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Low Velocity Impact, Vehicular Damage and Passenger Injury

ABSTRACT: *Low velocity motor vehicle accidents are a source of injury to many people every year, but the existence of these injuries is often challenged in the courts. The question raised is: "If the vehicle did not suffer any damage, how could the occupant become injured?" This paper reviews the pertinent literature and explains the mechanism of injury. The factors influencing the probability of injury are discussed. Fallacies of research methodology are explored as they relate to "real" victims.*

Low velocity collisions with little vehicular damage have historically been a source of conflict in the medicolegal arena. Clinicians dealing with TMJoint injuries often treat the symptomatic victims of these accidents. These patients exhibit signs and symptoms consistent with TMJ/cervical "whiplash" type injuries. Using computer-assisted diagnostics, such as Joint Vibrational Analysis (JVA), surface electromyography, and electrognathography (jaw tracking), integrated with radiography, tomography, and a thorough clinical examination, these injuries can be objectively documented and effectively treated.¹ Despite extensive documentation, the existence of and compensation for these injuries is frequently contested by insurance adjusters and third party payers, insurance defense attorneys, "independent" medical examiners and defense expert witnesses. The typical question is: "If the vehicle sustained such little damage, how did the patient get hurt so badly?" Often, defense attorneys will claim that the patient is merely seeking a financial windfall and the doctors are being complicitous. However, this question has been extensively researched and an answer has been formulated. A common low-speed motor vehicle accident (MVA) is the rear end collision. This MVA is responsible for the "whiplash" type of injury so contentiously litigated. Whiplash is more properly called a "forced hyperextension/forced hyperflexion" or "inertial acceleration injury." The accident biomechanics and resulting injuries are well documented in the medical, dental and chiropractic literature. There are multiple factors that determine if an injury occurs. Among the human factors are age, sex, pre-existing conditions, physical health and a prior history of trauma.² Another set of factors is the occupant positioning, including rotation, flexion and extension positioning of the body at impact. These factors impose angular force vectors on the body. Also relevant are: the seating position in the car; distance from the dashboard; distance from the headrest; deployment/impact with an airbag; and position of the seatbelt/lapbelt on the occupant. Automotive factors that effect the probability of injury include year, make, and model of the car. Car type determines seat construction, size, shape and position of the headrest; and the height, design and construction of the bumper.³ The Society of Automotive Engineers and other collision damage experts have done numerous

studies relating to soft tissue injuries in MVAs. These studies are not generally available in the medical/dental literature. Brown² and Murphy⁴ have done excellent work in cataloging these studies and enumerating the numerous factors involved in determining the likelihood of injuries.

Primarily drawing from the work of Smith and Macnab,⁶ the mathematics of collision bio/physio/mechanics are complex when all the forces and factors are considered. Fortunately, the calculations can be simplified by excluding numerous minor factors. Examples of these minor sources of energy dissipation would be noise and heat generation. The major forces remaining would be target vehicle acceleration and bullet vehicle acceleration, and damage to the bullet and target vehicles. Since the minor factors dissipate so little energy, virtually the entire force of the impact remains to be assigned. Smith states that measuring the force on the occupants of the target vehicle requires calculating the kinetic energy of the impact. From Newton's Second Law (Force = Mass x Acceleration) derives the formula for calculating kinetic energy:

$$\text{Kinetic Energy} = \text{KE} = 1/2 m v^2$$

Where m = the mass (weight) of the bullet vehicle and v = the velocity (speed). The large mass of motor vehicles means that even low velocity impacts create huge amounts of force. A 3500 lb. Honda Accord traveling ten MPH generates a force of 175,000 lbs./sec². A 5300 lb. Jeep traveling at 20 mph has a kinetic force of over one million pounds/sec². (This explains the growing concern over the increasing size and numbers of SUVs on the roads.) The Law of Conservation of Energy requires that the post-impact energy equal the pre-impact energy. This is expressed as:

$$\text{KE}_{\text{bullet vehicle}} + \text{KE}_{\text{target vehicle}} = \text{KE}_{\text{after}} + \text{KEVD}$$

where KEVD is the energy that went into vehicle damage. This equation shows that the magnitude the force delivered to the occupants of the target vehicle can not be directly correlated to the amount of vehicular damage sustained in the crash. Low KEVD vehicle damage) does not correlate to low KE after unless the bullet vehicle is extremely light and has a very low velocity. When comparing identical impact forces and varying only the amount of KEVD, the smaller the amount of vehicular damage, the greater the amount of kinetic energy available to damage the occupants. This effect is especially operative in low speed rear impact MVAs. Emori and Horiguchi⁷ stated that at a collision speed as low as 2.5 km/h (-1.6 mph) the cervical spine extension became "... almost 60 degrees, which is the potential danger limit of whiplash."

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To fully understand the impact that this force imparts on the target vehicle, we must look at the current state of automotive construction. In the 1970s, when the "econo-box" cars became common, these "disposable" vehicles would suffer much damage as the car bodies crumpled in even minor accidents. Consumers, the automotive insurance and safety industries all demanded sturdier bumpers on cars. Modern bumpers and stiff automobile frames have minimized vehicular damage in low speed collisions to the detriment of the passengers. Murphy's⁴ outstanding literature review searched the published works of experts in MVAs and found numerous studies to support these clinical observations. Quoting from

Romilly, et al.⁸ Murphy states:

... experimental results indicate that some vehicles can withstand a reasonable high-speed impact without significant structural damage. The resulting occupant motions are marked by a lag interval, followed by a potentially dangerous acceleration up to speeds greater than that of the vehicle. As the vehicle becomes stiffer, the vehicle damage costs are reduced as less permanent deformation takes place. However, the occupant experiences a more violent ride down which increases the potential for injury. Murphy also quotes:

... the average acceleration experienced by the occupant in the elastic [no damage] vehicle would be approximately twice that of the plastic [structurally damaged] vehicle. This theory implies that vehicles that do not sustain damage in low speed impacts can produce correspondingly higher dynamic loading on their occupants than those which plastically deform under the same or more severe impact conditions. There are numerous studies to support this theory. Carroll,⁹ Ameis,¹⁰ Hirsch,¹¹ Smiths, Parmar and Raymakers,¹² Sturzenegger,¹³ Ryan,¹⁴ Sturzenegger,¹⁵ and Nordhoff and Emori¹⁶ all directly support the fact that there is little or no correlation between vehicular damage and occupant injury and prognosis. This is not new information. In 1982, Macnab⁶ stated: "The amount of damage sustained by the car bears little relationship to the force applied." McConnell¹⁷ measured the tangential acceleration in human volunteers when subjected to rear impacts between 3.6-6.8 mph. The accelerometers typically measured forces in excess of ten Gs over the 150 msec following impact. It is the rapid acceleration over an extremely short time that makes these injuries so damaging. Though McConnell's conclusions were that there were no injuries from the forces generated by these low speed impacts, every one of the young healthy male test subjects developed symptoms consistent with low velocity, rear impact collision injuries, including one subject who was dropped from the study because of the severity of his pain. More importantly, McConnell's conclusions can not be generalized to any population outside of the study due to selection bias, low study numbers, and unduplicatable test conditions!

The first two factors involved in the development of symptoms are total kinetic energy developed and high acceleration. Defense attorneys, insurance adjusters and defense experts claim that people are subject to these same types of forces on carnival rides, playing sports, etc. and seldom suffer these injuries. This is not true. The duration of the peak acceleration is much different during a whiplash compared to plopping in a chair or riding on a roller coaster. Further, the direction of the force vectors is different in each of these activities. These differences render the comparisons meaningless for this is analogous to comparing apples to oranges. There is a third major difference between bumper cars and an unexpected lowimpact rear-end MVA. That difference is awareness. Again, Murphy has gathered research that supports the clinical observations. Quoting some of the authors, it becomes clear that the awareness factor is a major determinant of injury potential.

Sturzenegger, et al.¹³:

Patients struck when they were unprepared for the impact had a significantly higher frequency of multiple symptoms, higher headache intensity, and shorter interval of headache onset. The state of preparedness proved to be the first significant factor with respect to initial injury findings. Ryan, et al.¹⁴:

... [awareness] appears to have a strong protective influence and may prove to be a useful

prognostic indicator in clinical settings...subjects who were unaware of the impending collision had a greatly increased likelihood of experiencing persisting symptoms and/or signs of neck strain, compared to those who were aware...Subjects who were unaware of the impending collision were 15 times more likely to have a persisting condition than those who were aware.

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The works of Sturzenegger, et al¹⁵, Tease¹¹ and McCain,¹⁸ Smith, Lord,¹⁹ and Teasell²⁰ all confirm the above statements and emphasize the importance of awareness of the impending collision as a major determinant of injury. People being tossed about on carnival rides, playing sports, and even being test crash volunteers are all aware that they are undergoing adverse loading forces and can brace their muscles to mitigate the effects of these forces. The unsuspecting victim in the target vehicle has no warning of the impending impact. The speed at which the impact forces are generated in an MVA do not permit any protective reflex response in cases where the patient is unaware of the impending collision. McConnell's¹⁷ 1995 studies found these impact forces were applied over the first 150 msec. Lord¹⁹ states that the "acceleration-deceleration movements of the neck are typically completed within 250 msec." Since the myotactic reflex response takes approximately 500 msec, the victim has no ability to brace the body before impact. In 1995, Sturzenegger, et al.¹⁵ stated that the best predictor of persistence of symptoms at one year post-accident was: "... unpreparedness at the time of the accident... "

The fourth major determinant of injury is head position at the time of impact. Murphy⁴ cites numerous studies dating back to 1977 to document this fact. Webb²¹ stated that:

When the hyperflexion-hyperextension or hyperextension-hyperflexion occurs with head rotation present, the pattern of tissue injury is different, and the extent of damage produced is always more severe. Rotation increases stress in certain soft tissue structures, which then reach their limit of motion at an earlier point, thus resulting in more severe injury with less application of force. Sturzenegger, et al.¹³ reported that:

Rotated and inclined head position both led to a significantly higher frequency of multiple symptoms and increased neck pain and headache intensity, and showed a trend to shorter latency of headache onset. The Sturzenegger, et al.¹⁵ research reported that the additional predictors of symptom position at one year were "... rotated or inclined head position..." Bungee jumps, bumper cars, ski slopes, and football fields are just some of the numerous examples of situations where severe forces can be applied to the human body. Fortunately, the frequency of injury is low. This is a testimony to the resiliency of the human body. The four factors mentioned above are physical determinants of the likelihood of injury. Still, people are hurt in risky sports and games, and yet our courts are not flooded with suits from these activities. This lack of litigation highlights another differentiating factor between Mrs. Jones stopped at a traffic light and a race car driver. This fifth factor is the assumption of risk. Mrs. Jones does not assume the risk of injury from a negligent driver rear-ending her, while the race driver knows the risks and accepts them.

Summary

There is no direct relationship between vehicular damage and the injury to and prognosis for the occupant(s) of the damaged vehicle. Light vehicles at low speeds can generate

considerable forces. These forces are sufficient to cause significant bodily injury. Impact resistant bumpers and body frames are currently absorbing less force than in previous automotive designs. More kinetic energy is available for occupant injury. The occurrence of injury relates primarily to the amount of kinetic energy developed in the collision, the ability to dissipate that energy, victim awareness, body posture at impact and a myriad of other factors. Each accident and each victim is unique, and each must be evaluated objectively and individually based on the unique biomechanics and physics of the collision.

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Author's Note: The physics in this paper have been simplified for clarity of concept. For example, one kilogram often is defined as 2.2 pounds. Yet, kilograms are units of mass and pounds are units of weight. In the real world, "kilograms" and "pounds" are used interchangeably despite the marked difference in scientific definition. The underlying physics of low velocity accidents remains unaffected.

Derivation of Kinetic Energy from Newton's Second Law:

$F = ma$, so $KE = \text{Force} \times \text{distance} = mad$.

But, $d = 1/2 at^2$ so $KE = 1/2m(at)^2$

Since $v = at$, then $KE = 1/2mv^2$

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