DEVELOPING EXPERIMENTAL CERVICAL DUMMY MODELS FOR TESTING LOW-SPEED REAR-END COLLISIONS

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ABSTRACT

In recent years, many studies have been made in the biomechanical and other fields on, "whiplash" or cervical vertical sprain which is on type of injury sustained by vehicle occupants in low-speed rear-end collisions.

This paper describes a cervical analysis of whiplash occurring in the lower rear-end collision. In particular, it describes the use of a more humanized biomechanical cervical model to analyze cervical behavior in low rear-end collisions. The results of tests with this model were verified on the TRID-II Neck* and the Hybrid-III Neck models.

INTRODUCTION

The percentage of accidents resulting from collisions in recent years, accounts for 27.5 percent of all vehicle accidents in Japan(Figure 1.).Though the death rate is low in these type of accidents, the minor injury rate is very high (Figure 2.). About 90 percent of these minor injuries are neck injuries and the so-called " Whiplash injury " which is prone to occur in these low-speed rear-end collision makes up a large share of these injuries.

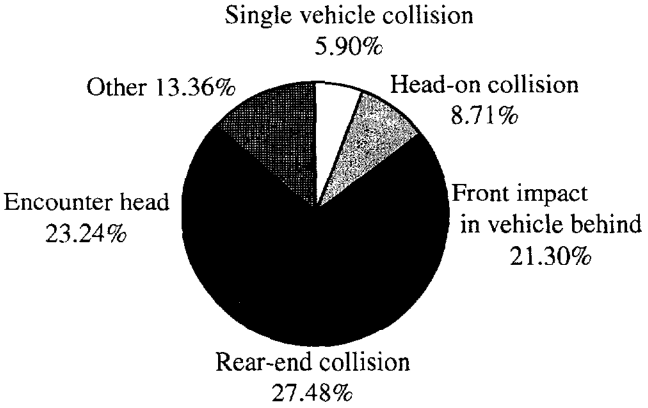

Figure 1. Accident typical other crew several ratioes.

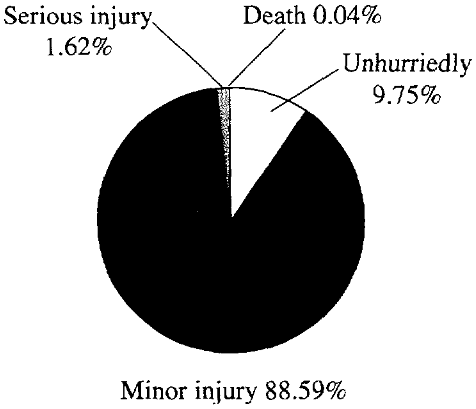

Figure 2. Injury level ratio of a rear-end collision driver.

A look at the totals for occurrence rate of neck injuries and barrier conversion speed (Figure 3.) shows that 70 percent of all people sustained their neck injuries at a barrier conversion speed (Delta V =) of approximately 8 kilometers per hour.

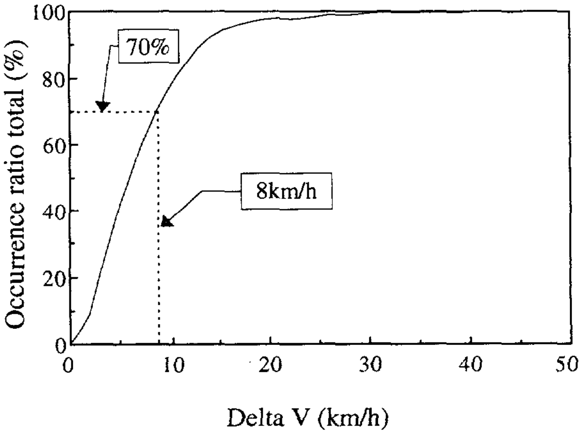

Figure 3. Neck injury accumulated occurrence rate of a rear-end collision

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* Dummy neck model for the rear-end collision as TNO company develops use.
(TRID = TNO Rear Impact Dummy)

With this as a background we commenced our study of whiplash injury occurring in rear-end collisions.

While making studies using a biomechanical cervical model that more closely approximates the human form. We also investigated the mechanism that causes whiplash and made comparisons with the TRID-II Neck and Hybrid-III Neck model.

NECK MODEL CONFIGURATIONS

Biomechanical Cervical Model

The neck of the human body (Figure 4.) is composed of cervical vertebrae, ligaments, intervertebral disks, muscles and the other items. The speed of muscular response to stimulation is approximately 150 to 250ms. We decided we could exclude taking into account other phenomena that exert effects on muscles. This model is therefore comprised of three elements : cervical vertebrae, ligaments and intervertebral disks. An integrated, polymerized artificial material with biomechanical properties that closely resembled the matching parts in the human body was used.

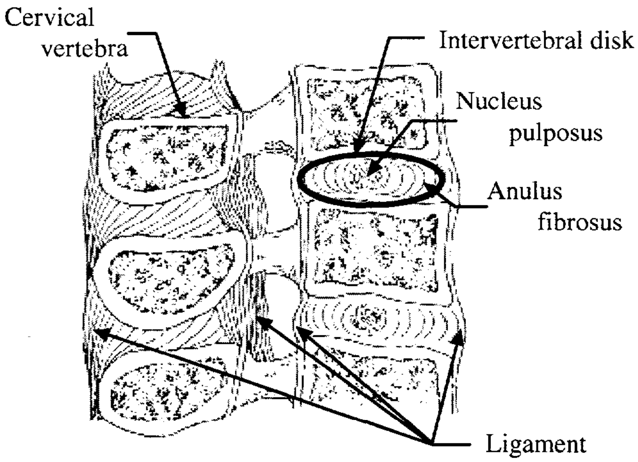

Figure 4. Structure of a human body neck

Substituting The Cervical Vertebrae

A copy of the cervical vertebrae were made from polyurethane based on a medical model of the cervical vertebrae[*].

Substituting The Ligaments

Three-dimensional textiles[**] were used for the ligaments. These were comprised of multifilament and cotton thread using coupling thread (multifilament etc.,) having the correct rigidity forming a three- dimensional structure both lightweight yet having good elasticity.

Substituting The Intervertebral Disks

Silicon rubber was utilized.

Other Items

The cervical ligaments were covered with colorless silicon rubber[***] in view of the soft tissue structures around the ligamentous neck. The colorless, transparent rubber allowed observation of movements of the biomechanical cervical model.

Figure 5 shows the biomechanical cervical model. The first cervical vertebra was eliminated in the Hybrid-III dummy that was actually used.

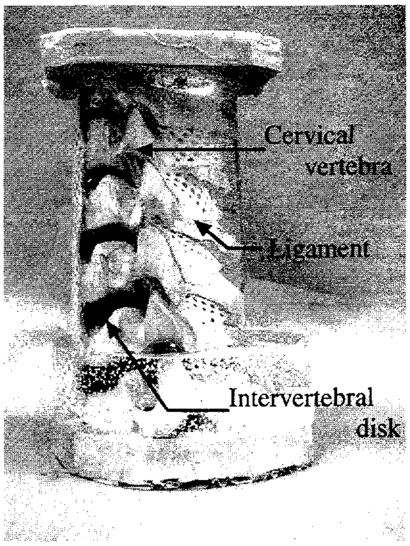

Figure 5. A new biomechanical neck model in rear-end collision

Hybrid- III Neck Model

The Hybrid-III dummy was developed based on experimental data from volunteers and cadavers. The neck structure is composed of five pieces of aluminum plate with hard rubber connecting them between the plates.

This neck model was designed for use in frontal impact tests at high speed so use of this model in low-speed impact tests needs further consideration.

TRID-II Neck Model

The TRID-II neck model was developed by TNO. This neck structure is composed of seven pieces: two upper and lower aluminum plates and five plastic plates. Integrates soft rubber disks were placed between each plate as a substitute for the intervertebral disks.

This neck model is only for use in rear-end collisions at low-speed of 25 kilometers per hour or less and more closely simulates the human body compared to the Hybrid-III neck model.

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[*] Cervical vertical model for a medical science, Synthes Ltd.

[**] Cubic-eye HA6003, Yunitika Co., Ltd.

[***] RTV Rubber KE1603, Shin-Etsu Chemical Co.,Ltd.

NECK MODEL COMPARATIVE VERIFICATION TESTS

Pendulum Test

Several pendulum tests were carried out as part of the conventional dummy certification tests including evaluations as to whether the biomechanical cervical dummy was adequate and cervical sections of each dummy model were also compared. Measurement items included the neck angle rotation and the neck bending movement.

Test Results and Discussions

In order to evaluate whether the biomechanical cervical dummy was adequate, the neck rotation angle and neck bending movement were collated and compared with previous documents[*] and the evaluation then carried out. (Figure .6)

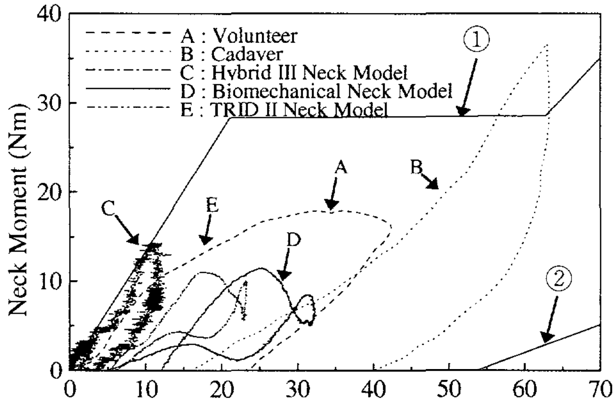

Figure 6. Neck extension torque vs angle responses

The cadaver test data is from results at a collision speed of 16 kilometers per hour and the volunteer test data is from results at 5 to 7 kilometers per hour. The dummy and biomechanical cervical model test data is from results at 5 kilometers per hour. The lines ① and ② in Figure. 6, are test results obtained from the cadaver and volunteer tests. The dummy test results must fall within this area.

Cadaver

Cadaver muscle tissue has no stiffness in the muscular tissue so the bending moment first occurs after a certain increase in the rotation angle.

Volunteer

Muscle tissue in volunteers has stiffness since the test subject contracts his muscles in anticipation of the impact.

Hybrid-III neck model

The Hybrid-III neck model was mainly designed for use in frontal impact tests and thus is too stiff for use in low-speed rear-end collision tests.

TRID-II neck model

The TRID-II neck model has a structure similar to that of the human neck so it more flexible than the Hybrid-III and has properties similar to the biomechanical cervical model.

Biomechanical cervical model

The head rotation angle of the biomechanical cervical model is greater that the other models in spite of a smaller bending movement. Therefore, the biomechanical cervical model is less stiff than the Hybrid-III neck model.

Based on the above results we concluded that the biomechanical cervical model had more flexibility when compared against the other dummy models. Whiplash damage also occurs when the subject does not anticipate a collision so muscle strain or contraction was not considered a significant factor here. In other words, our biomechanical cervical model simulates well the status of a driver who is not anticipating a collision.

Sled test

In the next step of the testing, sled tests were carried out using three neck models and neck action when not subjected to impacts was analyzed.

A driver seat was affixed to the sled as shown in Figure 7. A Hybrid III 50th percentile dummy was used and restrained with a seat belt. The different neck models were installed and test items such as dummy action and the load on the dummy neck at that time were measured. Test results are shown in Table 1.

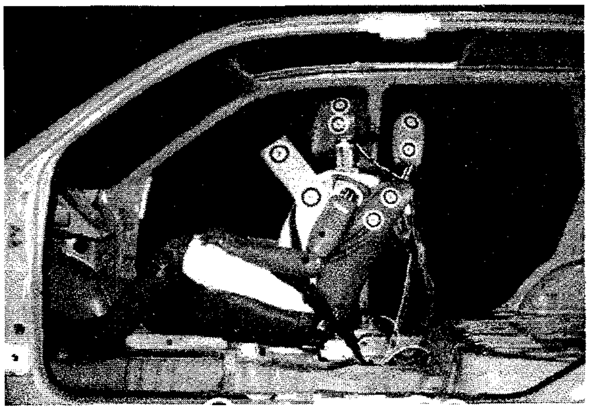

Figure 7. Sled test

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[*] Meltz,H.and Patrick,L.,Strength and Response of the Human Neck, SAE Paper No.710855 (1971)

Table 1. Test condition

Velocity	8 km/h
Seat	Front Drivers Seat
Headrest	It is existing
Dummy Model	Hybrid III 50th percentile dummy

Results and discussions

The head and chest time acceleration curves and head rotation angle obtained at a speed of 8 kilometers per hour are shown respectively in Figure 8, Figure 9, Figure 10.

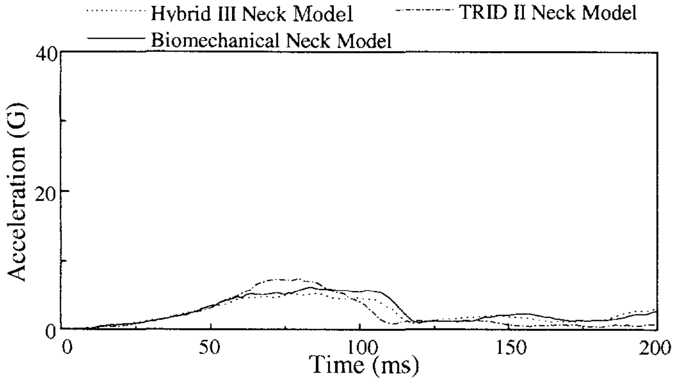

Figure 8. Chest acceleration

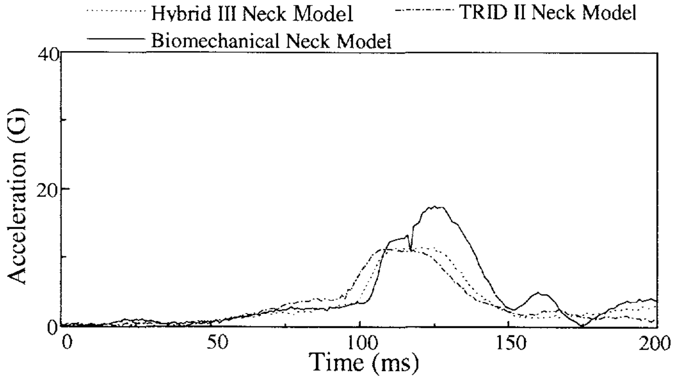

Figure 9.Head(C.G.) acceleration

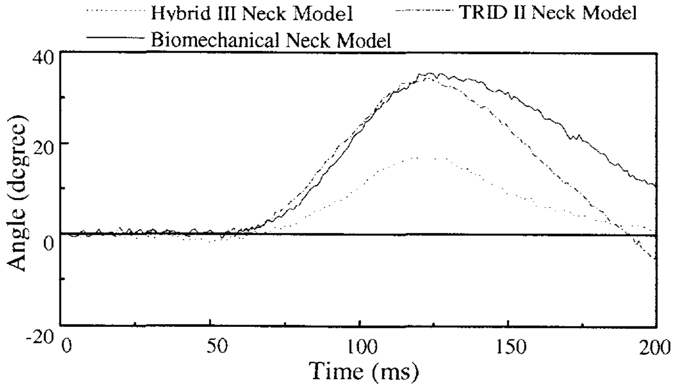

Figure 10. Head rotational angle

The chest time acceleration curve the same for both the Hybrid-III, TRID-II, and biomechanical cervical models after a reaction force from the back of the seat and returning forward after a maximum extension at approximately 100ms. In contrast, all head acceleration curves showed the same tendency up until the first 100 milliseconds after which a drastic difference appeared in the biomechanical model 110 milliseconds after the dummy head contacted the headrest. Also, on checking the head rotation angle versus the chest position in Figure 10, the biomechanical model and TRID-II models exhibited a large rotation angle while the Hybrid-III model showed almost no rotation. The biomechanical model had a larger rotation angle 120 milliseconds after contacting the headrest.

We can therefore conclude from the above results that:

(1) The Hybrid-III dummy head did not rotate *much due to* high neck stiffness after contact with the head restraint. The neck and head returned smoothly forward back to initial position as the chest`was moved by the reaction force from the seat.

(2) Neck stiffness in the TRID-II model was lower than that in the Hybrid-III. However, after contacting the head restraint, the neck and head smoothly returned to initial condition due to the reaction force from the seat.

(3) The biomechanical cervical model on the other hand, rotates after contacting the head restraint but the chest is pressed back by the reaction force from the seat. Since the chest moves forward at this time while the head still remains in a rearward position, an offset occurs in the relative forward motions of the head and chest.
Consequently we believe that this so-called "neck offset phenomenon (Figure 11.)" occurs between the cervical vertebrae due to a deviation or offset between the forward and rearward forces. This phenomenon was not encountered in the neck sections of the Hybrid-III Neck and TRID-II Neck models. (Figure 12., 13.). We also think that this phenomenon is responsible for causing "whiplash" or neck injury.

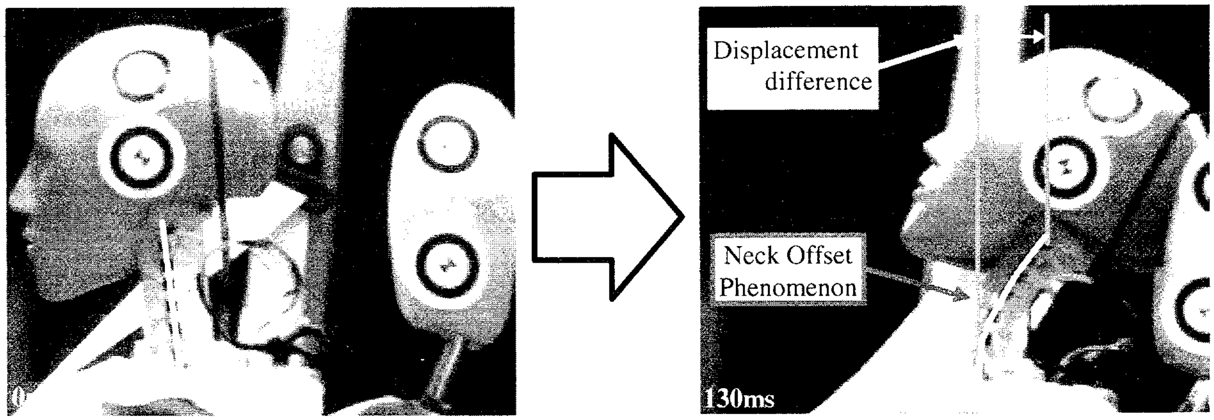

Figure 11. Biomechanical Cervical Model

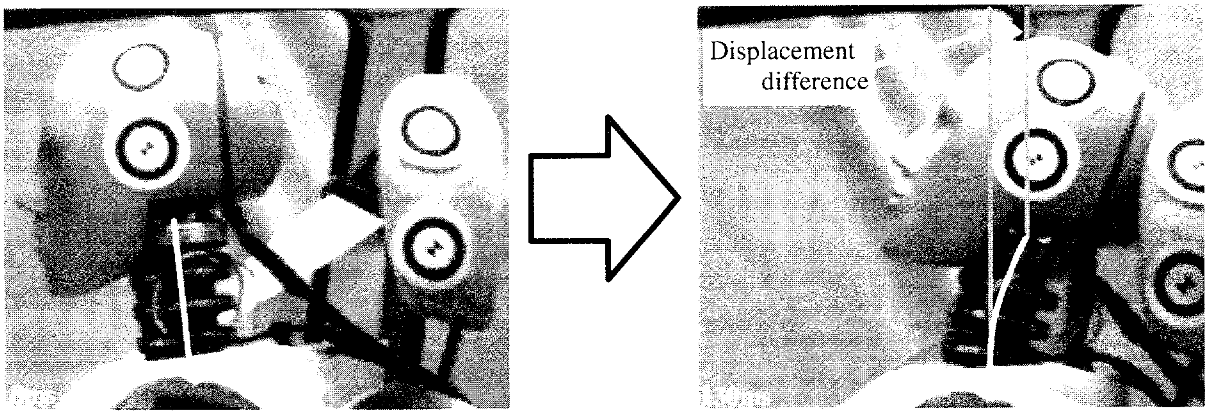

Figure 12. Hybrid- III Neck Model

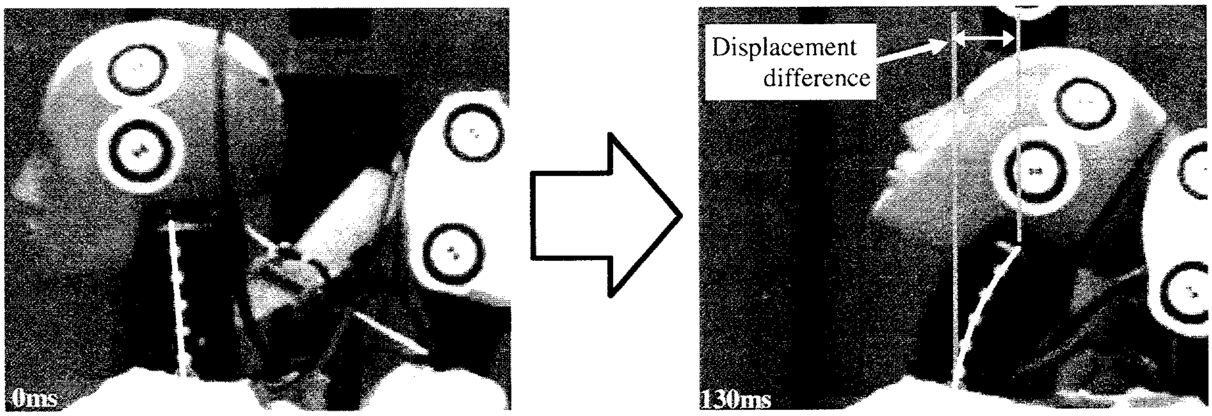

Figure 13. TRID-II Neck Model

CONCLUSION

In this study, the Hybrid-III neck model, TRID-II neck model and the biomechanical cervical model were subjected to the sled test and their performance analyzed. We found the following upon analyzing the results.

(1) Neither cervical flexion or deviation or offset in the cervical vertebrae structure could be found in the TRID-II neck in the current analysis performed in the low speed region.

(2) The biomechanical cervical model however revealed cervical phenomenon which did not appear in the Hybrid-III dummy test. We think that this phenomenon occurs between the second, third and fourth cervical vertebrae, initiating a large shearing force which presses on spinal nerves and blood vessels causing injuries.

(3) The Hybrid-III neck model had too much stiffness to allow a detailed analysis of neck behavior in low-speed rear-end collisions.

We conclude from this study that the biomechanical cervical mode holds great promise as a tool for exposing the mechanism that causes neck injury and further research and development of this model will yield even greater results in the future.

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