Biomechanics: a primer for motor vehicle collision injuries

A biomechanics primer for the plaintiff's attorney for rear, frontal, and side impacts.

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Recent data from the National Highway Traffic Safety Administration (NHTSA) indicates that there are about 2.7 million nonfatal injuries reported annually in the United States from motor vehicle collisions.[1] Biomechanics, for the purposes of this paper, is defined as how the various components of a biological system (human body) interact with mechanical forces during a crash event, thus producing occupant injuries. It is a study and analysis of the effects of external and internal forces on the human body and how these stresses produce movement or deformation of biological structures. Biomechanics is a field of study which utilizes the laws of physics and the human body's mechanics, including how muscles, tendons, ligaments, joints, other soft tissues, and bones react to collisions. As plaintiff attorneys, their experts and treating health-care providers have the burden of proof regarding injury causation, this article is focused on giving further insight into this arena.

One of the larger American databases of motor vehicle collision injury claims is published by the Insurance Research Council (IRC) which provides detailed survey analysis of more than 70,000 claims from 32 of the larger insurance carriers.[2] According to the IRC, 56 to 66 percent of all diagnoses given by health-care providers include neck strains/sprains; 49 to 56 percent back strains/sprains; 10 to 14 percent shoulder injuries; and eight to nine percent knee injuries. The following list covers a general breakdown of the more common and less frequent types of injuries along with acute or chronic post-traumatic conditions that this author has observed in practice including the review of many medical records and medical publications.

Common injuries

- Strains/Sprains of muscles, tendons, and ligaments are the most common injury type.
- Strain/Sprain injuries of the neck and back. The facet joint is the most common area for the cervical spine. Spinal instability is a common problem.
- Shoulder Injuries. Most shoulder injuries include rotator cuff tears and impingement syndromes. Clinical observations note most occur on outboard side; left shoulder for driver and right shoulder for front passenger.
- Knee injuries. Most occur from strikes on the dash, knee bolster, door panel, A-pillar, and center console.
- Contusions, lacerations, and abrasions
- Upper extremity injuries
- Facet joint injuries
- Sacroiliac and pelvic injuries
- Lower extremity injuries
- Disc injuries in the cervical and lumbar spine regions; including bulging, protrusions, or herniations. Many will have pre-existing degenerative changes noted.
- Traumatic brain injuries or concussions
- Chest wall and rib injuries (contusions, sprains, fractures)
- Fractures (vertebrae, skull, ribs, and upper and lower extremities)
- Internal organ injuries
- Seat-belt injuries
- Airbag injuries (burns, abrasions, contusions, and fractures)
- Steering wheel injuries
- Neck, thoracic, and lumbar pain
- Radiculopathy (nerve root) and referred pain from cervical and lumbar spine
- Headaches and migraines
- Myofascial pain and trigger points
- Thoracic outlet syndromes (primarily rear-end crashes)
- Psychological effects

Less frequent injuries

- Pregnancy-related injuries
- Jaw injuries or pain
- Breast or breast implant injuries
- Anosmia (smell disorders)
- Tinnitis (ringing in ear)
- Thoracic spine disc bulges or protrusions
- Spinal cord compression from disc protrusion
- Blurry vision
- Loss of taste
- Complex Regional Pain Syndrome (RSD)
- Carpal tunnel syndrome
- DeQuervain syndrome and Tenosynovitis
- Tremors
- Airbag propellant causing blurry vision and allergy-like symptoms

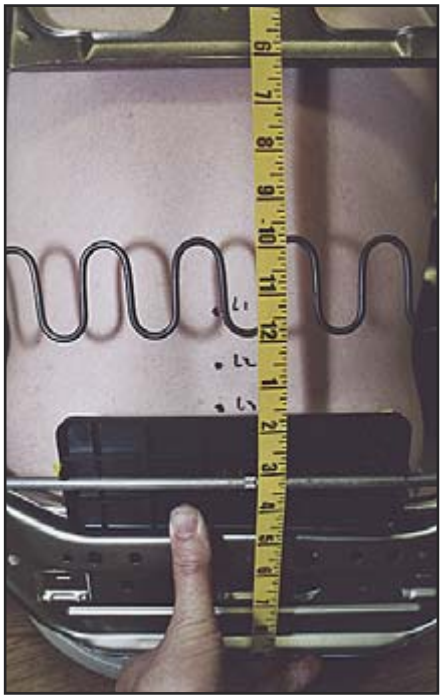
• Foot neuromas, plantar fascitis, hallux rigitis, and fractures
• Synovial cysts
• Fat necrosis from seat belts (breast-abdomen-pelvis)

How do injuries occur?

Injuries are typically produced from a combination of biomechanical stressors, including:
• Differential motion between body regions, e.g., the torso moving forward in a rear-end crash as the head lags behind.
• Direct contact with structures within the vehicle such as the seat belt, airbag, etc., resulting in contusions, lacerations, abrasions, strains, sprains, fractures, deformation, etc.
• Excessive movement (flexion, extension, rotation) of various tissues.
• Localized compression, tension, shear, and/or torsion in an area of the body.
• Time of the collision event. Short duration crashes are more likely to cause injury.
• Amount of force beyond human tolerance. Human tolerance is influenced by the state of the person's health, age, size, gender, etc.
• Muscular forces from bracing and/or responses to the collision.
• Startle responses. Some persons may overreact to the crash event by exhibiting excessive reactive movements. This may result in the person exhibiting greater motion than someone who does not startle as much.

Rear-end collisions: unique characteristics

The rear-end crash is unique because most neck injuries occur in low-speed impacts with decreasing frequency as the delta-Vs increase over 20 km/h. Neck and back injuries are in part due to occupant interaction with seatback and differential motion. Neck injuries appear in recent studies primarily from the facet joints colliding with each other as the neck flexes and extends. Lumbar and thoracic spine injuries



are felt to be due to biphasic motion as the normal spinal curves flatten as the torso sinks into the seat cushion. In addition, the dorsolumbar spine elongates or lengthens in the early stages of the impact. The author has had a couple of recent cases of one-level thoracic disc protrusions that upon investigation of the seat frame with the plaintiff seated in the seat, have found metal bars at the same area acting as loading areas and the cause of the protrusions. The photo above shows a case having a L5-S1 disc protrusion from the lumbar support. The bar holding the black support was bent proving a loading area in this region. The original seat was taken apart and compared to a new seat frame.

Frontal crashes: unique characteristics

Frontal impacts typically involve the occupant moving forward (inertia) at the same speed as the vehicle the occupant is seated in during the crash. Many injuries involve direct contacts with the vehicle interior as well as interaction with the seat belts, airbags, and steering wheel. Contusions, lacerations, abrasions, fractures and internal organ injuries are commonly observed in higher speed crashes. Strains and sprains of the spine and extremities are still common but generally take higher delta-Vs to cause injury than observed in either rear or side impacts. Airbag deployment may result in arm and hand abrasions, burns, and fractures. Driver interaction with steering wheels in vehicles without airbag deployment may result in serious chest and abdominal injuries.

Side crashes: unique characteristics

Side or lateral impacts may produce direct contacts and loading from the bullet vehicle. With only about 10-12 inches between a person's body and the outer portion of the side door and the front end of the bullet vehicle, there is little structure to absorb crash energy and crush. These impacts may result in serious head, shoulder, extremity, torso, and pelvic injuries from door intrusion or direct impacts with the bullet vehicle. Side airbags have been shown to mitigate serious injuries in many instances for adults, however, small children may have more severe injuries depending upon seating position and physical characteristics.

Multiple impacts

When an initial motor vehicle crash occurs and a second collision occurs with another vehicle or structure, the first impact may result in the occupant being in less than optimal seated position for the second crash. For example, after a rear impact the occupant's upper body rebounds forward and the person's head is next to the airbag ejection port when the vehicle strikes another vehicle in front and the airbag deploys. The airbag deployment may result in serious injury due to its proximity to the port.

Injury causation challenges

Medical or injury causation may be challenged by the insurance carrier and

their biomechanics expert. In most instances the defense biomechanist will not request to personally observe and measure the seated position of the plaintiff in the vehicle they were seated in at the time of the crash and yet they often calculate *accurate* acceleration levels and *absolute* injury risks.

Lee et al., concluded,

> In the biomechanical analysis of injury causation, a "one size fits all" approach is often adopted, which usually fails to consider individual-specific (i.e., age, sex, preexisting conditions, etc) and incident-specific (i.e., force/time history, occupant positioning, seat geometry, etc.) information.[3]

In cases where injury causation may be challenged at a later date, or has already been denied, the plaintiff's attorney needs to focus on establishing a likely mechanism for all claimed injuries, evaluate if there was a reasonable time frame for the onset of the injury or related symptoms in the medical records, and determine if there were other likely explanations for the injury or symptoms relative to the collision. The treating doctors may be contacted to determine if they believe the injuries are related to the crash. If surgery has been performed, the surgeon is the only person who actually visualized the bulging disc, rotator cuff tear, or other conditions. The surgeon should be asked if the tissue appeared to be of traumatic origins or from pre-existing degenerative changes.

If there are causation questions, the attorney may also consult with a biomechanist to get some direction as to what to look for in the police report or medical records which might be able to clarify various issues.

Remember that a biomechanist is limited in his or her opinions. Members of this profession have no license to give diagnostic or medical causation opinions so giving an opinion of this type requires a licensed physician, dentist, chiropractor, podiatrist, etc. As a result, the attorney may require opinions from the treating doctors or other experts.

What is important about seating position of the plaintiff?

Personal preferences and physical characteristics of drivers and passengers relate to how they position their seat, wear their seat belts, and position their body within the vehicle. Some prefer the seat forward, backward, more vertical or horizontal thus changing the distance between various components of the vehicle and their body. Some sit with their legs crossed, legs straight ahead, or legs spread apart thus changing proximity to side and front vehicle structures.

Seat belts do not fit every person in an optimal fashion. In some instances the shoulder harness in smaller occupants may be positioned against the neck which may cause high loading in the cervical spine. Arm positions at the time of impact, on and off the wheel, and at various positions may lead to arm and shoulder injuries and more severe injuries with airbag deployments. If the person is reaching for something with his or her arms in the rear seat, the person may have shoulder injuries. High-heeled shoes will position the ankle joint downward which may lead to more severe foot injuries.

Out-of-position occupants, or persons who are not seated in a straight forward position, are more likely to incur injury and may have more severe injuries. For example, if the driver has his or her head turned far to the left to see oncoming traffic and is struck in the rear, the ligaments in the neck will be pre-tensed leading to greater strain in the cervical spine. If an occupant is leaning forward, there will be a larger gap behind the person's back leading to higher acceleration levels in rear impacts and likewise, in frontal crashes, the person's head may be next to the dash thus increasing the risk of head injury.

Human tolerance variables

The literature shows that there are many human variables regarding human tolerance to collision events. Occupant age, size, weight, and physical state of health are some of the factors that have been shown to affect injury risk and severity. Degenerative musculoskeletal diseases, autoimmune disorders, previous injuries, prior surgeries, diabetes, and other disorders will lower the injury threshold and may hinder recovery depending upon its severity. The plaintiff's attorney can ask the treating doctors if there were any human tolerance issues.

Setting your priorities with new cases

From a priority perspective, the first area of biomechanical interest is attempting to understand how plaintiff injuries occurred by determining out what type of crash (rear, frontal, side impact) occurred, and if the plaintiff was the driver or passenger. Secondly, determine if the plaintiff was wearing a seatbelt, if an airbag deployed, if there were any secondary crashes, and if the plaintiff was seated in a normal position or out-of-position; that is, leaning forward, body turned, or in other positions.

A brief review of the ambulance/fire department and emergency room notes often give clues as to the injury mechanisms, e.g., bruising and lacerations. Radiographic findings may also assist in the analysis. The author recommends that the attorney asks the plaintiff to sit down and hand over two or three model vehicles. At that point, the plaintiff should describe the crash event and how he or she was seated and how the individual's body moved during the crash.

What does the attorney need relative to the vehicles?

For biomechanical purposes, vehicle motion during and after the crash determines occupant motion. Getting the po-

lice report, if available, is the first priority. If the crash is recent, obtaining photographs of the scene and locating all involved vehicles in order to get photographs is the next priority. If there are mid-1990s and newer Fords and Chevrolet vehicles involved in the crash, the attorney may be able to download data from the "Black Box" or Event Data Recorder and determine the impact speeds and duration. The data may be lost if the vehicle is involved in another crash or if there is a delay in getting the download if the vehicle is being driven. The attorney can always contact a reconstructionist to see if the data from a specific vehicle can be downloaded. Permission from the owner of the vehicle is required before this data can be retrieved and a "Chain of Custody" needs to be maintained. Getting recorded statements, witness statements, and deposition statements are generally next because there may be added information in these records.

What does the attorney need relevant to injuries?

Having a plaintiff's family member or friend take photographs of abrasions, lacerations, swelling, and bruises before they disappear is important for objective evidence or proof of an injury. In an ideal situation, a biomechanist would take photographs of the plaintiff seated in the same vehicle and take photographs that reproduce the position of the person immediately prior to the crash relative to the interior, seat belt, head restraint, steering wheel, etc. If the seat, steering wheel, dash, knee bolster, or other parts of the interior of the vehicle are damaged or repaired, be certain to take photographs and save the parts. The plaintiff needs to save all of the vehicle parts in a manner that prevents further damage or weather/water damage.

I remember one of my most exciting cases when I was asked to resolve a pelvic injury dispute from a side impact. Fortunately, the plaintiff had kept the totaled vehicle covered at home, and when I looked at the interior of her vehicle, I was able to see the door and leather seat compression marks from the red dye in her pants that she was wearing at the time of the crash where the thigh and pelvis was compressed when the door intruded against her body.

What is the role of the biomechanical expert?

The biomechanist may be asked to give opinions as to the forces of a collision event, occupant movement, acceleration levels, and likelihood of occupant injuries. Biomechanists rely on the change of velocity, impact duration, the direction of the impact(s) and the post-crash movement of the respective vehicles given by a traffic accident reconstructionist when analyzing a case. Analysis of the police report, crash diagram, emergency room and medical records, radiographic reports, and specific diagnosis as well as statements given in depositions, recorded statements, and interrogatories follow next. The focus is generally on what happened during and after the crash, occupant positioning, airbag deployments, contact areas, external evidence of bruising, contusion, and lacerations. This information, along with other biomechanical data and experience, is used to determine occupant kinematics, contact points, and acceleration levels or loading forces.

Comparing collision severity to published human tolerance levels is generally the next stage in the analysis. Various tolerance standards may be contrasted between the analysis of the collision event and the various injuries or diagnoses given by the various health-care providers.

There are several publications that list human tolerance levels for various regions of the body, such as J885 published by the Society of Automotive Engineers in 1986.[4] The attorney needs to keep in mind that many of the tolerance tests that are still considered standards in the biomechanical community today were performed before MRI scans and newer types of imaging technology were present. Many standards have relied on animal and cadaver studies that were published in the 1960s and '70s. Therefore newer studies may need to be considered in some cases, particularly with soft tissue and brain injuries.

Trivializing plaintiff's injuries?

Biomechanical opinions, from defense and plaintiff experts, may be in agreement in some cases. Some challenges may have validity and may include significant delays in the onset of symptoms or treatment, poor medical records, incorrect diagnosis, inconsistent testimony, previous medical history, and lack of objective findings. Some defense experts attempt to trivialize the collision severity by comparing the forces experienced by persons during activities of daily living (e.g., flopping into a chair) to those forces sustained during the crash event. This approach may be misleading if the plaintiff is not a stunt driver. Unless the direction, time, and forces are similar to that of the crash event it has little if any validity.[5]

Another common approach is to utilize published post-crash injury and symptom data from human crash subjects to illustrate that plaintiffs are unlikely to incur more than minor soreness lasting for only a couple of days. One must remember that persons who volunteer to be subjected to crash tests may not represent the general population or the plaintiff. There may not be enough data to a specific age and gender as well. For example, over the past 50 years of human testing only about10 females over the age of 40 have been tested in rear impacts.[6]

Playing the waiting game

Some plaintiff attorneys wait until the plaintiff's case has concluded before requesting medical records and seriously

evaluating the file. This approach may result in the attorney finding out that the case has major problems. In some instances significant pre-crash history and traumatic events after the crash have been overlooked or were unknown. It makes no sense to wait several months before investigating the medical records. The majority of defense cases that I have worked on in the past have had significant issues that would have resulted in settlement had the plaintiff's attorney recognized the problems earlier.

Case preparation

As soon as the plaintiff attorney accepts a case, injury causation research should be initiated with formal requests for all pertinent medical records, location of all vehicles, and all objective data such as photographs of the visible injuries and damage to the vehicles. This begins with getting the police report, getting photographs of the respective vehicles; photographing any bruises, lacerations, and physical evidence of trauma; obtaining witness statements early along with all medical records beginning with the fire department/EMS services.

If there are any previous medical issues relevant to the case, submit requests for copies. With current HIPAA laws, it is easier for the plaintiff to get copies of his/her records than for the attorney. Once the records have been received, it is important to review them to be certain they are complete.

If the vehicles have not been repaired, it is important to get photographs before any repair is initiated and during the repair process. Once the bumpers and outer parts of the vehicles have been removed, there may be additional evidence of crush or deformation. Second repair estimates are occasionally produced. If defendant/plaintiff vehicles have been totaled, the vehicles will disappear typically in one to two days, and many vehicles will not be photographed unless the attorney initiates it. If the plaintiff's vehicle is available, have photos taken with the person seated within the vehicle, with instructions to assume the position in which he/she was seated just immediately prior to the impact. Placing a tape measure in front or side of the plaintiff's head, shoulders, chest, knees, and any other injured areas will assist a biomechanist if the case goes into litigation.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