THE NECK INJURY CRITERION (NIC) IN DUMMY TESTS: A MATHEMATICAL SIMULATION STUDY

A. Eichberger, W. Körner
Steyr-Daimler-Puch Fahrzeugtechnik AG Graz, Austria
H. Steffan
Institute for Mechanics, University of Technology Graz

Abstract

Recent progress in injury mechanics of the human cervical spine has introduced a new neck injury criterion (NIC) for soft tissue injuries following rear impacts. This Criterion was investigated in pig and human subject experiments and has shown promising results. However, no standard test procedure has been established so far that allows for comparable research on improved head restraint systems using anthropometric test devices. Especially, proposed thresholds of NIC are only valid for pigs and human beings but not for Dummies. The aim of the present study is to calculate NIC in Dummy tests and to investigate the influence of parameter that have proven to be of importance from accident investigations. Such parameters are velocity change, acceleration level, shape of the acceleration pulse, head restraint position, seat back properties, etc. Additionally, the relationship between NIC and neck loads is investigated.

The seat of a middle class car was modeled using multi-body simulation techniques (occupant simulation software MADYMO™). Properties of the seat cushion, recliner joint and the head restraint were measured in quasi static loading tests and implemented to the model. The test object, a database of the 50^{th} percentile Hybrid-III Dummy - equipped with a more biofidelic neck (TRID neck) - was positioned according to standard seating procedures. Seat and head restraint were adjusted to standardized positions as used in frontal crash testing. To validate the whole model, a series of sled test tests were performed using the same conditions as in the numerical model. Tests were performed at three different velocities that were repeated several times to check the reproducibility of the test results. Results of simulation and sled experiments were compared and showed acceptable agreement. A parametric study was performed by variation of parameters listed above. NIC was calculated for these simulations using the formula agreed upon on a NIC standardization meeting (Gothenberg, 1998). NIC results were analyzed and compared to loads of upper and lower neck. The rebound motion was not investigated.

VELOCITY CHANGE: According to the literature, the velocity change (Delta V) of the struck car is of major importance in rear impacts. Delta V is commonly used to asses the impact severity and the risk for neck injury in actual collisions. Within this study, an idealized crash pulse (half sine shape, crash duration 100ms) was used to investigate the influence. The amplitude of the sine pulse was increased to study the influence of Delta V isolated from all other parameter. Results show, that the relationship between Delta V and NIC is almost parabolic, that means NIC seems to represent the amount of kinetic energy that is loaded to the occupant.
CRASH DURATION: Given a constant Delta V (16 km/h) and the shape of the crash pulse (half sine), the crash duration characterizes the "stiffness" of the impact, i.e. the influence of the car structure stiffness of the colliding vehicles. The crash duration was varied between 25 and 150 ms. Results show that NIC decreases with increasing crash duration. NIC decreases from a hard impact (50ms crash duration) to a soft impact (125ms) by approximately 25 %.
SHAPE: The influence of the shape of the crash pulse was investigated by comparing the simulation results of two trapezoid pulses with two levels: A crash pulse with a high first level and a low second level was compared to a pulse with a low first level and a high second level. The simulation showed that the moment of time where NIC and maximum neck loads occur are influenced significantly but not the level of NIC and neck loads.

HORIZONTAL DISTANCE: The influence of the head restraint position with respect to the horizontal distance between the head and the head restraint was investigated by adjusting the head restraint to several positions ranging from direct contact to a maximum horizontal distance of 200mm. Results of the simulation show that NIC and neck loads are low whenever the head restraint is close to the head. By increasing the gap, NIC and neck loads grow significantly until a horizontal distance of approximately 150mm. When enlarging the gap to more than 150mm, NIC increases not significantly anymore whereas neck loads are still advancing.

VERTICAL DISTANCE: Some studies indicate that the position of the head restraint with respect to the height influences the risk for cervical spine distortion. Therefor the vertical height was adjusted to different positions and - in one case - the head restraint was removed completely. Results of the simulations show that NIC increases when lowering the head restraint, but the difference between NIC in a simulation where the head restraint is positioned high (COG of head and COG of head restraint at same height) and a simulation where the head restraint is removed completely is only 10 percent. On the other hand neck loads, especially neck torque, increase drastically due to the extension motion of the neck (up to 500%). NIC has been designed for assessing the retraction motion and not for predicting hyperextension injuries.

SEAT BACK STIFFNESS: The influence of the recliner stiffness was investigated by varying the loading stiffness of the seatback, i.e. plastic deformations were not taken into account. Results show that NIC and neck loads can be reduced by using higher stiffness of the recliner joint. The positive effect of a stiff seat is that the head restraint does not move as far away from the head due to yielding of the seatback as in a simulation using a seat with a low stiffness. Contact of head to head restraint is earlier, limiting the amount of retraction and extension motion. Improved energy absorption of the seat back by plastic deformation or a damping system was not investigated. A seat that combines low recliner stiffness with controlled energy absorption may have positive effects but the head restraint should still limit relative motion of the head to the upper torso.

ACCORDING to this study, NIC and neck loads of the HYBRID-III Dummy (with the TRID neck) are correlated in rear car crashes where the head-neck extension motion is limited by a head restraint. NIC is not able to predict hyperextension injuries whenever the head restraint is very low or not present. NIC is sensitive to Delta V, acceleration pulse level, shape of crash pulse, head restraint position and seatback properties. Especially Delta V and the horizontal distance between head and head restraint influence NIC and neck loads remarkably. This study has several limitations. First of all, the biofidelity of the Hybrid-III (even when using the TRID neck) is limited. Secondly only one seat was investigated and thirdly although, the mathematical model was validated with sled tests, the accuracy of the model in extreme situations, especially at high velocities where seat back collapsing is to be expected, is not proven. It has also to be emphasized that the rebound (forward) motion has not been looked at.

This study suggests that it makes sense to use NIC as an indicator for the risk of soft tissue neck injuries in rear impact Dummy testing although the biofidelity of the Dummy is limited. To take into account the risk for neck injury resulting from hyperextension it is recommended to regard also neck loads respectively forces and moments in the upper and lower neck.

References

Aldman, B. (1986): An Analytical Approach to the Impact Biomechanics of Head and Neck. Proc. 30th Annual AAAM Conf., pp. 439-454, LC 64-1965

Boström O; Svensson, M.Y; Aldman, B; Hansson, H.A; Håland,Y; Lövsund,P; Seeman,T; Suneson,A; Säljö, A; Örtengren T. (1996): A new neck injury criterion candidate-based on injury findings in the cervical spinal ganglia after experimental neck extension trauma. Proc. Int. Ircobi Conf. on the Biomechanics of Impact, Dublin, Ireland.

Boström, O.; Krafft, M.; Aldman, B.; Eichberger, A.; Fredriksson, R.; Haland, Y.; Lövsund, P.; Steffan, H.; Svensson, M.Y.; Tingvall, C.(1997): Prediction of Neck Injuries in Rear Impacts Based on Accident Data and Simulations. Proc. Int. Ircobi Conf. on the Biomechanics of Impact, Hannover, Germany, pp. 251-264

Eichberger, A; Geigl,B.C; Moser, A; Fachbach, B; Steffan,H; Hell,W; Langwieder,K. Comparison of different car seats regarding head-neck kinematics of volunteers during rear-end impact (1996). Proc.Int. Ircobi Conf. on the Biomechanics of Impact. Dublin, Ireland.

Eichberger A., Steffan H., Geigl B.C., Svensson M., Boström O., Leinzinger P.E., Darok M. (1998): Evaluation Of The Applicability Of The Neck Injury Criterion (NIC) In Rear End Impacts On. Proc. 1998 Int. Ircobi Conf. on the Biomechanics of Impact, Gothenborg, Sweden, pp. 321-334

Eichberger A., Darok M., Steffan H., Leinzinger P.E., Boström O., Svensson M., (1999): Pressure Measurements In The Spinal Canal Of Post-Mortem Human Subjects During Rear-End Impact And Correlation Of Results To The Neck Injury Criterion (NIC). WAD World Congress '99, Vancouver (Canada)

Hell W., Langwieder K., Walz F. (1998): Reported Soft Tissue Neck Injuries After Rear-End Collisions. Proc. 1998 Int. Ircobi Conf. on the Biomechanics of Impact, Gothenborg, Sweden, pp. 261-274

v Koch. M.; Kullgren, A.; Lie, A.; Nygren, Å.; Tingvall, C. (1995): Soft tissue injury of the cervical spine in rear-end and frontal car collisions. Proc. Int. IRCOBI, Conf. on the Biomech. of Impacts, pp. 273-283

Krafft, M.; Kullgren, A.; Lie, A.; Nygren, Å.; Tingvall, C. (1996): Whiplash associated disorder-Factors influencing the incidence in rear-end collisions. Proc. 18th ESV Conf. in Melbourne, Australia, paper 96-S9-O-09

Lövsund, P.; Nygren, Å.; Salen, B.; Tingvall, C. (1988): Neck Injuries in Rear End Collisions among Front and Rear Seat Occupants. Proc. Int. IRCOBI Conf. on the Biomech. of Impacts, Bergisch-Gladbach, F.R.G., pp. 319-325

Matsushita T; Sato,T.B; Hirabayashi,K; Fujimura,S; Asawuama,T; Takatori,T. (1994) X-ray Study of the Human Neck Motion Due to Head Inertia Loading. Proc. 38th Stapp Car Crash Conf. pp. 55-64, SAE/P-94/279, SAE paper no 942208, ISBN 1-56091-543-9.

McConnell, W. E.; Howard, R. P.; Guzman, H. M.; Bomar, J. B.; Raddin, J H.; Benedict, J. V.; Smith, L. H.; Hatsell, C. P. (1993): Analysis of Human Test Subject Responses to Low Velocity Rear End Impacts. SP-975, SAE paper no. 930889, pp. 21-30, SAE Inc., ISBN 1-56091-360-6

Mertz, H.J.; Patrick, L.M. (1971): Strength and Response ofthe Human Neck. Proc. of 15th Stapp Car Crash Conf., pp. 207-255, SAE Inc., New York, LC 67-22372

Olsson, I; Norin, H; Ysander, L. (1990): An In-Depth Study of Neck Injuries in Rear End Collisions. Proc. 1990 Int. IRCOBI Conf. on the Biomechanics of Impacts, Bron, Lyon, France, p. 269-282.

O'Neill, B.; Haddon, W.; Kelley, A.B.; Sorenson, W.W. (1972): Automobile Head Restraints: Frequency of Neck Injury Insurance Claims in Relation to the Presence of Head Restraints. Am J Publ Health, Vol. 62, No. 3, pp. 399-406

Ono, K., Kaneoka, K.,(1997): Motion Analysis of Human Verviacal Vertebrae During Low Speed Rear Impacts by the Simulated Sled. . Proc. Int. Ircobi Conf. on the Biomechanics of Impact, Hannover, Germany. pp. 223-237

Örtengren, T.; Hansson, H.-A.; Lövsund, P.; Svensson, M.Y.; Suneson, A.; Säljö, A. (1996): Membrane Leakage in Spinal Ganglion Nerve Cells Induced by Experimental Whiplash Extension Motion: A Study in Pigs. J. Neurotrauma, vol.13, no. 3

Panjabi M. (1996): Whiplash trauma injury mechanisms: a biomechanical viewpoint. International Symposium WHIPLASH 96 Abstract book pp 19, Brussels, Belgium.

Parkin, S.; Mackay, G.M.; Hassan, A.M.; Graham, R. (1995): Rear end collisions and seat performance -To yield or not to yield, 39th annual proceedings-AAAM, pp. 231-244

States, J.D.; Balcerak, J.C.; Williams, J.S.; Morris, A.T.; Babcock, W.; Polvino, R.; Riger, P., Dawley; R.E. (1972): Injury Frequency and Head Restraint Effectiveness in Rear-End Impact Accidents. Proc. 16th Stapp Car Crash Conf., pp. 228-245, Soc. of Automotive Eng., New York, LC 67-22372

Svensson, M.Y. (1993): Neck Injuries in Rear-End Car Collisions - Sites and Biomechanical Causes of the Injuries, Test Methods and Preventive Measures. Dept. of Injury Prevention, Chalmers Univ. of Techn., S-412 96 Göteborg, Sweden, ISBN 91-7032-878-1;

Svensson, M. Y.; Aldman, B.; Lövsund, P.; Hansson, H. A.; Seeman, T.; Suneson, A.; Örtengren, T. (1993): Pressure Effects in the Spinal Canal during Whiplash Extension Motion - A Possible Cause of Injury to the Cervical Spinal Ganglia. SAE paper no. 1993-13-0013, Proc. 1993 Int. IRCOBI, Conf. on the Biomech. of Impacts, pp. 189-200, Eindhoven, The Netherlands

Temming J., Zobel R. (1998): Frequency and Risk of Cervical Spine Distortion Injuries in Passenger Car Accidents: Significance of Human Factors Data. Proc. 1998 Int. Ircobi Conf. on the Biomechanics of Impact, Gothenborg, Sweden, pp. 219-234

Walz F., Muser M.H. (1995): Biomedical Aspects of Cervical Spine Injuries. SAE International Congress and Exhibition, Detroit, Michigan, Febr. 27-March 2., SAE 950658 in SP-1077 (1995)

Wheeler J.B., Smith T.A., Siegmund G.P., Brault J.R., King D.J. (1998): Validation of the Neck Injury Criterion (NIC) using Kinematic and Clinical Results from Human Subject Tests. Proc. 1998 Int. Ircobi Conf. on the Biomechanics of Impact, Gothenborg, Sweden, pp. 335-348