Low Back Injuries in Low Velocity Rear Impact Collisions

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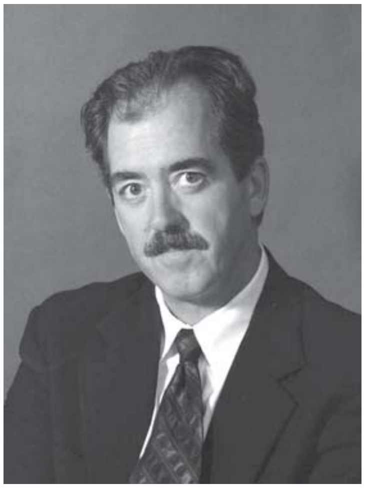

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Introduction

In low-velocity rear-impact motor vehicle collisions (MVCs), the most common injuries are the soft tissue type to the cervical spine. Correspondingly, neck pain is the most common complaint following this type of trauma. Other common complaints include headache, upper extremity pain and paresthesiae, upper back pain, lower back pain, dizziness, and balance disorders. There is a prevailing common misconception in medicine that, because the back is protected by the seat back in a rear impact MVC, the probability of injury there is minimal. This intuitive reasoning, as popular as it is, does not have any factual basis to support it. In this brief article I will review the current state of our understanding concerning the mechanical theories, risk, and incidence of back injury in rear impact MVC.

Mechanism of Injury

The biomechanical mechanism of injury in a low to moderate velocity rear impact MVC can be predicted on the basis of Newton's laws of motion. We will assume the occupant is belted into the front seat of a passenger vehicle for this analysis, and that the crash vector is a simple collinear (i.e., 180 degree) collision.

Newton's first law of motion holds that an object at rest will remain at rest unless acted upon by an unbalanced force. In this case, the unbalanced force is the forward moving seat on which the occupant is sitting. In rear impact crashes between relatively similar sized vehicles, the target (front) vehicle will typically lurch forward several feet within the first second. The occupant's inertia will resist the forward moving seat and will initially bend the seat backward. The degree to which this occurs depends on the coefficient of restitution of the seat back and the material properties of the seat padding, as well as the seat's internal design. However, most cars have seatbacks with coefficients of restitution of 0.3 to 0.7. As the car continues to move forward, the occupant is put into motion. Initially the lumbar spine flattens because the pelvis is thrust forward by the seat bottom. This results in flexion of the spine. As the occupant extends back into the seat, the lumbar spine extends. Simultaneously, there is a significant compression force in the spine as the curve flattens. The car is still moving forward at this point in time. Now, the potential energy stored in the seat back from the initial loading of the occupant is released as the occupant begins their forward excursion, thereby compounding this forward (i.e., re-entry) phase. The coefficient of restitution of the seat back imparts a spring like multiplication of this motion of 30 to 70%. In other words, if the car is accelerated such that it undergoes a velocity change of 5 mph, the occupant will experience a delta V of 6.5-8.5 mph. This is called *torso overspeed*, indicating that the torso's speed is now greater than that of the vehicle.

Backing up a bit, after the spine straightens maximally, during which it is under compressive loading strain, it then is subjected to tensile loads. As the seat back releases its potential energy as kinetic energy, and as the occupant is now moving forward, the lumbar spine is subjected to forward bending loads, with anterior disc compression. The joint capsules and posterior ligamentous complex, conversely, are under tensile loads. The seat belt then restrains the pelvis as the torso's forward inertia produces a posterior shear force across the lower lumbar discs.

All of this occurs in less than a quarter of a second and this means that another factor must be considered: *viscoelasticity*. In a nutshell, viscoelasticity is a property of all human tissues that influences the tissue's reaction to various forces and loads based on the loading or strain rate. Under higher loading rates, tissues become stiffer and more brittle, a property referred to as *anisotropy*. Ligaments and disc tissue are more likely to be damaged under very high loading rates such as we see in MVCs.

In rear impact MVCs, the human lumbar spine is subjected to very complex load paths that include compression, flexion, anterior and posterior shear, and rearward and forward bending. If there is any oblique nature to the collision or if the occupant is rotated at the time, torque further complicates the biomechanical sequence. This sequence as described here is illustrated in **Figures 1-4**. [Note that, although the thoracic spine is not illustrated here, injuries to this spinal region are also common.]

During experimental crash tests conducted at my institute, we have measured the accelerations imposed on human subjects' backs in low velocity car-to-car, full scale collisions. Volunteers were instrumented with calibrated accelerometers which recorded at a frequency of one recording every millisecond. In a direct collinear rear impact collision, the acceleration will be chiefly in the forward (x) and upward (-z) axes, using the standard SAE right hand coordinate system. When the collision vector is oblique, or when the torso is rotated relative to the car, more complex accelerations, which include the lateral (y) axis, are recorded.

An exemplar recording of a 7.5 mph delta V collision is illustrated in **Figure 5**. This was an oblique far side impact.

It is noteworthy that all of the complex loading and unloading – which includes loading path reversals – occurs in approximately one-third of a second. Peak accelerations are four times the force of gravity – well outside the boundaries of everyday experiences other than extreme or contact sports. Once again, from a biomechanical standpoint, the viscoelastic properties of human tissue are such that the stiffness increase will also increase the probability of tissue injury. Most vulnerable are the discs, facet joints, and supportive spinal ligaments, although nerve roots and the lumbosacral plexus can also be injured.

The potential size of the force imposed by the forward moving seat is underscored by 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 7000 N (close to 1600 lb).[1]

Partly deterministic in injury risk is the actual design of the seat back. Because earlier car seats were prone to fail completely in rear impact crashes, thereby increasing the risk of rear ejection, a new federal standard was implemented, which increased the strength and stiffness of seat backs. This has resulted in a dramatic 32% increase in the key spinal biomechanical responses, over a range of crash severities, with a shift from the 1980-1990s yielding seats to the new benchmark seats.[2]

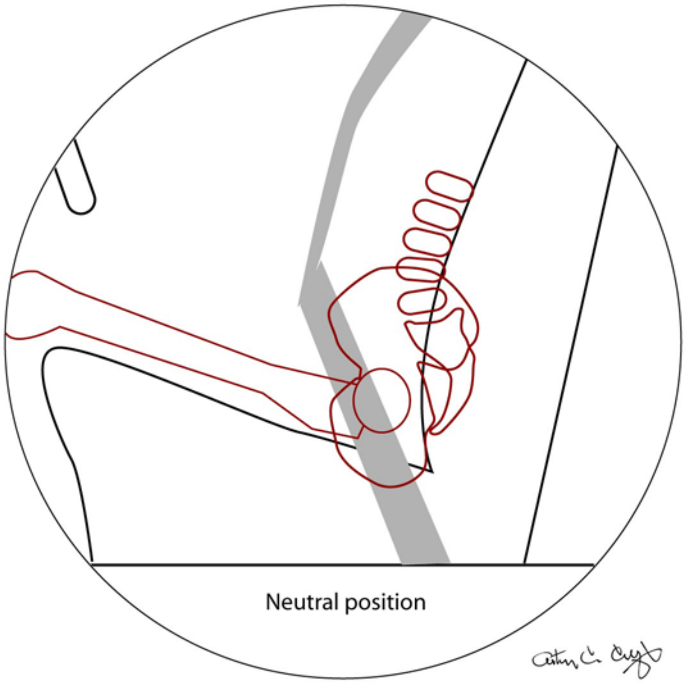

Figure 1. The neutral seated posture illustrating the normal lordotic lumbar curve (five lumbar vertebrae), the sacrum, the pelvis, and the femur. The seat belt and shoulder harness are illustrated in gray.

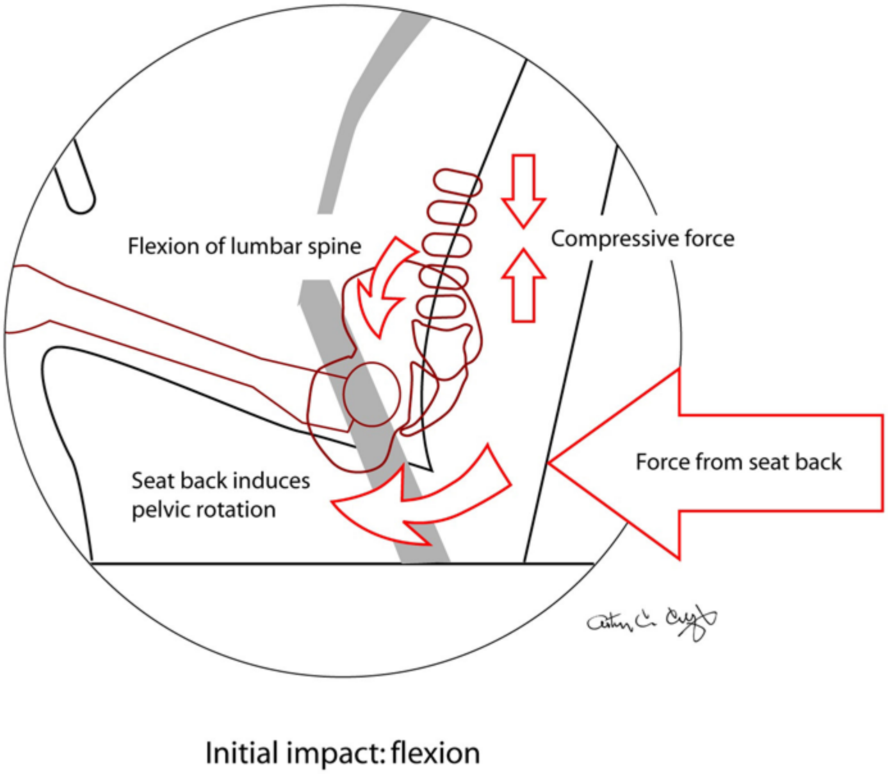

Figure 2. At the moment of rear impact, the lumbar curve is abruptly flattened as the pelvis rotates, and the spine is subjected to compressive loading. A flexion moment, or forward bending of the spine occurs.

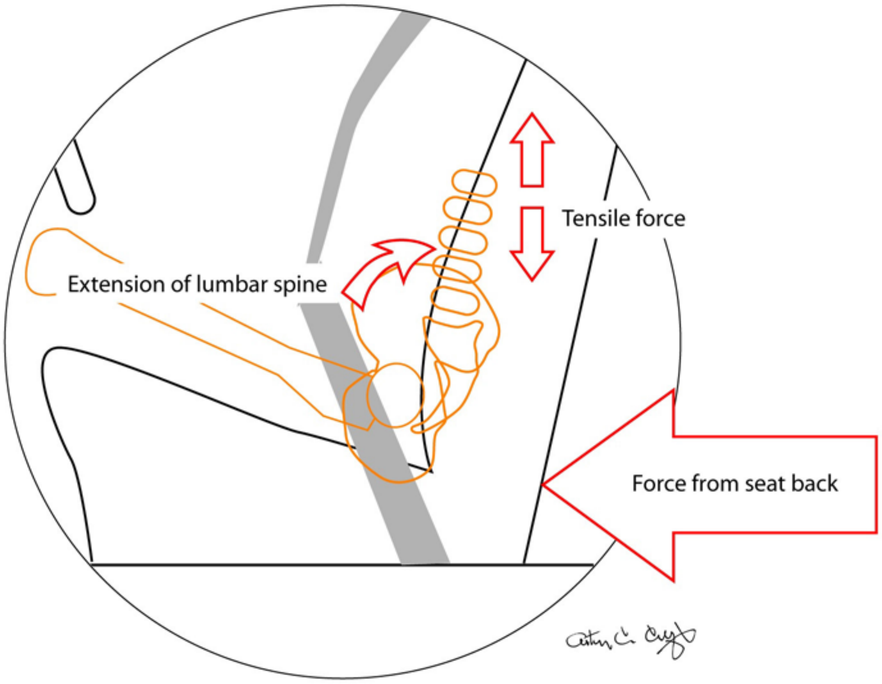

Figure 3. As the seat continues is forward motion, the lumbar spine undergoes extension (i.e., rearward bending). Compressive forces are replaced by tensile forces as the upward accelerating torso is restrained by the lap belt.

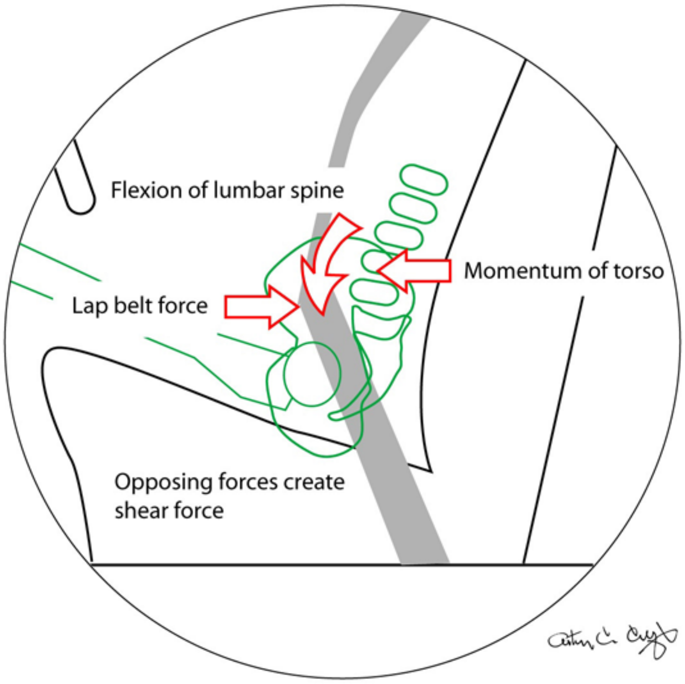

Figure 4. The second flexion moment of the spine occurs as the torso's inertia carries it forward and the pelvis is again restrained by the lap belt. This results in a horizontal shear force through the plane of the intervertebral discs.

Meanwhile, traditional designs featured horizontal braces at the level of the lumbar spine. These hastened the lumbar curve flattening and other biomechanical features illustrated in **Figures 1-4**.

The best seats today are the high retention seats with perimeter frame and compliant seat suspension that increase the flexibility of the seat trim, foam, and suspension hardware in the seat back. These are sometimes referred to as "catcher's mitt designs." This new high retention design features a strong rotational stiffness perimeter frame that pockets the pelvis and torso using seat trim and provides a seat stiffness and allows the maximal torso loads and head and neck loads to coincide, rather than having the torso load precede the neck load.[3] Seat stiffness, of course, is relative to occupant mass and inertia, and this may explain, in part, why the risk for spinal injury in females is approximately double that of males in low velocity crashes.[4]

Epidemiological and Clinical Data

While crash testing using humans and biofidelic crash test dummies, or cadavers, has provided us a great amount of biomechanical insight, these tests cannot be used to establish corridors for human tolerance to crash energy. To do so would require us to incrementally increase the crash energy until a substantial number of volunteers were injured and this would be highly unethical and a violation of the Helsinki Accord. Moreover, it would be impossible to replicate the myriad of real world crash conditions and broad subject variation. The best way to derive human tolerance levels and risk corridors is through observation of real world collisions. These *natural experiments* are part of the field known as trauma epidemiology. Since MVC and injuries are common, there is a large dataset available for this kind of analysis.

In both clinical and epidemiological studies, low back pain is quite common and is reported typically in 40-48% of all cases.[5-7] According to the Insurance Research Council (IRC),[8] personal injury protection (PIP) and bodily injury claims for cervical and lumbar injuries are the largest types resulting from MVC injury at 61% and 47%, respectively. One of the largest auto insurers in Sweden keeps records of all crashes in which property damage exceeds $4500US. To date, this database contains records of more than 25,000 crashes and 45,000 occupants.[9] In this database, injuries to the thoracic and lumbar spines are second only to cervical injuries.

Croft and Foreman[10] found low back pain (low back pain) in 57% of their whiplash cases (71% in broadside collisions). Braaf and Rosner[11] found low back pain in 42% of their cases. Hohl[12] found low back pain in 35% of his cases. Twenty-five percent of the patients in Hildingsson and Toolanen's study[13] had low back pain. In a prospective study, Gargan and Bannister[14] reported 32% of their group as having low back pain and an additional 10% developed low back pain as a late manifestation. This same percentage (32%) was found by Bring and Westman.[15] Magnússon[5] reported an incidence of 48% with low back pain. In their more recent follow-up of 35 patients followed for an average of 10.8 years, Watkinson et al.[16] found that, initially, 24% of the group complained of low back pain. Of these, 5% resolved later. However, after a 10.8 year mean follow-up, 34% complained of low back pain. It probably represents chronic postural adaptations to pain that, in most cases, developed later. Squires et al.[17] followed previously-studied patients[16,18] and reported a prevalence of back pain in half of this group after 15 years. More recently 40.5% of Brison et al.[6] group of rear-impacted subjects had low back pain at 24 month follow-up. And Jakobsson et al.[19] found thoracic and lumbar spine injuries second only to cervical injuries in rear impact crashes. In a recent study it was found that of those with neck pain following whiplash trauma, 43% of females and 31% of males also had back pain – a statistic found frequently in this literature.[7] In longitudinal studies of the management of whiplash injuries, thoracolumbar pain was reported in 47% of the patients[20] and low back pain in 43%.[21] In a recent study of whiplash injury in Spain, the proportion of victims complaining of neck pain was 100%, while 63.1% had low back pain.[22]

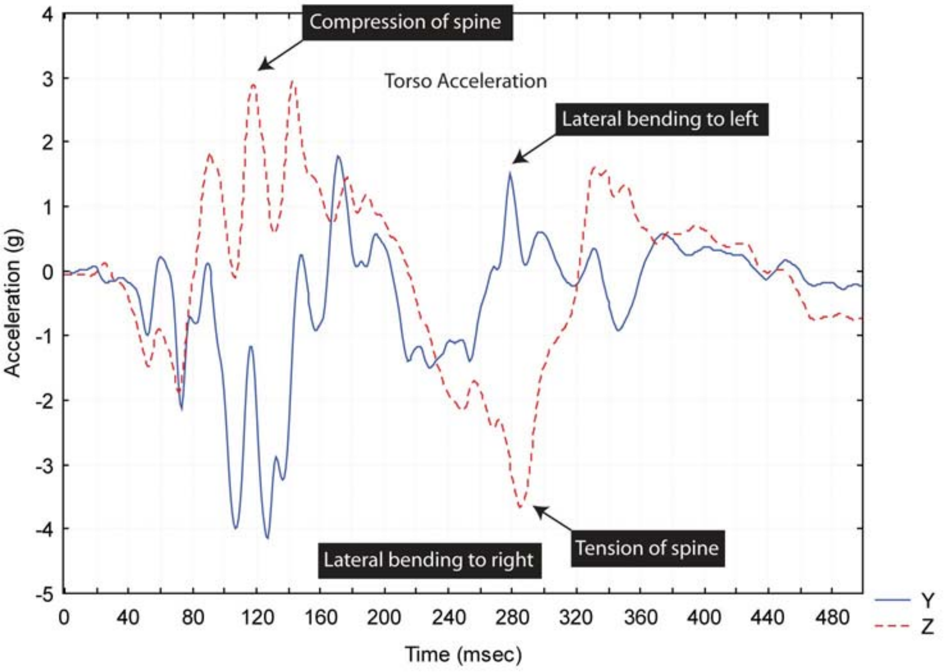

Figure 5. Acceleration-time history of female human subject volunteer in low velocity car-to-car, full scale crash. The point of impact was approximately 8:00 o'clock from the right side, mid-body. The net change of velocity for this vehicle was 7.6 mph. Property damage was minimal.

In a large epidemiological study in Sweden, which included 20,484 car occupants injured in crashes that occurred between 1995 and 2001, cervical spine soft tissue injuries comprised 65% and back injuries comprised 26%.[23] It is noteworthy that in studies of this kind, a proportion of patients are coded according to their primary complaint only, so the actual number of back injuries is probably underestimated. In a recent U.S. study, a series of real world crashes were carefully reconstructed, and clinical data from physician offices were tabulated. It was found that the average velocity change (i.e., delta V) for an injury-related rear impact collision was 3.97 mph.[24,25] Of the reported injuries, 23.3% were to the lumbosacral spine.

Summary

Contrary to popular belief, and perhaps contrary to what intuitive logic might recommend, rear impact collisions at relatively low and at moderate velocities can and often do result in lumbar and thoracic spine injuries. There is presently a large and compelling literature supporting this fact, while there is, to my knowledge, no sound scientific, epidemiological, or clinical peer-reviewed, indexed literature that has found otherwise.

While the precise mechanism of injury is not fully known at present, crash testing, such as that done at my institute and elsewhere, have allowed us to greatly refine the biomechanical models that offer the best biological plausibility.[26-33] The human spine is subjected to high levels of acceleration in two to three primary axes (x,y,z) depending on conditions, and rotation can occur around these axes. This six-degree-of-freedom complexity, occurring over a short time span of only 1/3 second, can result in overwhelming stresses and strains in spinal soft tissues including the discs, facet joint capsules and cartilage, and supportive ligaments. In that regard, viscoelasticity plays a pivotal role. ■

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