C37 Injury Biomechanics in Rollover Motor Vehicle Accidents

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The goal of this presentation is to demonstrate that analytic predictions from accident reconstructions and simulations of occupant dynamics can be used along with injury assessment and tolerance criteria to predict injury risks and probabilities of death for complex rollover accidents.

Rollover motor vehicle accidents (MVA), while relatively rare, are frequently associated with serious injury and death and thus contribute disproportionately to national MVA injury statistics. Due to the often devastating and sometimes deadly head and neck injuries involved, rollover accidents are also frequently involved in litigation, with case issues revolving around seat belt design, roof crush properties, and seat belt use. While there is an extensive experimental and analytical literature addressing these issues, there have been relatively few attempts to use the increasingly sophisticated tools of accident reconstruction and injury biomechanics in concert to study rollover accidents and their associated injuries. One of the advantages of such an approach is that the actual incident and its known injury patterns can be used as validation of the analytical models, thereby increasing confidence in their use to address issues raised in litigation. The authors' goal was to use commercially available software for accident reconstruction and occupant dynamics, along with federally mandated standards for injury assessment and tolerance criteria to provide generalizable tools for predicting injury risks and probabilities of death for complex rollover accidents.

Methods. Rollovers are among the more challenging motor vehicle accidents to reconstruct because they involve linear motions in three dimensions (x, y, z) and rotation about three axes (roll, pitch and yaw). Accident reconstruction software (Human Vehicle Environment [HVE] suite, Engineering Dynamics Corporation [EDC], Beaverton, Oregon, 97008) was used to simulate three complex rollover events, two involving issues related to seatbelt use and one involving alleged design defects related to seatbelts and roof crush. The Graphical Articulated Total Body (GATB) Model was used to compute occupant kinematics (position, velocity, and acceleration vs. time), joint angles and torques, and contact forces between the human occupant and contact panels attached to the interior of the vehicle. Injuries were characterized using the Abbreviated Injury Scale (AIS). The Head Injury Criterion (HIC) was used to assess the risk of head injury. Predicted neck moments and forces from each rollover were compared against known tolerance limits for the human cervical spine according to Federal Motor Vehicle Safety Standard (FMVSS) 208. The resulting criteria are referred to as N_{ij}, where the "ij" represent indices for the neck injury in combinations of compression-tension and flexion-extension. The Combined Thoracic Index (CTI) was used to assess the risk of thoracic injury. The Probability of Death (POD), based on epidemiological data relating injuries to mortality, was used to predict the probability of occupant fatality.

Results. For each of the three reconstructed rollover events, there was excellent concordance between the predictions of the analytical models and the physical measurements made at the scene, the participants' recollections and testimony about the event, and the injuries that the occupants actually sustained. In one high-speed rollover, ejection of an unbelted occupant through the sunroof was both predicted by the models and occurred in the accident. Miraculously, the ejected passenger sustained only moderate injuries, including a fractured pelvis, despite being found pinned beneath the vehicle. Significantly for the case at issue, the analyses predicted that she would more likely than not have been even more seriously injured had she been fully restrained. For the belted simulation, the head injury criteria was equivalent to a 60% probability of an AIS 4 head injury, a 51% probability of an AIS 3 neck injury and a 89% probability of an AIS 3 chest injury. Taken together, the predicted probability of death was 78.5%. In a second simulation, a partially restrained (without lap belt) passenger was predicted to have a high probability of a catastrophic neck injury from contact with the roof during its first impact with the ground, prior to his being ejected during subsequent rolls. Use of the lap belt did not significantly reduce the risk of neck injury (although it would clearly have reduced the probability of ejection). In a third simulation, a fully restrained passenger was predicted to contact the roof as the rolling vehicle impacted the roadway during its second roll. The predicted N_{ij} value was 1.93, well in excess of the injury threshold, and resulting in a 64% probability of an AIS 3 injury to the cervical spine. This was consistent with the extension-compression C6/7 injury that the occupant actually sustained. Parametric studies with a two-fold increase in roof stiffness, use of seatbelt pretensioners, and interior roof padding, reduced N_{ij} to 1.46, equivalent to a 41% probability of an AIS 3 injury to the cervical spine, a 25% reduction in neck injury risk.

Discussion. These simulations demonstrate that accident reconstruction and occupant dynamics can be used to predict vehicular and occupant kinematics during complex, high-speed rollover events along with occupant injuries that actually occur. This lends credibility to analytical predictions directed at answering case questions related to seatbelt use and alleged vehicular design defects. The findings further confirm that, while seatbelts clearly reduce the probability of occupant ejection during rollovers, they do not appear to provide sufficient protection against catastrophic head and neck injuries from rollover accidents. Moreover, it

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appears that relatively modest increases in roof stiffness, the use of restraint pretensioners, and roof padding can dramatically reduce these injury risks. Simulations such as those presented here can also be used to study vehicular design changes that might reduce the risk of occupant injury during rollover accidents.

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