When Driver Safety Fails – Then What?
Vehicular Accident Analysis: The Big Picture

Low-speed Impact Analysis

Michael L. Markushewski, B.S.
David Gushue, Ph.D.
Bradley Probst, M.S.
Charles Coward, M.D, M.S.
ARCCA, Incorporated
Penns Park, PA

Abstract

When a low speed crash occurs between two vehicles, evaluation of the conditions of the crash, assessment of fault, determination of velocity change, or calculation of forces and accelerations acting on the vehicles and the occupants may be required. After engineering and biomechanical analysis of the crash has been completed, the force levels generated in the particular crash may not appear to agree with the nature and severity of the claimed injuries.

The applied vehicle forces that occur during impact between two vehicles are governed by the laws of physics. Crash injury protection is governed by known and established human tolerance values to both inertial and impact forces and restraint system design. This paper will focus on the fundamental methods of analysis for the low-speed impact. The first step will consider analysis of the actual mishap itself, and the analytical methods for quantifying the force levels applied to the vehicle during the crash. The second part will evaluate the reported injuries from an occupant protection and biomechanical approach.

Introduction

There are times when it becomes necessary to identify the mechanism of the injuries claimed to be caused by a low-speed impact. This may be required because the claimed injuries do not appear to conform to the physics of the actual impact. Risk managers, safety, claims, and loss prevention professionals deal with property damage and bodily injury claims routinely which are alleged to have resulted from low-speed vehicle collisions. In some cases the claimed injuries do not comport with the description of the accident.

The applied vehicle forces during any impact are governed by the laws of physics. Crash injury protection is governed by known and established human tolerance values to both inertial and impact forces and restraint system design. For an injury to occur requires both, 1) a magnitude of force that exceeds human tolerance, 2) and a mechanism known to produce injury.[1] This paper will focus on the fundamental method of analysis of the low-speed impact. The first step will consider analysis of the actual mishap itself, and the analytical methods for quantifying the force levels applied to the occupants during the impact. The second step will be to conduct a biomechanical analysis of the specific injuries to determine whether there was an injury mechanism present during the subject impact.

Step 1. Accident Reconstruction

For the purposes of this paper, a low-speed impact will be classified as an impact at or below a 10 mph change in velocity (delta-V). Oftentimes the crash speeds are much lower than this value. In fact, in many low-speed impacts, the damage cited is in the form of scratches, scrapes, or minor deformation. Underlying damage beneath the scratches and scrapes is minimal, with deformed brackets, shock isolators, bumper bars or foam being cited as the main items needing repair or replacement. The majority of low-speed impacts are typically drive-away accidents. Common accident reconstruction methods and techniques cannot always be used. Oftentimes there is no, or little, measurable crush to the mishap vehicles. Given the lack of significant crush, the traditional method of using computational computer programs such as EDSMAC™ or EDCRASH™ for speed change specific to that vehicle cannot be used reliably at speeds below 10 mph.[2] The force required to crush or crumple metal requires a certain amount of energy, and the energy required is used to calculate speed change through the use of crush coefficients. When there is no measurable crush depth, computer programs such as these cannot and do not provide reliable results. Since an impact did occur, transfer of energy must be present; therefore, another technique is required to calculate the actual speed change during the impact, and ultimately, the acceleration levels present in the occupant space. Two approaches are presented here. The first approach will be demonstrated with the case example shown below. The vehicle in question sustained damage to the rear bumper cover during a rear impact. The damage is in the form of scratches in the paint on the bumper cover. The underlying damage consisted of a deformed left rear bumper reinforcement bracket. The level of damage to the vehicles is consistent with low-speed contact between the vehicles. This is consistent with the scratches being concentrated on the left corner of the bumper. This assessment was conducted by analysis of vehicle photographs which clearly show the location and nature of the damage, and analysis of the repair records for the vehicle which show the repairs were limited to repaint of the rear bumper cover, and replacement of the left rear bumper reinforcement bracket. The information was used to determine speed change during the impact.[3]

Force-Deflection Analysis

Since the transmission of impact energy is concentrated to the face bar and bumper support bracket or shock isolator, the question becomes; how much force is required to deform the bumper brackets? One empirical approach often used is to obtain an exemplar, undeformed bumper bracket and subject it to a test that can determine the force-deflection characteristics under load. Once obtained, the data

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[1] Eiband, A.M. (1959). Human Tolerance To Rapidly Applied Accelerations: A Summary Of The Literature. NASA Memorandum 5-19-59E, National Aeronautics and Space Administration, Washington, DC, June 1959.

[2] *EDSMAC*™ is an analysis program for single- or two-vehicle impacts. Based on the SMAC model originally developed at Calspan. E*DCRASH*™ is a reconstruction analysis program of single- or two-vehicle impacts. Based on the CRASH model developed at Calspan and extended by NHTSA. *EDCRASH* primary purpose is to determine impact speed and delta-V based on accident site and vehicle damage measurements, Engineering Dynamics Corporation.

[3] Siegmund, G.P., et al., (1996). Using Barrier Impact Data to Determine Speed Change in Aligned, Low-Speed Vehicle-to-Vehicle Collisions (SAE 960887). Warrendale, PA, Society of Automotive Engineers.

can then be used to determine the acceleration levels applied to the vehicle. The approach is shown below.

1. Empirically determine the force required to permanently deform a single bumper bracket throughout its entire stroking distance to give a Force-Deflection characteristic for the bumper bracket (F-D).

2. Determine damage to subject vehicle through photographic analysis, collision repair estimate information or inspection of the subject vehicle. For this analysis assume one bumper support bracket needed replacement because of impact deformation.

3. Compare damage from the exemplar bracket testing to actual damaged components.

4. Determine weight of subject vehicle and occupants and cargo.

5. Given a single bumper bracket is deformed, calculate: Total Weight / peak (F-D) to determine accelerations applied to the vehicle.

This approach will provide an upper bound or a conservative estimate since the empirical test data for the calculation is using the entire load carrying capability of the bumper support bracket when the actual damage to the subject vehicle may show the bumper bracket is not completely stroked. This approach is useful for directly calculating acceleration applied to the vehicle. If additional information is required to quantify the speed at impact, the following approach also works well.

Damage Threshold Speed Change Analysis

Another approach is analysis of test data from previously conducted impact tests on the subject vehicle, or an acceptable sister vehicle. Common sources for test data include the National Highway Traffic Safety Administration (NHTSA) tests. Crash tests are routinely conducted every year on cars sold in the U.S. The data collected from those tests include, among other things, crush coefficients for each vehicle tested. The crush coefficients can be used to assist the engineer in calculation of speed change based upon Conservation of Energy. This technique only applies to vehicles that actually have crush to metal or deformed body panels.

If no body crush occurs, as is commonly the case in low-speed impacts, another method that produces scientifically valid results is the use of Insurance Institute for Highway Safety (IIHS) test data. The IIHS routinely conducts low-speed tests for bumper strength evaluation. The test vehicle is impacted into various barrier types and impact directions at 5 mph impact velocity. The pre-impact speed of 5 mph added to the rebound velocity specific to the tested vehicle will provide the total delta-V of the impact. After each test, the IIHS documents the bumper components that become damaged from the impact. Typically the damage consists of deformed bumper brackets or shock isolators, or a deformed bumper face bar in area of impact. This information becomes useful empirical evidence of the damage that results from a 5 mph crash. Comparison and analysis of components replaced or repaired after the real-world crash to the IIHS test vehicle can be used to classify the impact speed and quantitatively determine the acceleration. If the bumper brackets or bumper face bar are not shown to be damaged or replaced on the damage appraisal and vehicle repair estimate from the real-world impact, it can be assumed there was not enough impact energy to permanently deform those components. Therefore, the crash can be categorized as one which did not transfer as much energy during the impact as the IIHS test exemplar. Less energy transfer equates to a lower impact speed than the staged IIHS testing. This approach permits a damage threshold speed change analysis and not a calculation of the specific delta-v for the impact. However this approach is very useful to quantify impact velocities relative to the IIHS testing.

While this analysis technique uses the results of staged low-speed impact tests to categorize the velocity change as greater than, or less than the IIHS test for a particular vehicle, most importantly for injury analysis, the accelerations produced during the subject incident can be calculated.[4] A typical acceleration-time profile for a low-speed automobile impact approximates a haversine in shape with a duration of approximately 200 milliseconds.[5] The change in velocity from the impact is equivalent to the acceleration multiplied by the time of the event. By knowing the time of the impact event, the acceleration produced from the impact can be calculated by the following formula. It should be noted that the area under the curve for a triangular waveform is mathematically equivalent to area under the curve for a haversine.

$$\Delta V = at/2 \text{ therefore, } a = (2\Delta t)/2$$

For a given 5 mph impact, the acceleration produced is 2.3 g.

For a biomechanical analysis, the accelerations applied to the occupant space are far more critical to determine injury potential than the actual delta-V of the impact. This is because human tolerance to injury is not velocity related but rather is acceleration based.

The National Highway Traffic Safety Administration (NHTSA) also conducts bumper impact testing under Federal Motor Vehicle Safety Standard Number 215 "Exterior Protection." The original standard issued for 1973 passenger cars required the car bumper to withstand 5 mph front and 2 ½ mph rear impacts against a perpendicular barrier without damage to certain safety-related components such as headlamps and fuel system components. However revisions to the bumper standard took place in May 14, 1982, effective for model year 1983 and subsequent model year passenger cars. This amendment ***reduced*** test impact speeds from 5 mph to 2.5 mph for longitudinal front and rear barrier and pendulum impacts and from 3 mph to 1.5 mph for corner pendulum impacts. The NHTSA data collected is not as comprehensive as the IIHS data. Therefore IIHS data is the preferred choice for this type of analysis.

Step 2. Biomechanical Analysis

By conducting a biomechanical[6] analysis of the events and injuries, an experienced biomechanical engineer can explore and investigate whether there was an injury mechanism present in this event that could have caused the claimed injuries. An example case study is shown below.

According to the Police Accident Report and other available documents, Mr. Jones was sole occupant of the vehicle and wearing the available seat belt in a 1986 Honda Accord that was traveling on Main Street at the intersection with Broad Street in Anywhere, USA. According to the facts available, shortly after the subject Honda Accord came to a stop for a traffic signal at the intersection at Broad Street, the front of an another vehicle struck the rear of the subject Honda Accord. According to the Police Accident Report the other vehicle left the scene of the incident. According to the Police Accident Report, the 1986 Honda Accord was driven from the scene.

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4 West, D. H., J. P. Gough, et al. (1993). "Low Speed Rear-End Collision Testing Using Human Subjects." Accident Reconstruction Journal.

5 Anderson, R.A., W.J.B., et al. (1998). Effect of Braking on Human Occupant and Vehicle Kinematics in Low Speed Rear-end Collisions (SAE 980298). Warrendale, PA, Society of Automotive Engineers.

6 Biomechanics definition: The study of the mechanics of a living body, especially of the forces exerted by muscles and gravity on the skeletal structure. The free dictionary.com. By education, a mechanical engineer (usually) with advanced education in human anatomy, physiology, tolerance of biological tissue, physics, neuroscience, kinematics, dynamics and engineering.

In the course of the analysis, the Police Report and the medical records pertaining to Mr. Jones were reviewed. In addition, repair records and estimates for the 1986 Honda accord were analyzed. Furthermore, photographs were provided which showed minor scratches and damage to the rear of the vehicle.

Reported Injuries of Mr. Jones:

Based on his medical records, Mr. Jones was diagnosed with the following injuries which he alleged were a result of the subject incident:

Cervical spine injuries

- C6-C7 disc herniation

Left shoulder injuries

- tear of the supraspinatus tendon
- superior labrum anterior-posterior (SLAP) tear

Right shoulder injuries

- tear of the supraspinatus tendon
- partial tear of the subscapularis tendon
- superior tear of the labrum

Lumbar spine injuries

- L1-L2 disc herniation
- L4-L5 disc bulge

An energy based crush analysis was used to determine the severity of the subject incident. The repair estimate of the subject 1986 Honda Accord was analyzed. The Police Accident Report indicates that subject incident was a rear impact to the subject Honda. In addition, the Police Accident Report indicates that the primary point of impact to the subject Honda Accord was to the rear, while the primary point of impact to the other vehicle was to the front of the vehicle. The repair estimate for the subject Honda Accord indicated that the primary damage due to the subject incident was to the rear bumper assembly. There is no indication of damage to the trunk or surrounding structure.

An engineering damage-based EDCRASH analysis[7] indicates that a single 10-mile-per-hour impact to the rear of a 1986 Honda Accord would result in significant and visibly noticeable crush to the rear of the Honda, with a maximum residual crush of 5.75 inches. Therefore, the engineering analysis shows significantly greater deformation would occur in a 10-mile-per-hour impact than that indicated by the repair records of the subject vehicle. The lack of significant rear-end structural crush to the 1986 Honda Accord therefore indicates that the subject incident is consistent with a collision resulting in a impact speed of less than 10 miles per hour.

Assuming an acceleration pulse with the shape of a haversine, with a duration of impact of 200 milliseconds, the peak acceleration associated with a 10-mile-per-hour impact is 4.53g. The average acceleration associated with this same impact is 2.3g.

The acceleration experienced due to gravity is 1g, which means that Mr. Jones's body experiences 1g of loading while in a sedentary state. Any motion or lifting of objects by Mr. Jones in his daily life would have increased the loading to his body beyond the sedentary 1g. Therefore, he experiences an

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7 E*DSMAC*™ is an analysis program for single- or two-vehicle impacts. Based on the SMAC model originally developed at Calspan. E*DCRASH*™ is a reconstruction analysis program of single- or two-vehicle impacts. Based on the CRASH model developed at Calspan and extended by NHTSA. *EDCRASH* primary purpose is to determine impact speed and delta-V based on accident site and vehicle damage measurements, Engineering Dynamics Corporation.

essentially equivalent acceleration on a daily basis while in a non-sedentary state as compared to the subject incident. The joints of the human body are regularly and repeatedly subjected to a wide range of forces during daily activities. Almost any movements beyond a sedentary state can result in short duration joint forces of multiple times an individual's body weight. Events, such as slowly climbing stairs, standing on one leg, or rising from a chair, are capable of such forces.[8] More dynamic events, such as running, jumping, or horseback riding, can increase short duration joint load to as much as ten to twenty times body weight.

Kinematic Analysis

The Police Accident Report and other available documents indicate that, at the time of the incident, Mr. Jones was 50 years of age, 67 inches in height, and weighed approximately 165 pounds. In addition, these documents indicate that Mr. Jones was wearing the available seat belt restraint system.

Using the fundamental laws of physics, as well as the engineering analysis of occupant restraint systems from numerous collisions, crash tests, and sled tests, the subject 1986 Honda Accord's occupant kinematic patterns can be determined. The laws of physics dictate that, when the other vehicle contacted the rear of the Honda Accord, had there been enough energy transferred to initiate motion; the Honda would have been pushed forward. This action would have caused Mr. Jones's seat to move forward relative to his body, which would have resulted in Mr. Jones moving rearward relative to the interior of the vehicle. This interaction between Mr. Jones and the vehicle interior would cause his body to load into the seat back structure and head restraint. Specifically, his head would move back toward the head restraint and his torso and pelvis would settle back into the seat back. The low accelerations resulting from the subject incident would have caused little, or no, forward rebound of Mr. Jones's body away from his seat back.[9,10,11,12] Any rebound that may have occurred would have been limited by the available restraint system. The low accelerations in the subject incident and the restraint provided by the seat back and seat belt system, then, were such that any motion of Mr. Jones would have been limited to well within the range of normal physiological limits.

From a biomechanical perspective, causation between an alleged incident and a claimed injury is determined by addressing two issues or questions:

1. Did the subject incident load the body in a manner known to cause damage to a body part? That is, did the subject event create a known injury mechanism?
2. If an injury mechanism was present, did the subject event load the body with sufficient magnitude to exceed the tolerance or strength of the specific body part? That is, did the event create a force sufficiently large to cause damage to the tissue?

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8 Mow, V. C. and W. C. Hayes (1991). Basic Orthopaedic Biomechanics. New York, Raven Press.

9 Cantor, A., Markushewski, M.L., et al, (2005) The Risk Benefit Analysis of Seating System Design, When Driver Safety Fails – Then What?, Session No. 725, Safety 2005, American Society of Safety Engineers

10 Saczalski, K., S. Syson, et al. (1993). Field Accident Evaluations and Experimental Study of Seat Back Performance Relative to Rear-Impact Occupant Protection (SAE 930346). Warrendale, PA, Society of Automotive Engineers.

11 Comments on Docket 89-20, Notice 1 Concerning Standards 207, 208 and 209, Mercedes-Benz of North America, Inc., December 7, 1989.

12 Tencer, A.F., S. Mirza, et al. (2004). "A Comparison of Injury Criteria Used in Evaluating Seats for Whiplash Protection." Traffic Injury Protection 5(1): 55-66.

If both the injury mechanism was present and the applied loads approached or exceeded the tolerance of the effected body part, then a causal relationship between the subject incident and the claimed injuries cannot be ruled out. If, however, the injury mechanism was not present or the applied loads were small compared to the strength of the effected tissue, then a causal relationship between the subject incident and the injuries cannot be made.

The question at issue here is whether the subject incident, as described by the vehicle and occupant kinematics above, created any of the mechanisms required to cause the injuries alleged by Mr. Jones. This question will be addressed below.

Cervical Injuries

Damage or injury to cervical intervertebral discs occurs when an environment creates both a mechanism for injury and a force magnitude sufficient to exceed the strength capacity of the disc. Disc injury can result from chronic degeneration of the disc itself or from acute insult; that is, a single event where forces are applied to the disc at magnitudes beyond its capacity or strength. Damage (injury) to the disc in the form of bulging or herniation can result. Based upon previous research, the accepted mechanism for acute intervertebral disc herniation involves a combination of hyperflexion or hyperextension and lateral bending with an application of a sudden compressive load.[13]

There is no reason to assume that the claimed cervical spine injuries are causally related to the subject incident. In a rear impact that produces motion of the vehicle, the Honda Accord would be pushed forward and Mr. Jones would have moved rearward relative to the vehicle, until his motion was halted by the seat back. Examination of an exemplar 1986 Honda Accord showed that the nominal seat back height with an unoccupied, uncompressed seat is 29.5 inches with the headrest in the full down position. The seat back height is approximately 31.5 inches with the headrest in the full up position. In addition, the seat bottom cushion will compress approximately two inches under the load of an occupant. Based on an anthropometric regression of Mr. Jones's age (50 years), height (67 inches) and weight (165 lbs), Mr. Jones has a normal seated height of 33.5inches. Therefore, the seat is tall enough to have prevented hyperextension of Mr. Jones's neck in the subject event. One would not expect to see anything more than minor transient neck stiffness and soreness due to the minor nature of this incident. With minimal accelerations and extension motions of the neck within the normal physiological range, one would not expect acute, traumatic injuries to the intervertebral discs of the cervical spine.

West et al. subjected five volunteers, aged 25 to 43 years, to multiple rear-end impacts with reported barrier equivalent velocities ranging from approximately 2.5 mph to 8 mph.[14] The only symptoms reported in the study were minor neck pains for two volunteers which lasted for one to two days. The authors indicated that these symptoms were the likely result of multiple impact tests. In a study documented in the European Spine Journal, fourteen male volunteers (aged 28-47 years) and five female volunteers (aged 26-37 years) participated in 17 rear-end type vehicle collisions.[15] The range of velocity change (delta-V) in the collisions was 5.2mph to 8.8mph. The range of mean accelerations experienced by the vehicles was 2.1g to 3.6g. Compare this to the average vehicle acceleration in the subject incident of less than 2.3g. In testing that simulated an automobile collision environment,

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13 White III, A. A. and M. M. Panjabi (1990). Clinical Biomechanics of the Spine. Philadelphia, J.B. Lippincott Company.

14 West, D. H., J. P. Gough, et al. (1993). "Low Speed Rear-End Collision Testing Using Human Subjects." Accident Reconstruction Journal.

15 Castro, W.H.M., Schilgen, M., Meyer S., Weber M., Peuker, C., and Wortler, K. (1997) "Do "whiplash injuries" occur in low-speed rear impacts?" European Spine Journal 6:366-375.

Mertz and Patrick subjected a volunteer to multiple rear-end impacts, both with and without a head restraint.[16] The authors subjected the volunteer to rear-end collisions with a peak acceleration of 17g in the presence of a head restraint, without the production or onset of severe cervical injury. In addition, well-supported live human subjects have regularly been exposed to g levels up to approximately 40g with no acute trauma during rear impacts.[17] The above research describes the response of human volunteers subjected to rear end impacts of greater severity than that experienced by Mr. Jones in the subject incident. The impact of the subject incident had an average acceleration at or below 2.3g. Mr. Jones's cervical spine would not have been exposed to any loading or motion outside of sufficient severity to cause intervertebral disc herniation.

Based upon the review of the available incident data and the results cited in the technical literature as described above, the subject incident created accelerations that were well within the limits of human tolerance and were comparable to a range typically seen during normal, daily activities. Nor did the event create the compression/bending loading mechanism required to acutely injure a cervical disc. As this crash event did not create the required injury mechanism and did not create forces that exceeded the limits of human tolerance, a causal link between the subject incident and the reported cervical disc injuries of Mr. Jones cannot be made.

Shoulder injuries

Mr. Jones claims that, as a result of the subject collision, he sustained a tear of the left supraspinatus tendon, a left SLAP tear, tears of the right supraspinatus and subscapularis tendons, and a tear of the right superior labrum. Note that the reports of imaging studies for the right and left shoulders conducted on April 8, 2003 and April 14, 2003, respectively, showed evidence of a tear in the right supraspinatus tendon and indicated a full thickness tear of the mid-fibers of the left supraspinatus tendon. Both the left and right labrum were intact. There was no impingement syndrome in the left shoulder.

Injuries to the shoulder joint occur when forces are applied in both the manner and magnitude necessary to create the injury mechanism and which exceed the tolerance or strength capacity of the effected tissue. The supraspinatus and subscapularis muscles are two of the four muscles of the "rotator cuff." Both run laterally from the scapula and insert onto the head of the humerus with the supraspinatus and subscapularis tendons, respectively.[18] The two mechanisms for rotator cuff injury are indirect loading of the shoulder while the arm is abducted and repetitive microtrauma to the shoulder joint.[19] The rotator cuff is commonly injured during repetitive use of the upper limb above the horizontal plane, e.g., during throwing, racket sports, and swimming.

The labrum is a cartilaginous structure within the shoulder joint that aids in preventing abnormal displacement of the humeral head.[20] The primary mechanism for damage to the labrum is from indirect compressive loading of the shoulder, e.g., falling with the arm extended or shoulder dislocation. SLAP (Superior Labrum Anterior-Posterior) is a term used to denote a specific type of

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16 Mertz, H.J. Jr. and Patrick, L.M. (1967). Investigation of the Kinematics and Kinetics of Whiplash (SAE 670919). Warrendale, PA: Society of Automotive Engineers.

17 Weiss M.S., Lustick L.S., Guidelines for Safe Human Experimental Exposure to Impact Acceleration, Naval Biodynamics Laboratory, NBDL-86R006.

18 Netter, F.H. (1989) Atlas of Human Anatomy, Ciba-Geigy Corporation

19 Moore, K.L. and Dalley, A.F. (1999) Clinically Oriented Anatomy, Fourth Edition, Lippencott Williams and Wilkins.

20 Wen, D.Y. (1999). "Current Concepts in the Treatment of Anterior Shoulder Dislocations." American Journal of Emergency Medicine 17: 401-407.

labrum injury. If the arm is forcefully bent inward at the shoulder, the humerus acts as a lever and tears the biceps tendon and labrum cartilage from the glenoid cavity in a front-to-back (anterior-posterior) direction.

In the subject incident, Mr. Jones moved rearward relative to his vehicle. By so moving, he loaded primarily into the seat back structure. Restraint forces would have been applied by the seat back over a large contact area with Mr. Jones's torso and pelvis. This interaction with the seat back would have both limited the motion of the left and right shoulders and minimized any forces that might have been applied. Rebound from the seat back, if any, would have been minor and constrained by the shoulder and lap portions of the seat belt.

The body actions that occurred during the subject event did not create any of the injury mechanisms described above known to cause serious damage to the muscles and tendons of the rotator cuff or the labrum of the glenohumeral joint. As this event did not create a mechanism for damage to the left supraspinatus tendon or the right supraspinatus or subscapularis tendons, no causal relationship can be drawn between these claimed injuries and the subject incident. Likewise, as this event did not create a mechanism for damage to the labrum of his shoulder, no causal relationship can be drawn between these claimed shoulder injuries and the subject incident.

According to his medical records, Mr. Jones was diagnosed with degenerative disease of both the left and right shoulders. More specifically, tendinosis of the supraspinatus tendon, subacromial spurs, degenerative changes of the anterosuperior labrum, Grade I chondromalacia, and impingement syndrome were identified in the right shoulder of Mr. Jones. Note these conditions are indicative of pre-existing degenerative changes. Tendinosis may be defined as internal tendon degeneration and is often associated with an imbalance between tendon breakdown and tendon repair. Likewise, Mr. Jones's left shoulder was noted to have Grade I chondromalacia, hypertrophic tissue accumulations, and an unfused acromial apophysis. There was no injury mechanism present to causally relate Mr. Jones's reported bilateral shoulder injuries to the subject incident.

Lumbar injuries

As with cervical injuries, the mechanism for acute damage to a lumbar intervertebral disc is the sudden application of both compressive and bending loads with magnitudes beyond the strength of the disc tissue. In a rear impact of the type seen here, the lumbar spine of a driver is well supported by the seat and seat back. This support prevents injurious motions or loading of the lumbar spine. The seat back would limit the range of movement to well within normal levels; no kinematic injury mechanisms are created. The seat back would also distribute the restraint forces over the entire torso, limiting both the magnitude and direction of the loads applied to the lumbar spine. Neither the mechanism nor the force level associated with lumbar intervertebral disc damage are created by this event.

Live human subjects have regularly been exposed to g levels up to approximately 40g with no acute trauma during rear impacts.[21] The subject incident had an average acceleration at or below 2.3g. Mr.

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21 Weiss M.S., Lustick L.S., Guidelines for Safe Human Experimental Exposure to Impact Acceleration, Naval Biodynamics Laboratory, NBDL-86R006.

Jones's lumbar spine would not have been exposed to any loading or motion outside of the range of human tolerance.[22]

Based upon the review of the available incident data and the results cited in the technical literature as described above, the kinematics or occupant motions caused by this incident were well within the normal range of motion associated with the lumbar spine. The subject event did not create the compression/bending loading mechanism required to acutely bulge or herniate a lumbar disc. Finally, the forces created by the incident were well within the limits of human tolerance for lumbar disc strength and were within the range typically seen in normal, daily activities. For these reasons, a causal link between the subject incident and the lumbar injuries claimed by Mr. Jones cannot be made.

Accident Reconstruction and Biomechanical Conclusions:

- The velocity change for this impact was less than 10 mph.
- The peak acceleration associated with this 10-mile-per-hour impact is 4.53 g with an average acceleration of 2.3 g.
- The forces applied to the subject Honda Accord during this rear-end event would tend to move Mr. Jones's body back toward and into the seat back structure. These motions would have been limited and well controlled by the seat structures and would be well within normal movement limits. No seat failure occurred therefore the restraining forces would have been minimized due to their distribution over a large area of the posterior torso, head and pelvis.
- The kinematics caused by this incident were well within the normal range of motion for the cervical spine. There is no injury mechanism present in the subject incident to account for Mr. Jones's claimed cervical intervertebral disc injuries. As such, a causal relationship between the subject incident and the disc injuries cannot be made.
- The loading and kinematics of both the left and right shoulders in the subject incident were minimal and well within the limits of human tolerance and physiological motion. The subject event lacked the physical mechanism required to produce acute tears in the tendons of the rotator cuff or in the labrum bilaterally. As such, a causal relationship between the subject collision and the left and right shoulder injuries claimed by Mr. Jones cannot be made.
- Similarly, the kinematics or occupant motions caused by this incident were well within the normal range of motion for with the lumbar spine. The subject event did not create the compression/bending loading mechanism required to cause an acute disc herniation at L1-2 or a disc bulge at L4-5. Finally, the forces created by the incident were well within the limits of human tolerance for lumbar disc strength. For these reasons, a causal link between the subject incident and the lumbar disc injuries claimed by Mr. Jones cannot be made.

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22 Gushue, D., Probst, B., Benda, B, Joganich, T, McDonough, Markushewski, M.L., (2006). Effects of Velocity and Occupant Sitting Position on the Kinematics and Kinetics of the Lumbar Spine during Simulated Low-Speed Rear Impacts. Safety 2006, Seattle, WA, ASSE.