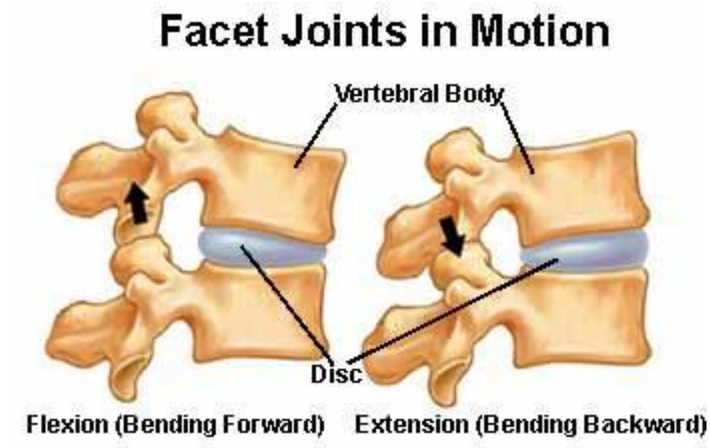


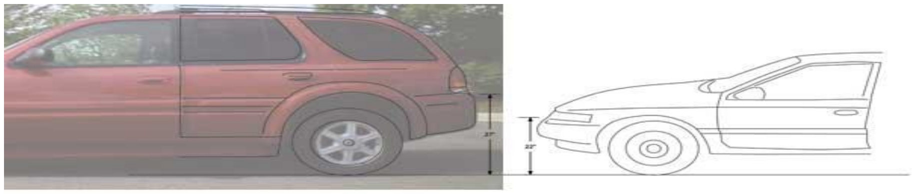
The Biomechanics of facet joint injury during whiplash

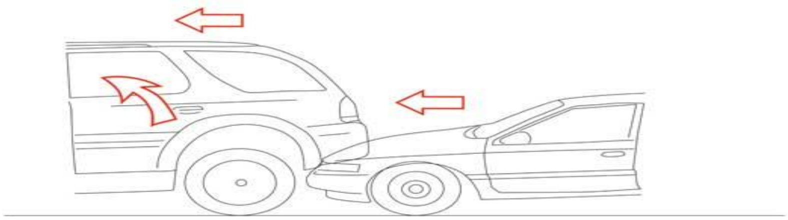
By Matthew J. DeGaetano, DC and Steve Baek, DC
Certified in Personal Injury

I was recently retained as a expert in a personal-injury litigation in which a man, while stopped in traffic, was struck from the rear by a 1997 Mercury Sable. The impact forced his SUV the car in front of him. While the property damage to his 2007 Buick Rainer was relatively superficial as far as I could determine from photographs (no other information was available about the Corvette other than there was property damage), the victim's sustained damage to rear bumper, and the under carriage The damage to the rear of the SUV appeared superficial, although frame damage cannot be ruled out.

The 30-year-old man complained immediately of low back pain. After 6 weeks of conservative treatment he underwent epidural facet joint injections at L3-4 and L4-5. Subsequently, the man developed a rather profound chronic pain.

These intriguing questions, of course, potentially invite new questions concerning the appropriateness of treatment considering there was minimal property damage to the SUV. And yet, the question of the acuteness of the injuries is an issue for biomechanical assessment. So, I started with a search of the literature to visualize what happened at the time of the crash, in order to demonstrate how the larger SUV with little damage could create the facet joint injuries. Let's look at the assessment; we'll delve into the biomechanical issues of the PEEK cage placement and provide a final denouement of my analysis. There are several forces to consider first is the rearward then the vertical component, as seen below.





Physical Evidence of Forces

In addition to the obvious signs of a crash (crushed sheet metal, bent or damaged bumper components, etc.), other subtle, but telling, signs can become important clues as to the forces experienced by a SUV's occupants in a crash. When the occupant loads the seat belt/shoulder harness webbing violently in a crash, lasting evidence may be visible in several forms: 1) "brinelling" (the wearing down of sharp surfaces) of the locking pawl and/or spool socket of the retractor mechanism results from the forced stripping out of webbing which is resisted by the ratcheting of these gears, 2) the anchorages of the seat belt and shoulder harness at the floorboard (most commonly) and B pillar respectively, may be deformed, 3) "witness marks" (visible or palpable irregularities) may be visible on the webbing material as it was drawn under high pressure through the D ring assembly, 4) the plastic D ring assembly may also show witness marks from the webbing spooling under pressure, 5) the guide rails and/or seat back frame may be bent or deformed, and 6) the head restraint supports may be deformed. Such witness marks are also useful in determining whether the restraint belts were actually worn, although marks are not always visible.

We often consider the principal direction of force (PDOF), which is generally indicated as the direction of forces through the crash vehicles and designated as a clock direction. A direct frontal impact, for example, would be a 12 o'clock PDOF.

However, occupant kinematic responses will coincide with the PDOF: the occupant of one vehicle will tend to move toward the center of mass of the other vehicle and vice versa. Studies have shown that for drivers wearing shoulder harness and lap belt, a 10 o'clock PDOF frontal crash will tend to produce spleen injuries, while for the passenger, with the diagonal belt crossing the opposite shoulder, liver injuries are more likely (1). Facet injuries should be considered in a similar vein.

Ono et al. (1997) One of the two most important human subject crash test studies of 1997 was that of Ono et al. (2). They not only subjected human volunteers to rear impact low speed crash tests, as others have done, but, in addition to filming the entire sequence on high speed videotape, they also captured the events with high speed videofluoroscopy (cineradiography) to view the finite motions of the cervical spine during actual impact loading. Subjects were 12 healthy Japanese males with an average age of 24 years and no history of cervical spine injury. The authors used a sled apparatus as they had used in the past (3) to simulate a rear struck vehicle. They also measured the sEMG activity before and during the crash pulses. All tests were conducted without head restraints. The clinical version of this paper was published later in Spine (4).

The subject's muscles in the relaxed state did not affect the head-neck-torso kinematics upon rear end impact. The ramping-up motion of the subject's torso was observed as a result of the inclination of the seat back. Axial compression forces occurred when this motion was applied to the spine, and very likely represent one of the facet joint injury mechanisms. Furthermore, the more rigid the seat cushion, the greater was the axial compression force applied to the spine. On the other hand, the torso rebounding caused by the softer seat cushion tended to intensify the shearing force applied to the vertebrae.

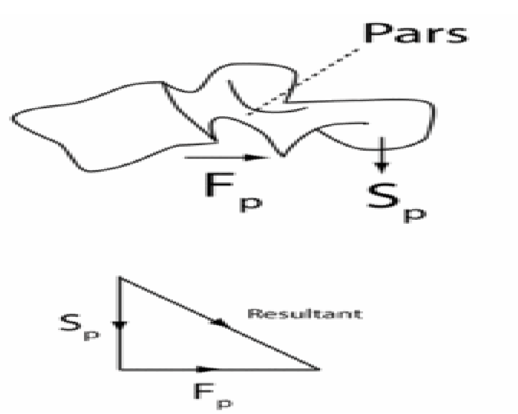
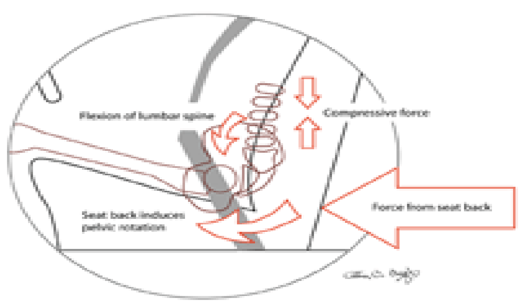


Fig. above: The force Fp was applied to the inferior facet as illustrated. The force Sp, which exists normally (but not in the experiment), is that generated by paraspinal musculature. The resultant vector of those forces is one of simple tension along the neutral axis of the pars. Note, however, that bone is stronger in compression than in tension that would create forces that would injure the facet joints.

Based on the results of our crash tests at the Spine Research Institute of San Diego (SRISD), the initial response of the lumbar spine in a rear-impact crash is flattening of the spine with flexion and compression. This is followed immediately by extension, which coin-cides with the compressive phase. So, what of the forces produced in a rear-impact delta V collision? Recent cadaver sled tests simulating rear impacts at up to 10 mph indicate early forward pelvic rotation, which would be coincident of lumbar extension (See Figure below). Crash tests at SRISD, as well as those of others, have demonstrated a strong vertical acceleration of the lumbar and thoracic spine during the initial phase of a rear-impact crash test (i.e., the so-called vertical ramping effect). This produces a large axial compressive force in the lumbar region. In recent finite element analysis (FEA) simulations of rear-impact crashes of 15.5 mph, researchers reported the contact force between the pelvis and seat back was more than 7,000 N (close to 1,600 lb-f).9 This would produce a horizontal (extensile) line of force, and would coincide with ramping and compression, thus creating injury to the lumbar facet joints.



Initial impact: flexion

References
1. Augenstein J, Perdeck E, Bowen J, Stratton J, Horton T, Singer M, Digges K, Malliaris A, Steps J: Dummy measurement of chest injuries induced by two-point shoulder belts. 44th Annual Proceedings of the
Association for the Advancement of Automotive Medicine, Chicago, IL, Oct 2-4, 2000, 1-15.
Klinghoffer K, Murdock MG. Spondylosis following trauma. Clin Orth Rel Res, 1982;166:72-4.

2. Ono K, Kaneoka K, Wittek A, Kajzer J: Cervical injury mechanism based on the analysis of human cervical vertebral motion and head-neck-torso kinematics during low speed rear impacts. 41st Stapp Car Crash Conference Proceedings. SAE paper 973340, 339-356, 1997.

3. Ono K, Kanno M: Influences of the physical parameters on the risk to neck injuries in low impact speed rear-end collisions. International IRCOBI Conference on the Biomechanics of Impact, Eindhoven,
Netherlands, 201-212, 1993.

4. Kaneoka K, Ono K, Inami S, Hayashi K. Motion analysis of cervical vertebrae during whiplash loading. Spine 24:763-769, 1999.

5. Schulte TL, Lerner T, Hackenberg L, Liljenqvist U, Bullmann V. Acquired spondylolysis after implantation of a lumbar ProDisc II prosthesis: case report and review of the literature. Spine, Oct. 15, 2007;32(22):E645-8.

6. Green TP, Allvey JC, Adams MA. Spondylolysis: bending of the inferior aricular processes of lumbar vertebrae during simulated spinal movements. Spine, 1994;19(23):2683-91.

7. Cyron BM, Hutton WC, Troup JD. Spondylolytic fractures. J Bone Joint Surg (British), November 1976;58-B(4):462-6.

8. Cyron BM, Hutton WC. The fatigue strength of the lumbar neural arch in spondylolysis. J Bone Joint Surg (British), May 1978;60-B(2):234-8.

9. Kitagawa Y, Yasuki T, Hasegawa J. Consideration of possible indicators for whiplash injury assessment and examination of seat design parameters using human FE model. 20th International Conference of the Enhanced Safety of Vehicles (ESV), Lyon, France, 2007.

10. Croft AC. Whiplash and Mild Traumatic Brain Injuries: A Guide for Patients and Practitioners. Coronado: SRISD Press; 2009.

11. Viano DC. Seat properties affecting neck responses in rear crashes: a reason why whiplash has increased. Traffic Inj Prev, September 2003;4(3):214-27