Simulation on The Occupant Kinematics Response and Neck Injuries During Low Speed Rear Impact

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Abstract –A rear impact model with BioRID II dummy, seat and seat belt is built using MADYMO code, and the influence of seat properties and seating posture on occupant kinematics responses neck injuries is studied. The simulation results show that head restraint position, seat back cushion stiffness, recliner stiffness and occupant seating posture have great influence on occupant head-neck kinematics responses, neck injuries can be reduced by proper seat design.
Keywords: Rear impact, neck injuries, seat

1 Introduction

A car occupant may suffer from neck injuries in low velocity car rear end impact. Although classified as AIS 1(minor), neck injuries can cause a long term symptoms, such as neck pain and stiffness, headaches, dizziness, sleep disturbances, etc.

It is widely recognized that the mechanism of whiplash injuries is the hyperextension of human neck and proper head restraint can prevent neck injuries. But some research reports showed that although the head restraint was used and the neck has not hyper extended, neck injuries always happened also [1]. Through field data analysis and rear impact tests, P. Prasad, A. Kim found that if the seat was too stiffness, although the head restraint had a good position, neck injuries would occur also, and deformable seat can provide prevention to occupant neck during wide range velocity of rear impacts [2]. During NASS accident database, about 2/3 of the target vehicles had changed their momentums before rear impacts because of braking, steering and so on, so occupants were out-of-position. Charles Y. Warner, Charles E. Stother reported that little seating position change could lead the occupant neck loads to increase greatly during rear impacts [3].

This paper builds a rear impact model using MADYMO code, analyzes the effect of seat properties and occupant seating position on occupant kinematics and injuries.

2 Occupant Motion Phases during Rear Impacts

Occupant kinematics responses can be divided into three phases during rear impacts, as shown in Figure 1.

(1) Retraction/Extension Phase

First, the thorax is accelerated by seat back, while the head, due to its inertia and has not contacted with the head restraint, is still at the initial position. The head has not started to rotate, the head is merely translated relative to the thorax, the upper cervical spine is flexed and the lower cervical spine is extended.

The head starts to rotate backward, and the whole cervical spine extends. The upper cervical spine changed from flexion to extension.

When the rearward movement of the head is stopped by the head restraint, the retraction/extension phase is concluded.

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(2) Forward Movement

After the head has contacted with the head restraint, it begins to move forward relative to the seat. Both head and thorax will rebound because the internal energy stored by seat components transfers back to the occupants.

If thorax reverses its movement earlier than head, the retraction phase will be prolonged. And if head reverses its movement earlier than thorax, the retraction phase will be shortened.

(3) Protraction/Flexion

Because completely inelastic seats do not exist, occupant will rebound in this phase. When the seat belt retractor is acted, forward movement of occupant thorax will be restrained by seat belt, while the head moves forward still. The cervical spine starts to flex. Because of the damping effect of thorax cage and more spine vertebras participate in the flexion and extension motion than in first phase, the loads on the individual vertebra and intervertebral structures are smaller.

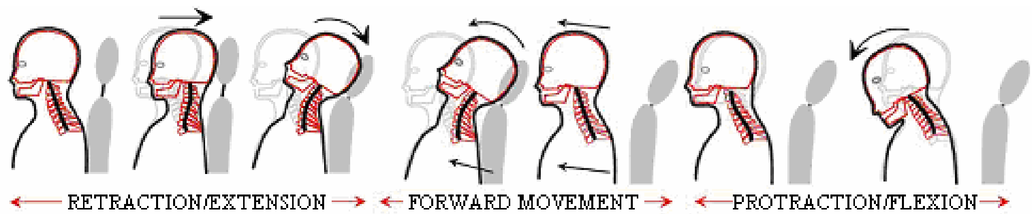


Fig.1 Three phases of occupant movement during rear end impacts

3 Mechanisms of Neck Injuries

King summarized the neck injury mechanisms to date, but none of them can fully explain the neck injuries. The main hypothesis on the neck injury mechanisms are listed as follows:

(1) One hypothesis is that neck injuries are caused by severe hyperextension such that the head's extension angle exceeds 90º. Later, the introduction of the headrest failed to prevent neck injuries perfectly, so other hypotheses were proposed.

(2) In another one, pain is caused by the spinal nerves or the dorsal roots as the result of increased pressure in the spinal canal and the cervical region.

(3) Hypothesis based on facet joint surface impingement between upper and lower vertebrae. Shear forces and axial forces are exerted on the cervical vertebrae. Facet joint injury occurs as the result of the facet joint impingement when the lower articular process of the upper cervical vertebra contacts the upper articular process of the lower cervical vertebra.

4 Method

The rear impact computer simulation model is built in MADYMO code platform, the whole model consists of 5 systems, i.e. reference space, occupant, vehicle, seat and seat belt.

Occupant is simulated using BioRID II 50th ellipsoid model. BioRID II is the most biofidelic dummy to simulate the human responses during rear impacts up to now. The whole BioRID II ellipsoid model consists of 48 bodies.

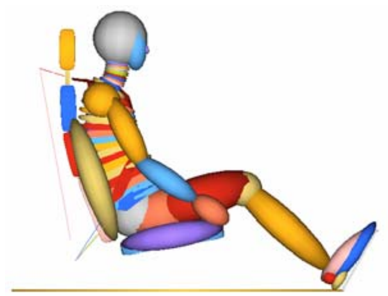
Vehicle system consists of only 1 body named *floor*, the *floor* body is connected with reference space by FREE joint. Through defining the position degrees of freedom of the FREE joint, vehicle can move according desired crash acceleration pulse.

Seat belt system consists of standard belt model and membrane FE model.

Seat system consists of 3 bodies, i.e. seat base, seat back and head restraint.

The crash pulse is shown as Figure 3, the vehicle delta-v is set at 17 km/h, the peak acceleration is 9 g and endurance is about 90 ms.

A parameter study with different seats is carried out to found out how the seat parameters affect the neck injuries. The parameters selected for parameters study are headrest position, seatback cushion stiffness, recliner stiffness and occupant seating position. The neck moment, neck force, T1 velocity and acceleration and head rotation relative to torso are calculated in each simulation to assess the injuries.



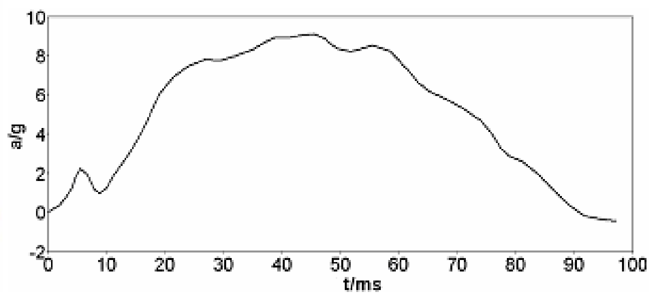


Fig.2 Rear impact model **Fig. 3 Vehicle crash pulse**

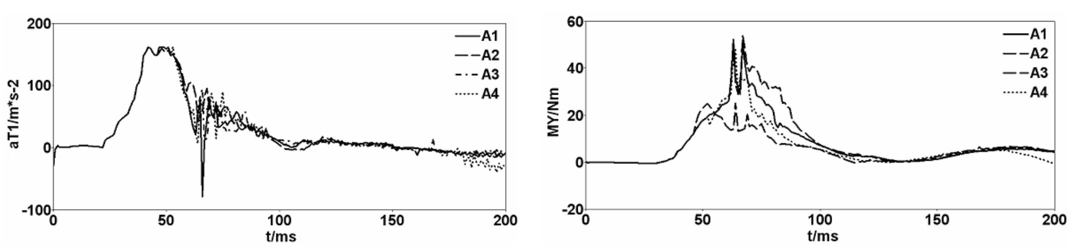
5 Simulation Results

5.1 Effect of head restraint on neck injuries

First, the vehicle delta-v is 17 km/h, occupant is set at normal seating position, seat back is rigidly connected with seat base, only analyse the effect of seat restraint position on neck injuries during rear-end impacts. Head restraint height is set at two levels, i.e. 700mm(low) and 800 mm(high), distance between head and head restraint is also set at two levels, i.e. 50mm(near) and 100 mm(far). 4 simulations (No.A1~A4) are finished, the results are shown in Table 1.

The results make it clear that head restraint position has great influence on neck kinematics responses. Head restraint position almost has no influence on thorax acceleration (shown as Figure 4 (a)), but with the reduction of distance between head and head restraint, head contacts with head restraint earlier, relative rotate angle between head and thorax, neck moment, shear force and axial force decreases greatly.

Insufficiency of head restraint height results in head rearward rotation can't be prevented and increases of rotate angle between head and thorax, neck moments and loads.



(a) thorax acceleration (b)lower neck My

Fig.4 Effect of head restraint position on occupant responses

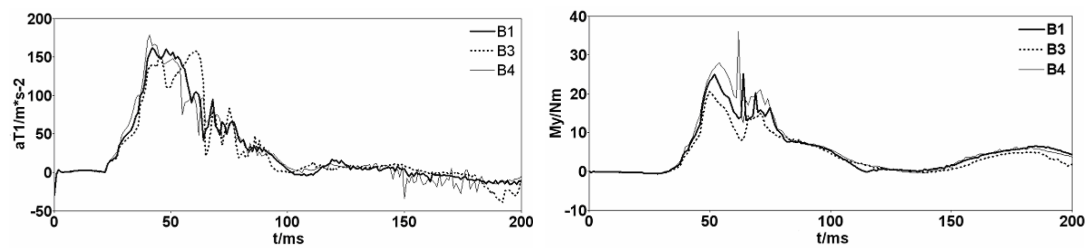
Lower neck moment *My* time history curves of BioRID II dummy are shown as Figure 4 (b). At the first 48 ms, because head hasn't contacted with head restraint, the 4 moment curves are uniform. At time of 48 ms, head starts to contact with head restraint during case A2, results in lower neck moment reaches the peak value at 52ms, and the peak value is the minimum of the 4 cases. The time head starts to contact with head restraint in other cases are prolonged, induces the lower neck moment continue increasing and achieve high peak values.

5.2 Effect of seat back cushion stiffness on neck injuries

Based on the configuration of A2, stiffness of upper and lower seat back cushion is changed to study the influence of seat back cushion stiffness on neck injuries. Stiffness of upper and lower seat back cushion is divided into 3 grades, i.e. high, medium and low, 9 simulations (No.B1~B9) are finished.

Simulation results of 5 cases are listed in Table 2. Stiffer lower seat back cushion and softer upper seat back cushion results in reduction of neck moments and neck loads.

Figure 5 shows the thorax acceleration curves of case B1, B3 and B4. During case B1, an original seat is used, upper seat back of B3 is softer than that of B1 while lower seat back is stiffer, upper seat back of B4 is stiffer while lower seat back is softer. Thorax acceleration peak value of B3 is smallest of the 3 cases, and the acceleration curve of B3 is the gentlest one, results in lower neck moments and loads. Thorax acceleration peak value of B1 is the highest, and the shape of the thorax acceleration is steepest, leads to higher neck moments and loads.



(a) thorax acceleration (b)lower neck My

Fig.5 Effect of seat back cushion stiffness on occupant responses

5.3 Effect of recliner stiffness on neck injuries

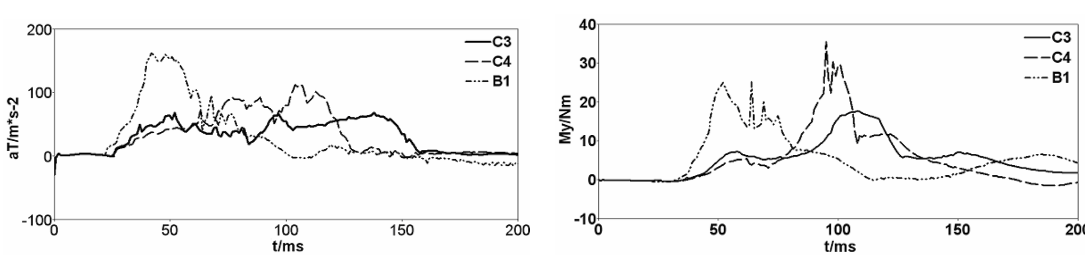
Different to above seats, these seats are based on B1, and their seat backs can rotate around seat base through deformable recliner during rear impacts.

Recliner stiffness (moment vs. angle characteristics) is a linear function, slope of the function is set to 3 grades, i.e. low (43.5 Nm/deg), medium （87 Nm/deg）and high (174 Nm/deg), the initial yielding point is divided 2 levels, i.e. high (570 Nm) and low (200 Nm). Simulation results are shown as Table 3.

Using deformable recliner, thorax acceleration decreases obviously, while neck moments and loads do not always reduce and are affected by recliner characteristics greatly.

When recliner initial yielding point is 200 Nm, the seat back rotates back too easy at the beginning of the rear impact, results in head restraint moves far away from head and delays head contacts with head restraint. While recliner initial yielding point is 570Nm, the above phenomenon doesn’t take place, the protection effect is better.

When recliner initial yielding point is 570 Nm and slope of recliner stiffness function is 43.5Nm/deg (Case C3), the neck moments and loads are lower than other cases, thorax acceleration peak value is the lowest and head contact head restraint on time.



(a) thorax acceleration (b)lower neck My

Fig. 6 Effect of recliner stiffness on occupant responses

Figure 6 shows the thorax acceleration curves of C3, C4 and B1. No recliner is used of Case B1, although head contact with head restraint very early, but the thorax acceleration peak is too high. Both C4 and C3 have deformable recliner. Because recliner initial yielding moment of C4 is too low and slope of recliner stiffness function is too high, results in lower thorax acceleration at the beginning of impact and higher acceleration at the end. Recliner stiffness of C3 is much proper, results the least peak thorax acceleration value and the most smooth thorax acceleration curve. So, the neck moments and loads of C3 are smaller than other cases.

5.4 Effect of seating position on neck injuries

During above study, occupants are all in normal seating position (NSP), but in real accidents, many occupants are out-of-position (OOP). Hence, it is necessary to investigate the head-neck kinematics responses and neck injuries of OOP occupants during rear impacts.

On base of A1~A4, B1~B9 and C1~C6, the BioRID II is pitched down for an angle of 32° (No. OOPA1~OOPA4, OOPB1~OOPB9 and OOPC1~OOPC6), Table 4 lists some of the simulation results.

Results of OOP occupants are much different from that of NSP occupants, such as: (1) OOP occupant will ramp up along seat back more than NSP occupant, this maybe result in head restraint can not support head well, hypertension of neck and even collision of head to car roof. (2) Neck moments and loads of OOP occupant are much greater than that of NSP occupants. (3) More serious rebound of OOP occupants will occur if the seat is of high stiffness.

Neck moments and loads of OOPA1 and OOPA2 are almost same, no obvious effect of head restraint position on neck injuries is found. The time of head of OOP occupant starts to contact with head restraint is too late that the maximum neck moments and loads are generated before that time. Head restraint doesn’t exert its restraint function to head of OOP occupant, exposing the neck to a high neck injury risk.

Effect of recliner characteristics on OOP occupant is similar to that of NSP occupant. Proper stiffness of recliner can also decrease neck moments and loads of OOP occupant. Neck injury risk of OOP occupant is much high than NSP occupant, using deformable components to absorb impact energy and reduce thorax acceleration, is an effective measure to reduce neck injury risk of OOP occupant.

6 Conclusions

During rear impacts, head restraint position influences the occupant kinematics responses greatly. Increasing head restraint height and decreasing distance between head and head restraint are helpful to make head contact head restraint earlier, avoid hyperextension of neck and reduce neck moments and loads.

Introducing of plastic deformable recliner, makes the seat back can rotate rearward during rear impacts, proper stiffness characteristics can decrease thorax acceleration and make head contact with head restraint in time, so greatly reduces the neck moments and loads.

Seat back cushion stiffness also has influence to neck injuries. Simulation results show that softer upper seat back cushion and stiffer lower back cushion can decrease neck injury risks.

Seating position is an important factor that affects the head-neck kinematics responses greatly. Neck injury risks of OOP occupant are much higher than that of NSP occupant, protection of OOP occupant is much important. Recliner stiffness is the most important factor affect neck injury of OOP occupant, deformable seat is benefit to reduce neck injury risk.

No matter the occupant seating posture, lower thorax acceleration level and earlier of the time when head starts to contact with head restraint, are helpful to reduce neck moments and loads.

7 References

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Table 1 Effect of head restraint position on neck injuries

No.	Head position		Δθ (°)	Head acc(g)	Thorax acc (g)	Upper neck Fx (N)	Upper neck Fz (N)	Upper neck My (Nm)	Lower neck Fx (N)	Lower neck Fz (N)	Lower neck My(Nm)	t0 (ms)
	Height	Backset										
A1	High	Far	65	30	17	-395	-254	-30	-585	304	52	64
A2	High	Near	43	35	17	-187	-336	-22	-469	300	25	47
A3	Low	Far	78	28	17	-449	-568	-30	-606	275	54	68
A4	Low	Near	73	37	17	-333	-715	-14	-777	-311	48	54

Note：t0, the time head starts to contact with head restraint。

Table 2 Effect of seat back cushion stiffness on neck injuries

No.	Stiffness		Δθ (°)	Head acc(g)	Thorax acc (g)	Upper neck Fx (N)	Upper neck Fz (N)	Upper neck My (Nm)	Lower neck Fx (N)	Lower neck Fz (N)	Lower neck My(Nm)	t0 (ms)
	Height	Backset										
B1	Standar	Standar	43	35	17	-187	-336	-22(6)	-469	300	25	47
B2	Soft	Soft	43	31	17	-228	-431	-26	-469	462	25	47
B3	Soft	Stiff	42	35	16	-171	-357	-18	-402	419	21	47
B4	Stiff	Soft	43	31	18	-223	-346	-32	-509	443	36	47
B5	Stiff	Stiff	42	31	17	-195	-300	-21	-422	330	23	47

Table 3 Effect of recliner stiffness on neck injuries

No.	Stiffness		Δθ (°)	Head acc(g)	Thorax acc (g)	Upper neck Fx (N)	Upper neck Fz (N)	Upper neck My (Nm)	Lower neck Fx (N)	Lower neck Fz (N)	Lower neck My(Nm)	t0 (ms)
	Yield	Slope										
C1	570Nm	174Nm/°	48	24	11	-192	-303	-10	-420	174	29	80
C2	570Nm	87 Nm/°	42	17	8	-131	-345	-6	-434	137	25	88
C3	570Nm	43.5 Nm/°	35	14	7	-73	-304	-6	-325	-126	18	100
C4	200Nm	174Nm/°	51	35	12	-228	-459	-12	-570	255	35	92
C5	200Nm	87 Nm/°	48	27	9	-159	-474	-8	-524	-185	33	108
C6	200Nm	43.5 Nm/°	47	20	7	-91	-471	-5	-487	-182	30	122

Table4 Responses of out-of-position occupant

No	Δθ (°)	Head acc(g)	Thorax acc (g)	Upper neck Fx (N)	Upper neck Fz (N)	Upper neck My (Nm)	Lower neck Fx (N)	Lower neck Fz (N)	Lower neck My(Nm)	t0 (ms)
OOPA1	83	14	46	-224	905	-36	-345	1315	19	130
OOPA2	78	20	46	-224	905	-35	-379	1316	19	110
OOPC1	61	25	18	-339	739	-76	-572	715	31	136
OOPC2	64	30	13	-247	-753	-58	-450	-581	23	145
OOPC3	55	39	11	-192	-796	-46	-491	-590	21	155
OOPC4	72	27	24	-338	978	-95	-688	916	33	141
OOPC5	67	38	14	275	-904	-85	-660	-728	-41	154
OOPC6	66	55	17	359	-1244	-70	-697	-966	-51	156