COMMON FLAWS IN DEFENSE ACCIDENT RECONSTRUCTIONISTS DELTA V CALCULATIONS

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There are a number of common flaws in the analyses conducted by defense accident reconstructionists when they calculate Delta V in automobile accidents. This usually leads to an underestimation of the Delta V. These same flaws are seen in reports across the country and are based on methodology originally developed by Biodynamic Research Corporation (BRC) of San Antonio, TX, an organization that received more than $7.6 million in funding for services during its formative years from 1990-1995. In this report, all of the common flaws will be thoroughly analyzed.

Reporting a Barrier Equivalent Velocity As If It Was A Delta V

The most common and almost universal error by defense accident reconstructionists is to report a figure for Delta V when it is actually a figure for Barrier Equivalent Velocity (BEV).

In a typical case, for example, a defense engineer claimed that the Delta V for a subject Nissan was in the 6 to 8 mph range. He based this figure solely on testing from the Insurance Institute for Highway Safety (IIHS) testing which involves an impact between exemplar vehicles and a solid barrier. Impacts between a vehicle and a solid barrier results in a figure for Barrier Equivalent Velocity (BEV), not Delta V, and the defense engineer's failure to distinguish between the two may have led to an underestimation of the Delta V.

The accident reconstruction textbook from Texas A&M University which is considered an authoritative addresses this issue. The authors asked: "Will a vehicle which adheres to the 5 mph bumper standard protect the vehicle from significant damage in impacts up to 5 mph?" Answer:

> "NO! A review of Figures 1-1 and 1-2 indicate the standard requires a 5 mph impact with a barrier. This is also known as a Barrier Equivalent Velocity, or BEV. **Clearly an impact with a wall at 5 mph is much more severe than an impact from a Yugo at 5 mph. The concept of change in velocity, or Delta V is the important feature here. One must be careful to speak in terms of change in velocity (or at least acceleration) in comparing the bumper standard requirement to vehicle-vehicle crashes."**

The authors, both certified accident reconstructionists, clearly distinguish between BEV and Delta V. Comparing vehicle-to-barrier impacts to vehicle-to-vehicle impacts is like comparing apples to oranges. The first produces a BEV, not a Delta V. The defense engineer made no attempt to convert the BEV to Delta V using standard methods. Because of this fact, his Delta V figure for the Nissan may not have been accurate.

One of the most basic and fundamental facts of accident reconstruction is that BEV and Delta V are not the same. Nonetheless, the engineer presented BEV as Delta V. Literally all defense engineers do the same. Delta V can be as much as 100% greater than BEV. A study from the Society of Automotive Engineers (SAE) stated:

"DELTA V COMPARED TO BARRIER EQUIVALENT IMPACT VELOCITY"

"When performing an accident reconstruction, often it is necessary to express the severity of a collision with a consistent and definable severity measure. Historically, Delta V has been used due to its importance for impact speed determination. Additionally, Delta V serves as a measure of potential injury exposure. Quantifying Delta V, therefore, is one of the major objectives when performing an accident construction . . . the following definitions are to be assumed for this analysis:

Delta V: The actual change in velocity, during the impact phase of a collision, that a vehicle experiences. Generally considered as a severity measure of a car to car impact, Delta V can also refer to the total change in velocity experienced during a rigid barrier impact.

Barrier Equivalent Velocity (BEV): This is the equivalent impact velocity of a vehicle into a fixed rigid barrier that would result in the same magnitude of crush as observed on a subject vehicle under analysis. The BEV and the Delta V will generally not have the same magnitude for a subject vehicle in a car to car collision, except under certain circumstances."

The study continues: "The bulk of publicly available crash test data is rigid barrier government compliance tests. A utilization of this data can allow the reconstructionist to determine the BEV for a given accident vehicle. Although the nature and shape of the crush may differ in the car to car impact, the magnitude of the absorbed crush energy between the rigid barrier and the subject vehicle is the same at the matching BEV. Once the BEV is calculated, the Delta V may then be computed using Conservation of Momentum and Conservation of Energy methods.

As seen in the car to car staged collision, the crush energy is shared mutually but not necessarily equally, between the two vehicles. This differs from a rigid barrier impact which directs all of the crush energy into the one test vehicle. The impulse or acceleration pulse in the two vehicle collision will have different characteristics than the rigid barrier test. The car to car impact will generally have a longer acceleration pulse duration when compared to a similar Delta V rigid barrier impact . . . If the accelerations are lower, crushing forces will be lower, resulting in lower overall vehicle crush." (Kerkhoff et al, 1993)

A 2001 SAE article assessed four classes of vehicular impact testing: "vehicle to vehicle, vehicle to infinitely massive rigid barrier, vehicle to infinitely massive compliant barrier and vehicle to finite mass movable rigid barrier." The author concluded: "For a prescribed level of vehicular dynamic deformation, it is possible to have a 100% variation in the change in vehicle velocity (Delta V), depending upon the structural dynamics of the testing involved . . . As has been shown, a wide variation in the change in vehicle velocity (Delta V) can be developed for a given level of dynamic deformation, depending upon the type of test utilized by a researcher." (Burkhard, 2001) (Emphasis added)

Another 2001 SAE study provides the mathematical formula needed to convert BEV to Delta V. (Carpenter and Welcher, 2001) Here is the abstract of the study with emphasis added:

ABSTRACT

> Accident reconstruction typically requires estimating the change in velocity (Delta-V) imparted to vehicles during collision. Estimating Delta V commonly involves measuring or estimating the deformation of the vehicles involved in a collision. Material coefficients, which relate barrier equivalent velocity (BEV) to deformation of the two vehicles, are then interpolated or extrapolated from barrier crash test data. Finally, the Delta-V for each of the two vehicles is usually calculated using single-degree-of-freedom (SDOF) impact mechanic formulas . . . Relative closing speed and Delta-V are then related to BEV by a factor that is efficiently a function of relative vehicle weight and relative crush progression behavior. (Emphasis added)

The Delta V required to cause a prescribed amount of damage to the subject target vehicle as a result of a vehicle-to-vehicle collision is generally greater than the Delta V required to produce the same amount of damage to an identical vehicle as a result of a rigid barrier-to-vehicle impact. It is possible to have a 100% variation. Considering the IIHS testing which results in a BEV of 6-8 mph in this case, the Delta V could have been in the range of 6-16 mph. If we assume that the Delta V is 50% greater than the BEV which would be an average, the Delta V in this case would be in the range of 9 to 12 mph. A Delta V in this range is widely agreed to be consistent with significant injury in most individuals, and was consistent with the diagnosed injuries in this case.

Therefore, the first flaw to look for in the defense engineer's report is whether a BEV was reported as a Delta V, or if the engineer failed to properly convert the BEV to the Delta V and in failing to do so underestimated the Delta V in these grounds alone.

Minimizing or Ignoring the Medical Records and Practicing Beyond Engineering Bounds

An injury causation analysis requires genuine consideration and reliance upon the medical records. In most cases, the defense engineer completely ignores and dismisses the medical records. Even if the engineer comments on the medical records, it is essential to challenge those comments on the basis of foundation since engineers have no medical training, education or experience that would provide them the expertise to read and comprehend medical records. Therefore, while they are required to genuinely rely on medical records in their analysis, they are wholly unqualified to read and comprehend medical records and so any of their opinions in this area must be excluded by the court.

In Arizona, the Arizona Department of Insurance concurred with this position so strongly that it issued a formal Circular Letter which has the power of law on the subject. Circular Letter 2000-2 states:

> "A fair and reasonable investigation includes a genuine effort to determine the nature and extent of the injuries actually sustained by the claimant. Though a claims investigation may begin with an assessment of the likelihood of the claimed injury based on certain characteristics of the collision and its observable consequences, the investigation must progress to an evaluation of all the reasonably available relevant evidence to determine what injury the particular claimant actually sustained. If an insurer merely determines that it has an arguable basis to assert that it is unlikely that a claimant could have been injured at all or beyond a certain extent based solely on the

relative speed of the collision and the extent of resulting physical damage, the insurer has not completed a fair and reasonable investigation of the claim.

Generally, a fair and reasonable investigation of a first or third party claim for bodily injury arising out of a vehicular collision should include consideration of, at a minimum, if reasonably available: (1) claimant statements; (2) witness statements; (3) police reports; (4) visual evidence depicting the full nature and extent of the physical damage to all vehicles involved in the collision and any other property damage; and (5) relevant medical records and physician statements pertaining to both medical history of the claimant and treatment arising out of the subject collision. If the insurer is unable to obtain any of this basic information, the claim file should reflect the attempts to obtain the information and an explanation as to why the information was unavailable. An insurer may not refuse to accept or consider relevant information offered by the claimant.

These same general principles apply to the use of biomechanical or injury causation analyses to evaluate low impact claims. This kind of analysis is an attempt to extrapolate the severity of bodily injuries resulting from a collision through assessment of the objective consequences of the collision, particularly the physical damage to the vehicles. Because it is a predictive exercise that ultimately cannot yield more than an opinion as to the likelihood of bodily injury, it cannot constitute the sole basis for a final claim decision that comports with the requirements of A.R.S. § 20-461. Before it may arrive at a final decision, the insurer must also genuinely consider the other available relevant evidence to determine what specific injuries the particular claimant actually sustained as a result of the collision."

Defense engineers never *genuinely* consider the relevant medical records. No engineer is qualified by training or education to do so. Here is the legal definition of an engineer in Arizona which is nearly identical to that of every state. No engineer should be allowed to opine outside of his actual scope of practice. ARS 32-101 states:

11. "Engineer" means a person who, by reason of special knowledge of the mathematical and physical sciences and the principles and methods of engineering analysis and design acquired by professional education and practical experience, is qualified to practice engineering as attested by registration as a professional engineer.

12. "Engineering practice" means any professional service or creative work requiring engineering education, training and experience and the application of special knowledge of the mathematical, physical and engineering sciences to such professional services or creative work as consultation, research investigation, evaluation, planning, surveying as defined in paragraph 22, subdivisions (d) and (e), design, location, development, and review of construction for conformance with contract documents and design, in connection with any public or private utility, structure, building, machine, equipment, process, work or project. Such services and work include plans and designs relating to the location, development,

mining and treatment of ore and other minerals. A person shall be deemed to be practicing or offering to practice engineering if the person practices any branch of the profession of engineering, or by verbal claim, sign, advertisement, letterhead, card or any other manner represents that the person is a professional engineer, or is able to perform or does perform any engineering service or other service recognized by educational authorities as engineering. A person employed on a full-time basis as an engineer by an employer engaged in the business of developing, mining and treating ores and other minerals shall not be deemed to be practicing engineering for the purposes of this chapter if the person engages in the practice of engineering exclusively for and as an employee of such employer and does not represent that the person is available and is not represented as being available to perform any engineering services for persons other than the person's employer.

22. "Land surveying practice" means the performance of one or more of the following professional services:

(d) Measurement by angles, distances and elevations of natural or artificial features in the air, on the surface and immediate subsurface of the earth, within underground workings and on the surface or within bodies of water for the purpose of determining or establishing their location, size, shape, topography, grades, contours or water surface and depths, and the preparation and perpetuation of field note records and maps depicting these features.

(e) Setting, resetting or replacing of points to guide the location of new construction.

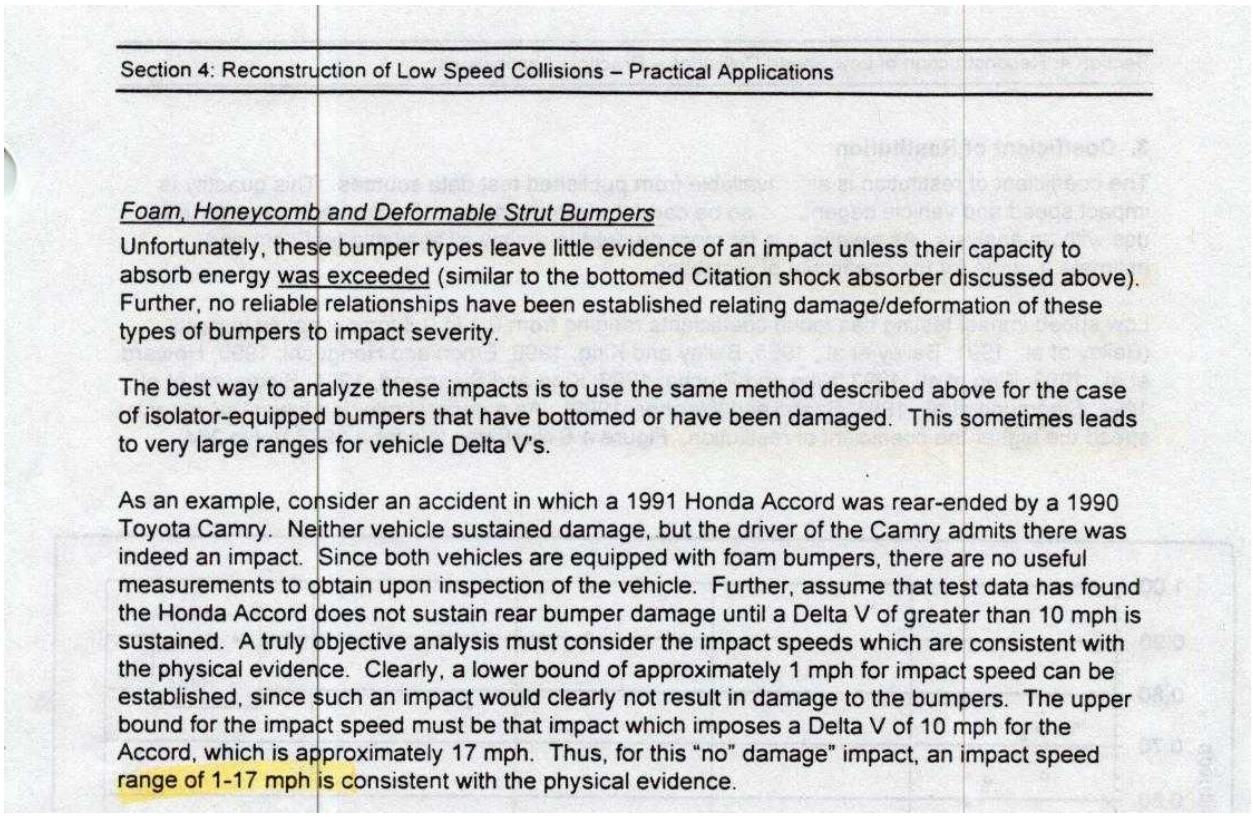
Biomechanical Engineering is recognized by educational authorities as engineering (see, e.g. http://biomechanical.stanford.edu/Main_Page for the curriculum of the Department of Mechanical Engineering at Stanford University; http://bioen.okstate.edu/graduate/graduatemech.htm for the curriculum of the M.S. and Ph.D. programs available in Biomechanical Systems within the Biosystems and Agricultural Engineering Department at Oklahoma State University).

Dr. Peles' determination of Delta V is based on an evaluation of the amount of force necessary to cause the crush damage which was caused by the subject accident. This is a generally reliable method except when the bumpers are equipped with energy or impact absorbers as was the case in the subject accident. As noted by Dr. Peles, the bumper of the subject Nissan Pathfinder was equipped a "foam impact absorber." The following is what Texas A&M University states regarding accident reconstructions involving such bumpers:

Underestimating Delta V in Vehicles With Foam, Honeycomb and Deformable Strut Bumpers

Many passenger cars are equipped with bumpers that consist of a plastic cover with a foam impact absorber behind it. Some accident reconstructionists will inspect the bumper after a collision and take measurements of the amount of permanent crust damage. Usually there

is very little evidence of permanent crush since the foam absorber did the job of absorbing and releasing the force without showing any signs afterward of an impact. The reconstructionist will then conclude that the only forces involved were those responsible for causing the crush that was still visible and able to be measured. This crush is then measured, a crush analysis is performed, and a Delta V is calculated. All of the force applied to the foam absorber is ignored and so the true Delta V is underestimated. Here is what Texas A&M University states regarding accident reconstructions with bumpers equipped with foam, honeycomb or deformable struts:



Section 4: Reconstruction of Low Speed Collisions – Practical Applications

Foam, Honeycomb and Deformable Strut Bumpers

Unfortunately, these bumper types leave little evidence of an impact unless their capacity to absorb energy was exceeded (similar to the bottomed Citation shock absorber discussed above). Further, no reliable relationships have been established relating damage/deformation of these types of bumpers to impact severity.

The best way to analyze these impacts is to use the same method described above for the case of isolator-equipped bumpers that have bottomed or have been damaged. This sometimes leads to very large ranges for vehicle Delta V's.

As an example, consider an accident in which a 1991 Honda Accord was rear-ended by a 1990 Toyota Camry. Neither vehicle sustained damage, but the driver of the Camry admits there was indeed an impact. Since both vehicles are equipped with foam bumpers, there are no useful measurements to obtain upon inspection of the vehicle. Further, assume that test data has found the Honda Accord does not sustain rear bumper damage until a Delta V of greater than 10 mph is sustained. A truly objective analysis must consider the impact speeds which are consistent with the physical evidence. Clearly, a lower bound of approximately 1 mph for impact speed can be established, since such an impact would clearly not result in damage to the bumpers. The upper bound for the impact speed must be that impact which imposes a Delta V of 10 mph for the Accord, which is approximately 17 mph. Thus, for this "no" damage" impact, an impact speed range of 1-17 mph is consistent with the physical evidence.

Therefore, certain facts can be stated:

1. "No reliable relationships have been established relating damage/deformation of these types of bumpers to impact severity." Therefore, the amount of Delta V to which the an impact absorber was exposed in any particular case is unknown. The reconstructionist can determine the amount of force required to cause the physical damage but that may be only part of the forces that occurred with the accident.
2. Texas A&M states that when a vehicle is equipped with a foam bumper, "there are no useful measurements to obtain upon inspection of the vehicle." Such measurements would include measurements of crush damage. These measurements are not considered useful because they do not consider the amount of force absorbed by the absorbers and so can be misleading.
3. It is unknown how much force is absorbed and released by the impact absorber in the bumper. This is additional force above that required to cause the physical damage which was the sole basis of the reconstructionist' s Delta V calculation.

4. If this additional amount of force was added in then the total Delta V in this case could substantially increase from the reconstructionist' s figure.

In conclusion, the Delta V in such a case is unknown since the reconstructionist did not consider the amount of force that was absorbed and released by the impact absorber. It is a well-accepted fact in the field of accident reconstruction that these types of absorbers show little or no evidence of impact and so crush measurements are not useful in such cases and may even be misleading. This is a very basic and fundamental concept in accident reconstruction that most reconstructionists either knows or should know, but ignore in their analyses.

Relying Solely on Photographs and Not Performing a Physical Inspection or Reviewing Repair Estimates

A fatal flaw of any accident reconstruction is to solely rely on photographs in the absence of either a physical inspection of the vehicle before repairs have been performed or review of repair estimates. Review of photographs has been proved unreliable.

A study published by the Society of Automotive Engineers was entitled "Evaluating the Uncertainty in Various Measurement Tasks Common to Accident Reconstruction." (SAE 2002-01-0546) In the section on "Measuring Vehicle Crush," the researchers report the findings of an experiment performed with 17 accident reconstructionists. Each was asked to measure the depth and length of crush damage on a van. The results: "the average crush depth recorded by the 17 participants ranged from 11.8 to 34 inches, with an average of 19.4 inches and a standard deviation of 5.2 inches. The reported length of the damage area ranged from 45 to 78 inches, with an average of 62.4 inches and a standard deviation of 9.9 inches."

When the participants were asked to evaluate crush damage from photographs, the results were an average estimated crush of 13.6 inches with a standard deviation of 4.2 inches (review of one photo), and an average estimated crush of 13.1 inches with a standard deviation of 3.3 inches (review of two photos).

Clearly, review of photos alone is not reliable.

"**Eyeballing" Method of Calculating Delta V**

This method simply consists of an accident reconstructionist looking at the vehicle and stating that "based on my experience, I conclude that the amount of Delta V required to cause this damage is in the range of 4-5 mph." Many reconstructionists actually write reports in this manner even though it is a violation of all of the rules of accident reconstruction. This "eyeballing" technique of determining Delta V is completely invalid and should never be accepted. No one is able to simply look at a vehicle and make an accurate determination of Delta V.

Computer Program Generated Delta V Calculations

One report from an accident reconstructionist concluded that his Delta V conclusion was based on an analysis using "the damage based mode of EDCRASH reconstruction software . . ."

The reconstructionist did not provide any evidence that the EDCRASH reconstruction software produces results that are valid or accurate. No independent external scientific studies were cited that have proven the validity or accuracy of this software. No evidence was provided that this software program has achieved general acceptance in the accident reconstruction community. All that was provided is the reconstructionist' s personal attestation that this software program produces valid and accurate results. That is not enough to require acceptance of this software and its results.

Furthermore, the reconstructionist did not provide the input variables which he used with the software program. Therefore, it was impossible to check his work to determine if it was accurate.

Considering all of these facts, the reconstructionist did not establish a basis for anyone to accept the results of the EDCRASH software calculation of Delta V in this case. This would be true of any other software program with similar facts.

Calculating Delta V Using Crush Analyses

Delta V can be calculated accurately using the crush analysis method if the method is used properly. One example of an inaccurate application of the crush analysis method is Cipriani method. This method was widely used until it was scientifically analyzed with extensive Frye hearings in Virginia to examine whether the method is scientifically valid and if it has achieved general acceptance in the relevant accident reconstruction community. The Virginia Supreme Court reviewed the Frye Hearing results and conclusively determined that the actual Cipriani method, defended by Dr. Alfred Cipriani himself, failed the test for validity and reliability. The Court ruled that "the challenged (Cipriani) expert testimony is speculative, is founded upon assumptions lacking sufficient factual basis, relies upon dissimilar tests, and contains too many disregarded variables. Consequently, we hold that the testimony is unreliable as a matter of law, and, therefore, the trial court erred in admitting it." (*Tittsworth v. Robinson,* 252 Va. 151, 475 S.E.2d 261 (1996))

Therefore, it is essential that if an accident reconstructionist uses the crush analysis method, the method must be used properly. The stiffness coefficient of each part of the vehicle that was crushed must be found and listed, along with the source. The exact physical measurements of the crush width and depth for each part must be reported. The formula used for calculating Delta V must be included in the reconstructionist' s report, not just the final conclusion. Stiffness coefficients must come from the same vehicle as that involved in the subject accident, not dissimilar vehicles. Then, and only then, may a crush analysis-derived Delta V be accurate. It is very rare for an accident reconstructionist do to a truly complete and scientific crush analysis Delta V determination. In most cases, shortcuts and guesses are made which can be uncovered with careful examination.

Conclusion

In most cases, accident reconstructionists, hired by the defense, are not objective and aim at trying to underestimate the Delta V. In this report you have now learned all of the most common ways that Delta V is commonly underestimated. Look for these flaws and you will commonly find them.

Bibliography

Barnsley, L.; Lord, S. and Bogduk, N.: "Whiplash Injury--Clinical Review," *Pain* 58(1994), 283-307.

Bartlett, W., Schmidt, B., Wright, W., Masory, O., Navin, F., Brach, R., Stanard, T. and Baxter, A.: ""Evaluating the Uncertainty in Various Measurement Tasks Common to Accident Reconstruction," SAE 2002-01-0546, 2002.

Bogduk, Nikolai: "Point of View," *The Spine Journal* Volume 24. Number 8.1999, p. 770.

Bogduk N and Yoganandan N: "Biomechanics of the cervical spine Part #3: minor injuries," *Clinical Biomechanics* 2001; 16:267-275.

Braaf, M.M. and Rosner, S.: "Whiplash Injury of the Neck: Symptoms, Diagnosis, Treatment and Prognosis," *N.Y. State J. Med.* 58:1501-1507, 1958.

Brault, John R., MS; Wheeler, Jeffrey B, MS; Siegmund, Gunter P.; BASc, Brault, Elaine J., MS, PT: "Clinical Response of Human Subjects to Rear-Ed Automobile Collisions," *Arch Phys Med Rehabil*, v. 79, p. 72-80, 1998.

Burkhard, PM: "Delta V, BEV and Coefficient of Restitution Relationships as Applied to the Interpretation of Vehicle Crash Test Data," SAE 2001-01-0499, 2001.

Carpenter, Nicholas J. and Welcher, Judson B.: "Stiffness and crush energy analysis for vehicle collision and its relationship to barrier equivalent velocity (BEV)," SAE 2001-01-0500, 2001.

Centano CJ, Freeman M, Wilkins WL: "A review of the literature refuting the concept of minor impact soft tissue injury." *Pain Res Manage* 2005; 10(2):71-74.

Duffy MF, Stuberg W, DeJong, S, Gold KV and Nystrom AN: "Case Report: Whiplash-Associated Disorder From a Low-Velocity Bumper Car Collision: History, Evaluation, and Surgery," *Spine*, v. 29, n. 17, pp. 1881-1884, 2004.

Freeman, M.D., Croft, A.C., Rossignol, A.M., Weaver, D.S. and Reiser, M.: "A Review and Methodologic Critique of the Literature Refuting Whiplash Syndrome," *Spine*, v. 24, n. 1, pp. 86-98, 1999.

Freeman, M.D., Rossignol, AM and Hand, ML: "Forensic Epidemiology: A systematic approach to probabilistic determinations in disputed matters," *Journal of Forensic and Legal Medicine* 15 (2008) 281-290.

Freeman M, Croft A: "Correlating crash severity with injury risk, injury severity, and long-term symptoms in low velocity motor vehicle collisions." *Med Sci Monit* 2005; 11(10): RA316-321.

Freeman MD, Croft AC, Nicodemus CN, Centano CJ, Elkins WL: "Significant Spinal Injury Resulting From Low-Level Accelerations: A Case Series of Roller Coaster Injuries." *Archives of Physical Medicine and Rehabilitation*: 2005; 86: 2126-2130.

Hildebrand, Kevin A. And Frank, Cyril B.: "Scar formation and ligament healing," *CJS*, vol. 41, no. 6, p. 425-429, 1998.

Howard RP, Hatsell CP and Guzman HM: "Temporomandibular joint injury potential imposed by low velocity extension-flexion maneuver," *J. Oral Maxillofacial Surg*. 53:256-62, 1995.

Howard RP, Benedict JV, Raddin JH and Smith HL: "Assessing neck extension-flexion as a basis for temporomandibular joint dysfunction," *J Oral Maxillofacial Surg*. 49:1210-3, 1991.

Hubbard RD, Quinn KP, Martínez JJ, Winkelstein BA: "The Role of Graded Nerve Root Compression on Axonal Damage, Neuropeptide Changes, and Pain-Related Behaviors," *Stapp Car Crash Journal*, Vol. 52, pp. 33-58, November 2008.

Hynes LM, Dickey JP: "The rate of change of acceleration: Implications to head kinematics during rear-end impacts," *Accident Analysis and Prevention*, v. 40, p. 1063-1068, 2008.

Ito S, Ivancic PC, Panjabi MM, Cunningham BW: "Soft Tissue Injury Threshold During Simulated Whiplash – A Biomechanical Investigation," *Spine* 2004; 29:979-987.

"Energy Absorbers,@ I-CAR ADVANTAGE -- Technical Information for the Collision Industry," Volume VIII, No. 2, March-April, 1995, pp. 7-11.

Jakobsson, Lotta; Lundell, Bjorn; and Alfredsson, Bo: "Protecting against whiplash in rear-end collisions," *Volvo Technology Report*, No. 1, p. 20-31, 1998.

Jakobsson, Lotta; Lundell, Bjorn; Norin, Hans; and Isaksson-Hellman, Irene: "WHIPS – Volvo's whiplash protection study," *Accident Analysis and Prevention*, v. 32, p. 307-319, 2000.

Kaneoka, K., Ono, K., Inami, S., Hayash, K.: “Motion analysis of cervical vertebrae during whiplash loading,” *Spine*, v. 24, n. 8, p. 763-769, 1999.

Kerkhoff JF, Husher SE, Varat MS, Busenga AM and Hamilton K: “An Investigation into Vehicle Frontal Impact Stiffness, BEV and Repeated Testing for Reconstruction,” SAE 930899, 1993.

Krafft M, Kulgren A, Tingvall C, Bosrom O. Fredriksson R: “How crash severity in rear impacts influences short- and long-term consequences to the neck.” *Accident Analysis and Prevention* 2000; 32:187-95.

Kumar, Shrawan; Narayan, Yogesh; and Amell, Tyler: “Role of awareness in head-neck acceleration in low velocity rear-end impacts,” *Accident Analysis and Prevention*, v. 32, p. 233-241, 2000.

Macnab, I.: "Acceleration Extension Injuries of the Cervical Spine," in *The Spine*, Rothman, R.H. and Simione, F.A.; W.B. Saunders, 2nd Edition, Volume 2, 1982, p. 647-660.

Magnusson, T.: “Extracervical symptoms after whiplash trauma,” *Cephalagia*, V. 14, 1994, P. 223-7.

McConnell WE, Howard RP, Guzman HM, et al: “Analysis of human test subject kinematic responses to low velocity rear end impacts.” Society of Automotive Engineers Tech Paper Series 930889, 1993:21-31.

McConnell WE, Howard RP, Poppel JV, et al: “Human occupant kinematic response to low speed rear-end impacts.” Society of Automotive Engineers Tech Paper Series 940532 1994:23-35.

Nolan. Joseph M., Preuss, Charles A. and Jones, Sara L.: “An update on the relationships between computed Delta Vs and impact speeds for offset crash tests,” Insurance Institute for Highway Safety, U.S. Department of Transportation, Paper Number 98-S6-O-07.

Panjabi MM, Ito S, Pearson AM and Ivancic PC: “Injury Mechanisms of the Cervical Intervertebral Disc During Simulated Whiplash,” *Spine* 2004; 29:1217-1225.

Severy, D.M., Mathewson, J.H. and Bechtol, C.O.: “Controlled automobile rear-end collisions, an investigation of related engineering and medical phenomena,” *Canadian Services Medical Journal*, p. 727-759.

Panjabi MM, Ivancic PC, Maak TG, Tominaga Y and Rubin W: “Multiplanar Cervical Spine Injury Due to Head-Turned Rear Impact,” *Spine*, v. 31, number 4, pp 420-429, 2006.

Prasad, A.K.: “CRASH3 Damage algorithm reformulation for front and rear collisions.” SAE Technical Paper Series 9000098, Society of Automotive Engineers, Warrendale, PA 1990.

Siegmund, Gunter P., et al: “Head/Neck Kinematic Response to Human Subjects in Low-Speed Rear-End Collisions,” Society of Automotive Engineers, #973341, 1997.

Siegmund, G.P., Brault, J.R., and Wheeler, J.B.: “The relationship between clinical and kinematic responses from human subject testing in rear-end automobile collisions,” *Accident Analysis and Prevention*, v. 32, p. 207-217, 1999.

Siegmund, Gunter P., et al: “The relationship between clinical and kinematic responses from human subject testing in rear-end automobile collisions,” *Accident Analysis and Prevention*, v. 32, p. 207-217, 2000.

Siegmund GP, David MB, Quinn KP, Hines E, Myers BS, Ejima S, Ono K, Kamiji K, Yasuki T and Winkelstein BA: “Head-Turned Postures Increase the Risk of Cervical Facet Capsule Injury During Whiplash,” *Spine*, volume 33, number 15, pp. 1643-1649, 2008.

Sturzenegger, M.; Radanov, B.P.; DiStefano, G.: “The Effect of Accident Mechanisms and Initial Findings On The Long-Term Course of Whiplash Injury,” *J. Neurology*, 1995, v. 242, p.443-449.

Svensson, M.Y., Aldman, B., Hansson, H.A., Lovsund, P., Seeman, T., Suneson, A., and Ortegren, T.: “Pressure effects in the spinal canal during whiplash extension motion: a possible cause of injury to the cervical spinal ganglia.” Proceedings of the 1993 International IRCOBI Conference of Impacts, September 8-10, Eindhoven, The Netherlands.

Szabo, T. and W.R. Haight: Course Text Book for *Collision Reconstruction for the Medical Practitioner*, Texas A&M University, 1999.

Texas A&M University, *Collision Reconstruction for the Medical Professional*, 1999.

Tominaga Y, Maak TG, Ivancic PC, Panjabi MM and Cunningham BW: “Head-turned rear impact causing dynamic cervical intervertebral foramen narrowing: implications for ganglion and nerve root injury,” *J Neurosurg Spine* 4:380-387, 2006.

Turek, Samuel L.: *Orthopaedics – Principles and Their Application*, Third Edition, J.B. Lippincott Company, Philadelphia, 1977.

Watkinson, A., Gargan, M.F. and Bannister, G.C.: "Prognostic Factors in Soft Tissue Injuries of the Cervical Spine," *Injury*, volume 22(4), p. 307-309, 1991.

Watts, Alan J., Ph.D.; Atkinson, Dale R., B.S.; Hennessy, Corey J., M.A.: *Low Speed Automobile Accidents – Accident Reconstruction and Occupant Kinematics, Dynamics and Biomechanics*, Second Edition, Lawyers and Judges Publishing Company, Tucson, AZ 1999 and Third Edition, 2003.

Welcher, J.B. and Szabo, T.J.: "Relations between seat properties and human subject kinematics in rear impact tests" *Accident Analysis and Prevention*, 2001, v. 33, p. 289-304.