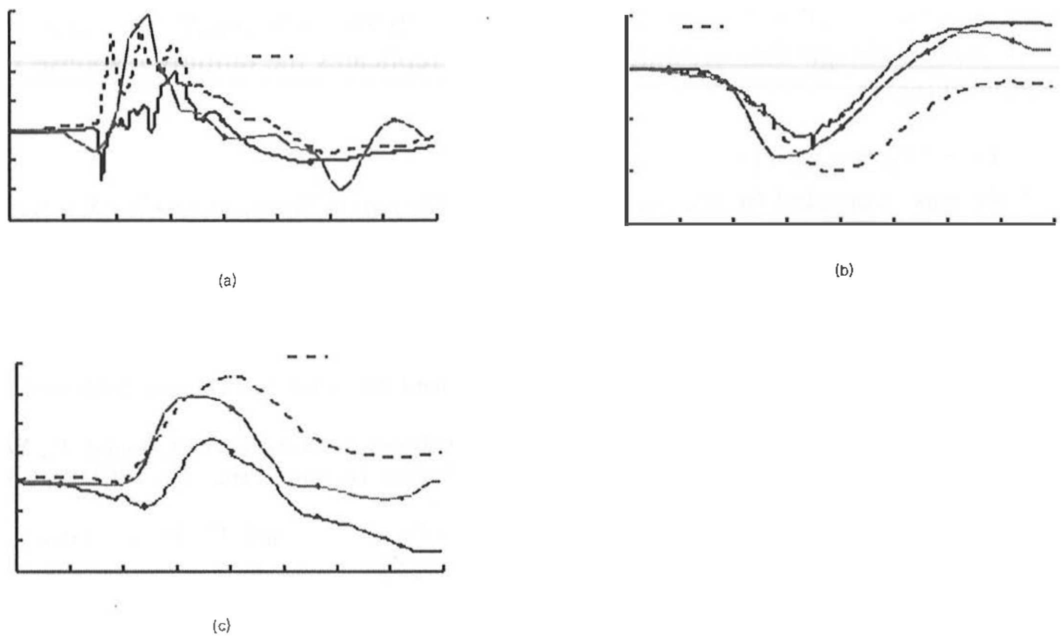

Figure 3. The neck model response and the volunteer response corridor at Δv 7 km/h. Head x-acceleration (a), Head-Tl X-displacement (b), Head -Tl angular displacement (c).

This study showed that a combination of elastic stiffness and damping in the muscle substitutes, together with a progressive joint stiffness, correlated well with the head kinematics found in the volunteer tests (Fig. 3). The muscle elements decreased the neck resistance to retraction motion (rearward translational motion of the head relative to T1 without angular head motion) while maintaining the desired resistance to rearward and forward angular displacement of the head.

The simulation results showed that to obtain the angular and translational response of the head found in the volunteer tests, the muscle strings connected to springs and dampers had to be added. Linear spring connected to the strings made the rearward angular head motion start too late and the head passed its starting angle too early in the following forward recoil. Without muscle strings the duration of the pulse became too short when the desired peak value was reached. The result of a factorial test (Linder et al., 1998) showed that damping could generate the desired response both in peak value and in duration of the response.

The rotation of the head relative to T1 showed a forward rotation before initiating the backwards rotation. This is entirely due to the motion of T1. The head of a volunteer does not move in flexion before the extension motion. This was found both in the volunteer tests and in the simulations. The magnitude of relative forward rotation and the timing are similar to those found in other volunteer tests (Siegmund et al., 1997).

Designing a dummy neck for an articulated dummy spine with a human like T1 motion differs significantly from the case with a neck mounted on a rigid thoracic spine (like the Hybrid III-dummy). For a given head motion (translational and angular) the T1 angular motion (Fig. 3) results in a completely different neck bending motion than that of a neck mounted on a rigid thoracic spine. For this reason it is not meaningful to make comparisons between the Hybrid III-neck and the improved neck. A meaningful comparison can only be made between dummies of different design.

The present MADYMO model was designed in the development phase of a mechanical dummy. It proved to be a powerful tool in this process and made it possible to evaluate and test many different neck design solutions which would have been very time consuming using only mechanical tests. This first step in the development process focused on creating a model that replicate the fundamental properties of the real dummy neck and that yielded a head response similar to that of the volunteers. The next step will be to adapt the model to the final BioRID dummy design thus creating a model that replicates the dummy response in various crash environments.

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