ORIGINAL

No: 123156

IN THE SUPREME COURT
OF THE STATE OF ILLINOIS

WILLIAM KEVIN PEACH, Plaintiff-Appellee, v. LYNSEY E. McGOVERN, Defendant-Appellant.	On Appeal from the Appellate Court of Illinois Fifth District, No. 5-16-0264 On Appeal from the Circuit Court of Marion County, Illinois, No. 14-L-28 Honorable Kevin S. Parker, Trial Judge

BRIEF OF APPELLEE/~~CROSS RELIEF REQUESTED~~

stricken by order 8-3-18

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ORAL ARGUMENT REQUESTED

July 6, 2018

Order entered 8-3-18 by the Court striking articles set forth in A1-A26 of appendix to appellee's brief and any argument in appellee's brief referencing the Articles

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Appellee's brief due 7-6-18

POINTS AND AUTHORITIES

A1- A26 stricken by order 8-3-2018 and any argument in appellee's brief referencing articles.

STANDARD OF REVIEW

"We review *de novo* a trial court's denial of a motion for a directed verdict or a judgment n.o.v. *Jackson*, 372 Ill. App. 3d at 1068. A directed verdict or a judgment n.o.v. is properly entered where all the evidence, when viewed in the light most favorable to the nonmoving party, so overwhelmingly favors the moving party that no contrary verdict based on that evidence could ever stand. *Maple*, 151 Ill. 2d at 453. In ruling on a motion for a directed verdict or a judgment n.o.v., the court does not weigh the evidence, nor is it concerned with the credibility of the witnesses. *Maple*, 151 Ill. 2d at 453. Instead, the court may only consider the evidence, and any rational inferences therefrom, in the light most favorable to the nonmoving party. *Maple*, 151 Ill. 2d at 453." *Ford v. Grizzle*, 398 Ill. App. 3d 639, 650, 338 Ill. Dec. 325, 336, 924 N.E.2d 531, 542 (2010).

STATEMENT OF FACTS

The facts at trial revealed that Plaintiff, William Kevin Peach, had been at the home of Nicole Carter, his girlfriend, until about 10 p.m. on July 17, 2010 when he decided to drive home.(SPC 86, SPC 69) He stopped for a stop sign on N. Shelby St. with its intersection with E. Main St. in Salem, Illinois waiting for traffic to clear. He was driving a 1985 Nissan pickup truck. Suddenly, he was struck in the rear of his truck by Defendant Lynsey McGovern who was driving a 2001 Mitsubishi Eclipse.

His head hit the rear window. He was in a daze.(SPC 85) He estimated her speed at 20-25 mph and she was on her cellphone. Defendant said she was fully stopped when her foot slipped off the brake and she rolled into Peach. (SPC 77-78)

The drivers got out of their cars and Peach told Defendant they should call the police and exchange information. Defendant turned around and told Peach she wasn't giving him anything, got back into her car and drove away. Peach's back bumper was dented and it looked like Defendant's front bumper was cracked. It looked like a plastic bumper.

Peach's neck felt like someone "set a match to my neck." He then drove back to Carter's house. (SPC 85) He still had the neck pain, a headache and felt like he was in a daze. Carter decided to take Peach to the emergency room at Salem Township Hospital.

The ER staff put him in a neck collar and put him on a backboard. (SPC 86) The ER staff did blood work, x-rayed him and took some MRI images. Peach was in the ER for several hours before Carter could take him home. (SPC 70) While there, a nurse called the Salem police to report the accident. (SPC 100) Salem police sergeant Garland Simmons came to the ER to talk to Peach.

Peach remembered the Defendant's license plate number and when he told Sergeant Simmons that she had just driven away, he attempted to contact the Defendant at her home to issue her a traffic complaint, but no contact could be made that night. (SPC 101) Simmons returned the next day and Defendant was there. Defendant admitted being in a motor vehicle collision the day before. Simmons then had Defendant come to the police station to make a report and issued Defendant a citation for failure to reduce speed to avoid an accident. (SPC 102-103) McGovern pleaded guilty to the traffic offence. (SPC 76)

Peach sought further medical treatment from his family physician, Dr. Luecha two or three times who prescribed a neck brace and referred him to the Orthopedic Center in Mt. Vernon where he was seen by Dr. Templer. (SPC 72, 89) His medical expenses totaled $23,385.62. (SCC 59-71, Plaintiff's Exhibit 1)

Dr. Templer testified by evidence deposition. (SPC 144-145, SCC 72-84, Plaintiff's Exhibit 2) He is board certified in anesthesiology and pain management and is now practicing in Minot, North Dakota.(SCC 72) He first saw William Peach as a patient on October 5, 2010 when he was practicing in Mount Vernon, Illinois. Peach's chief complaint was neck pain. Peach had had chronic neck pain since the motor vehicle collision of July 17, 2010 when he was rear-ended. Peach had an MRI on September 16, 2010. (SCC 73) It showed a straightening of the normal lordosis consistent with muscle spasm and pain. The MRI further showed that Peach had a right disc protrusion at C 3-4 with foraminal narrowing on the right, compression of the right lateral recess, compression of the dural sac and compression of the anterior margin of the spinal cord. Dr. Templer could tell it was a recent injury or acute rather than degenerative, consistent with having been recently caused in July, 2010.

At the C 4-5, there was a moderate right and left posterolateral disc/osteophyte complex. (SCC 74) which was compressing the left anterolateral margin of the spinal cord creating moderate left and right foraminal stenosis. This was not acute, but it could be causing him shoulder pain.

He has minimal disc bulging at the C 5-6. There is a small central nuclear protrusion with a slight compression of the anterior margin of the dural sac. This is acute or recent and can be a source of pain. The injuries at the C 3-4, 5-6 are consistent with a rear-end collision. (SCC 75)

There is also some component of facet arthropathy. It is consistent with a whiplash injury which he thought was causing Peach pain.

He prescribed a tapering steroid Dosepak, an anti-inflammatory medication and suggested a medial branch block for facet joint evaluation. The branch block was done on November 11. 2010. Neither helped his neck pain but he did get some relief from the headaches. (SCC 76) The last time Dr. Templer saw Peach was December 2, 2010 when Peach was offered an epidural injection which he refused.(SCC 77)

Dr. Templer's final diagnosis was: whiplash syndrome, chronic neck pain, cervical facet arthropathy, cervical annular tear, and possible cervical radiculopathy, cervical foraminal stenosis, cervical degenerative disc disease. This condition was absolutely caused by the motor vehicle collision of July 17, 2010 which also accelerated the degenerative changes to the disc.(SCC 79)

On cross-examination by defense counsel, the doctor was asked to assume the collision was at a speed slower than the 25 to 30 miles per hour described by Peach and what effect that would have had on the hyperextension of Peach's neck. The doctor's answer was that it would all depend on the kinetics. "I don't know the car he was driving. I don't know the weight. I don't know how much material was crushed, was not crushed. At a low impact it depends on what force is put from his car to the neck. It could be a low-speed injury, depending on the vehicles involved, and where the accident occurred where absolutely it could still cause a significant hyperflexion/extension injury."(SCC 81)

Defense counsel then asked if the photos of the two vehicles in the collision showed that the only damage to Defendants Mitsubishi Eclipse showed a bent license plate and "perhaps" a slight crack in the bumper and that the only damage to Plaintiff's Nissan truck was a "slightly" bent bumper would that affect his opinion as to whether any of the abnormalities were related to the accident. Dr. Templer said he could not answer the question just from the damage to the car. That is not his expertise. You can't say it definitely is not. He said he was relying upon the objective findings in the MRI. (SCC 82) Defense counsel then asked the Doctor to speculate whether some other event may have caused those findings. The doctor answered that "...a lot of things could have caused the injury but he did not know of anything. Everything fits for a hyperflexion/hyperextension injury for whiplash syndrome. These can occur even at low speeds. This is well documented."

The questioning continued in the same vein over standing objection. (SCC 83-84). The trial court overruled the objection.

At the close of evidence, the Court directed a verdict for plaintiff on negligence, reserving the questions of causation and damages for the jury.(SPC 148)

The first words out of Defense counsel's mouth in closing argument was: "A picture is worth a thousand words." He then spent his entire closing argument talking about the photographs and the doctor's answers to his speculative questions. (SPC 172-177)

The jury returned a verdict in favor of Defendant and against Plaintiff.(SCC 54) Judgment was entered on that verdict on February 23, 2016. (C 232) Plaintiff filed a Post Trial Motion on March 21, 2016 (C 233-235) which was denied May 27, 2016. Plaintiff filed his timely Notice of Appeal on June 20, 2016.(C248).

Defendant filed a motion to strike plaintiff's appendix and all related argument pertaining to the appendix in the appellate court. That motion was ordered to be taken with the case. The appendix consisted of two articles on the relationship between the damage to vehicles and injuries to the occupants of those vehicles. Neither article was submitted to the trial court as evidence in support of any argument asserted by plaintiff. The appellate court allowed the Motion to Strike, holding that since neither article was part of the record on appeal, the introduction of new evidence on appeal was improper.

ARGUMENT

I. The Photos and Testimony of Damage To the Vehicles Are Irrelevant To Show a Correlation Between Damage To The Vehicles and Injury To Their Occupants Without Supporting Expert Opinion That Satisfies the *Frye* Test

The appellate court held that photographs are not relevant to show a correlation between the damage to the vehicles and injury to the vehicle's occupants, citing *Baraniak v. Kurby*, 371 Ill. App. 3d 310, 312, 862 N.E.2d 1152, 1154 (1st Dist. 2007). "The *Baraniak* court recognized the rule set forth in *DiCosola v. Bowman*, 342 Ill. App. 3d 530, 794 N.E.2d 875 (2003), that "no Illinois case stands for the proposition that photographs showing minimal damage to a vehicle are automatically relevant and must be admitted to show the nature and extent of a plaintiff's injuries. There simply is no such bright-line rule that photographs depicting minimal damage to a post-collision vehicle are automatically admissible to prove the extent of a plaintiff's bodily injury or lack thereof." *DiCosola*, 342 Ill. App. 3d at 535."

The Fifth District concluded that where the injuries were as complicated as Mr. Peach's and his treating physician, Dr. Templer testified that they could occur in low impact collisions and Templer did not have the expertise to make the correlation between impact and injury, expert testimony was required before the photos were deemed relevant and admissible.

Plaintiff would go further. The best analysis of the question Plaintiff has been able to find is *Whiting v. Coultrip,* 324 Ill. App. 3d 161, 258 Ill. Dec. 111, 755 N.E.2d 494 (3d Dist., 2001). There, not only did the Appellate Court find that the introduction of vehicle damage photos to make the correlation between damage and occupant injury was reversible error, the testimony of Gerald Harris, an engineer specializing in biomechanics and biomedical engineering, and Fred Monick, an engineer were also ruled inadmissible. Monick calculated the forward and lateral gravitational forces (G-forces) experienced by plaintiff. Using Monick's findings, Harris determined that the amount of force actually experienced by plaintiff was not sufficient to cause the injuries alleged. W*hiting at* 164.

While neither the Appellate Court nor Plaintiff are advocating the adoption of the *Daubert* criteria for admission of scientific evidence, the case does have some value in determining what evidence should be evaluated by either test.

> "If the trial court determines that the proffered testimony [or evidence] will assist the trier of fact to understand the evidence or determine facts in issue, then the court must ask, does the proffered testimony constitute "scientific" evidence? In *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579, 125 L. Ed. 2d 469, 113 S. Ct. 2786 (1993), the Supreme Court averred that "science" represents a process whereby theories are proposed and refined. The word "scientific" implies a grounding in the methods and procedures of science while "knowledge" indicates more than a subjective belief or unsupported speculation. To qualify as "scientific knowledge" then, an inference or assertion must be derived by the scientific method. *Daubert*, 509 U.S. at 590, 125 L. Ed. 2d at 481, 113 S. Ct. at 2795. *Webster's* defines scientific method as "the principles and procedures used in the systematic pursuit of intersubjectively accessible knowledge and involving as necessary conditions the recognition and formulation of a problem, the collection of data through observation and if possible experiment, the formulation of hypotheses, and the testing and confirmation of the hypotheses formulated." *Webster's Third New International Dictionary* 2033 (1986)." *Whiting* at 166.

The Whiting Court then found that: "There is no evidence in the record that use of photographs and repair estimates is a generally accepted method in the field of engineering for determining G-forces. See generally, *Clemente,* 183 Misc. 2d at 934, 705 N.Y.S.2d at 800 HN11 (the use of repair costs and photographs as a method for calculating the change in velocity of two vehicles at impact is not a generally accepted method in any relevant field of engineering)." *Whiting* at 168.

After determining that the use of photos and/or testimony regarding those photographs to make a correlation between vehicle damage and the occupant's injury was based upon science, the *Whiting* Court subjected the testimony to a *Frye* analysis.

"If the trial court determines that the proffered testimony constitutes scientific evidence, then the court must ask, is that scientific evidence "novel," or does it involve instead a firmly established method or technique?"

Whiting at 167.

This Court has never examined this proffered and heavily used theory to deny damages to injured plaintiffs, nor has any Illinois Appellate Court examined the alleged correlation other than the *Whiting* Court. Defendant's claim that it is "common sense" is the usual claim of validity. In fact, the amicus brief of the IDC uses the term "common sense" (6 times), "reasonable inference" (10 times), "fair inference", "life experience", "ordinary experience", "accepted assumptions", "common logic", "common experience", and "simple inference" to support its claim that admission of photographs to argue that there is a correlation between vehicular damage and the occupant's injury is relevant and admissible. Nowhere in either brief, defendant's nor *amicus* IDC, are any medical or engineering studies or publications mentioned as supporting this alleged "common knowledge".

This Court has adhered to the "general acceptance' standard established in *Frye v. United States*, 54 App. D.C. 46, 293 F. 1013 (D.C. Cir. 1923) for the admission of scientific evidence.

In *Harris v. Cropmate Co.*, 302 Ill. App. 3d 364, 376, 235 Ill. Dec. 795, 805, 706 N.E.2d 55, 65 (1999) the Court explained the *Frye* plus reliability analysis:

> "In attempting to prove that evidence subject to *Frye* is admissible under that standard, its proponent may use -- and the trial court may consider -- the following: (1) scientific publications and law review articles; (2) prior judicial decisions in Illinois and other jurisdictions; (3) practical applications of the technique or method; and (4) testimony or affidavits of experts regarding (a) the acceptance of the technique or method within the relevant scientific community, and (b) the attitudes of their fellow scientists. See *Kirk*, 289 Ill. App. 3d at 332, 681 N.E.2d at 1077; see also 1 J. Strong, McCormick on Evidence § 203, at 870 (4th ed. 1992) (and cases cited therein).."

While defendant claims this is "common sense", the correlation between vehicle damage and occupant injury is a scientific question as the *Whiting* Court found, and as the Fifth District found in this case. There are authoritative publications contradictory to defendant's "logical" and "common sense" correlation.

~~In *Correlating Crash Severity With Injury Risk, Injury Severity, and Long-Term Symptoms In Low Velocity Motor Vehicle Collisions,* Croft and Freeman, Medical Science Monitor 2005, 11(10): RA316-321, (A1-6), the authors found that property damage is an unreliable predictor of injury risk or outcome in low velocity crashes. They also found that the MIST protocol for defense (Minor Impact Soft Tissue) formulated~~

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by various insurance companies to be invalid.

The same result was found in the paper *Lack of Relationship Between Vehicle Damage and Occupant Injury*, Robbins, M.C., SAE paper 970494, Society of Automotive Engineers, 1997;117-119.(A7-11) "...the crush damage does not relate to the expected occupant injury, i.e., the more vehicle damage, the more chance that the occupant is injured, is not a conclusion that can be made. In fact, it is more likely the reverse....This conclusion has been demonstrated by both mathematical expression and practical examples. " (p.119) The author then went on to describe the various factors and mathematical formulas that were necessary to take into consideration to qualify a valid opinion. Significant to this case, Robbins states that,

> "...on a vehicle with a chassis, no serious visual deformation may occur even though it is subjected to relatively high speeds of impact. Classically, we see this in the case of pickup trucks...that are traditionally fitted with a solid bumper-to-bumper chassis. Many of these types of vehicles are subjected to relatively severe impacts with little or no resulting damage to their bodies and bumpers... Motor vehicle bodies or bumper-to-bumper chassis offer little or no crushing effect on arresting obstacles when impacted; thus, relatively high G forces can be experienced by occupants when rear-ended, resulting in whiplash injury. The use of stiff motor vehicle bodies and chassis will also produce a spiked G force loading to occupants, even if little damage occurs to vehicle body or chassis." Robbins, p18.

Medical studies are equally critical of such assumptions. In *Deceleration During "Real Life" Motor Vehicle Collisions-A Sensitive*

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~~*Predictor For The Risk of Sustaining a Cervical Spine Injury?* Ebel, Kramer, Huber-Lang Hartwig and Dehner, Patient Safety in Surgery 2009, 3:5, (A12-19) the authors found that the predictive value of the trauma impact as assessed by the change in velocity of the car due to the collision for the resulting cervical spine injuries that they investigated for their study was not a conclusive predictor for cervical spine injury in real-life motor vehicle accidents.~~

~~Likewise, in *The Influence of Morphology on Cervical Injury Characteristics,* Stemper, Pintar and Rao, Spine, Volume 16, Number 25S, ppS180-S186, 2011, (A20-26) the authors found that there were many other factors that impacted the severity of injury in rear end collisions other than damage to the vehicle or force of impact and that low velocity contact can lead to serious injury.~~

The *Whiting* court, at 169, recognized that the testimony of these experts regarding the correlation of vehicular damage and occupant injury was not demonstrated by the "experts" to be "...generally accepted and empirically tested methods in determining that plaintiff could not have sustained the type of injury claimed...."

Defendant has not submitted a single peer reviewed publication in either the medical or engineering field to support her "common sense" theory.

At a minimum, this Court should require a party to comply with its ruling in *People v. New* (*In re Det. of New*), 2014 IL 116306, ¶ 25, 386 Ill. Dec. 643, 648, 21 N.E.3d 406, 411 when a party attempts to utilize a photograph or expert testimony to claim there is a correlation between damage to a vehicle and injury to an occupant. "In Illinois, the admission of scientific evidence is governed by the Frye standard (*In re Commitment of Simons*, 213 Ill. 2d 523, 529, 821 N.E.2d 1184, 290 Ill. Dec. 610 (2004) (citing *Frye v. United States*, 293 F. 1013 (D.C. Cir. 1923)), which has now been codified by the Illinois Rules of Evidence: ...., the proponent of the opinion has the burden of showing the methodology or scientific principle on which the opinion is based is sufficiently established to have gained general acceptance in the particular field in which it belongs." Ill. R. Evid. 702 (eff. Jan. 1, 2011).

While it may seem to be a simple correlation given the acceptance by Courts who believe they have the requisite "common sense knowledge" in the misconception and rule favorably on admission of the photographs and allow opening and closing arguments based upon the photographs, it is not so simple and leads, as here, to severely injured Plaintiffs receiving little or no compensation.

Here, defendant submitted no testimony or other corroborating evidence to validate her argument. Defense counsel was allowed to make the argument without exposure to cross examination, essentially becoming defendant's star witness.

This Court, in *Voykin v. Estate of Deboer*, 192 Ill. 2d 49, 59, 248 Ill. Dec. 277, 282, 733 N.E.2d 1275, 1280 (2000), recognized that the human body is complex and that how a prior injury effects a person's current injury is a question which cannot be answered by laymen and requires medical testimony. So too the effect on the body of the occupant of a vehicle when struck by another vehicle is dependent on many variables. It is only reasonable to require expert testimony that is based upon generally accepted scientific bases before finding that photos showing minimal damage to the vehicle or vehicles involved equates to prove or disprove the severity of the injury to the occupants of that vehicle.

It was once "common knowledge" that the earth was flat. It is time we dispose of the "common knowledge" that there is a correlation between damage to a vehicle and the injury to its occupant. The Appellate Court's holding regarding the inadmissibility of the photographs in this case should be affirmed.

II. Even if the Appellate Court's Decision is Held to Be a Judgment *Non Obstante Veredicto*, the Facts of the Case Justify the Appellate Court's Decision

Defendant is correct that the standard to be applied to the grant of a Judgment n.o.v. is that it must be shown that"...the evidence, when viewed in its aspect most favorable to the opponent, so overwhelmingly favors movant that no contrary verdict based on that evidence could ever stand." *Maple v Gustafson,* 151 Ill.2d 445, 453, 603 N.E.2d 508,177 Ill. Dec. 438 (1992) citing *Pedrick v. Peoria & Eastern R.R. Co.,* 37 Ill.2d at 510.

The issues to be decided by the jury were: was the plaintiff injured and was the defendant's negligence the proximate cause of plaintiff's injuries (Plaintiff's instruction 25, IPI 21.02 Modified, C32) and the nature and extent of plaintiff's injuries and the amount of damages to be awarded for those injuries.(Defendant's instruction 3A, IPI 30.01, given over Plaintiff's objection, C 33).

The Appellate Court in this case correctly held that testimony about the speed and force of impact and the extent of damage to the vehicles and the photographs of the vehicles was irrelevant and improperly admitted. That testimony and evidence should not to be considered when analyzing the remaining issues before this Court.

The parties agreed that their vehicles collided and that Plaintiff was stopped at a stop sign when Defendant's vehicle struck the rear of Plaintiff's truck. The parties agreed that there was damage to both vehicles. Defendant admitted that she pleaded guilty to failure to reduce speed to avoid an accident and that she left the scene of the accident prior to the arrival of the police.

The uncontested testimony was that Plaintiff was injured as a result of the collision. The medical testimony of Dr. Templer was uncontested by any witness as was his testimony that Plaintiff's injuries could be caused by a low impact collision.

Defendant's argument on this issue assumes that the photos and defense counsel's "testimony" in opening and closing was relevant and admitted. She also assumes that there is some issue of credibility which would allow the photos admission. Whether or not the defendant's speed on impact was 5mph or 30mph is irrelevant to any issue in the case because speed on impact is only one of many variables that determine the extent of plaintiff's injuries, ~~*The Influence of Morphology on Cervical Injury Characteristics*, Stemper, Pintar and Rao, Spine, Vol. 36, No. 25S, pp S180-S186, (A20-26)~~ and no witness' relevant testimony took into consideration or depended on speed at the time of impact or the amount of damage to the vehicles which is irrelevant. Dr. Templer was quite clear: "Everything fits for a hyperflexion/hyperextension injury for whiplash syndrome. These can occur even at low speeds. This is well documented." Templer deposition, p 49, SC C 83. ~~See for example: *Deceleration During 'Real Life' Motor Vehicle Collisions—a Sensitive Predictor for the Risk of Sustaining a Cervical Spine Injury?*, Elbel, Kramer, Huber-Lang, Hartwig and Dehner, Patient Safety in Surgery, 8 March 2009. (A12-19)~~

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Defendant's interpretation of Doctor Templer's testimony is specious. There was extensive testimony about objective evidence of Plaintiff's injuries. Dr. Templer testified about the MRI taken after the collision: "The first thing that stands out is there's straightening of what's called the normal cervical lordosis...That's consistent with muscle spasm and pain....He had a right posterolateral disc protrusion at C3-4....This resulted in a foraminal narrowing on the right side, so where the nerve comes out the right...that would be the C4 nerve. There is compression of the right lateral recess, compression of the dural sac and compression of the anterior margin of the spinal cord, all on the right side." Deposition of Dr. Michael Templer, January 22, 2016, pp 11-12, SC C73-74.

....

"....[A]lso on C3-4, at that level there is no spurring noted which would be more consistent with degenerative changes. The disc was hydrated. Both of these represent acute findings....[T]hat would mean that they're recent, that these aren't degenerative changes that he's accumulated, that this is something that would be recent." pp 14-15, SC C 74.

....

"At C5-6 he has minimal disc bulging. There's a small central nuclear protrusion. This is confined by the outer annular fibers.

Slight compression of the anterior margin of the dural sac." p 17, SC C 75

....

"...This showed essentially what's called an annular tear or an annular fissure, which is—you get something called a high-intensity zone, a white area in the disc. This is consistent with a tear to the disc. Once again, this is more of an acute or subacute finding, something that's happened recently....When that tears, that can be a source of pain. We have nerve fibers in the outer annulus, so that can cause neck pain directly."

....

"This is a more of an acute finding. Once again, this disc...appeared also to be hydrated, meaning that on the MRI there was good water content in the disc, meaning this would also represent more of an acute/subacute finding." Pp 17-18, SC C 75

....

"He had cervical sprain or strain, which is consistent with—it's essentially what whiplash is. So what happens when we're involved with an injury, rear-ended..." P 19, SC C 75

....

Q. Doctor, what's your final diagnosis?

A. Whiplash syndrome, chronic neck pain, cervical facet arthropathy, cervical disc herniation, possible cervicogenic pain, cervical annular tear, and possible cervical radiculopathy, cervical foraminal stenoses, cervical degenerative disc disease.

"Q. Doctor, do you have an opinion based upon a reasonable degree of medical certainty as the whether or not any of those conditions were caused by the motor vehicle accident of October (sic) 17, 2010?

A. Absolutely, I'd say that the whiplash would be caused by it. I think there's a good chance that the annular tear that we talked about, the integrity of the loss of the disc that was reported at C5-6 could have been caused by the accident. The facet disease could certainly and is common to be caused by whiplash injury. The foraminal narrowing and the radicular symptoms can be caused by the disc material which could be caused by the accident. It can accelerate degenerative changes to the disc." pp 34-35, SC C 79.

Defendant claims that the Doctor equivocated on the cause for Plaintiff's injuries. Defense counsel is basing that on the admission by the doctor that there could be another cause.

First, the questions were objected to from the inception as asking the Doctor to speculate. There was no evidence of another proximate cause and the trial court erred in overruling plaintiff's objection to the line of questioning. Templer deposition, pp 48-49, SC C 83. The line of questioning which allegedly led to defense counsel's argument that the collision was not the proximate cause of plaintiff's injuries was not as counsel would have it be.

"Q. Would you agree with me that the objective findings did not tell you in and of themselves whether they were related to this automobile collision or not?

A. No. Obviously unless you have an MRI right before and right after, I don't know where that's ever happened. I can only say that—what's acute and subacute, the findings that I find.

Q. Okay. So there could have been some other event—

A. Of course.

Q. --that caused that—those findings?

Mr. Ripplinger: Well, now I'm going to object that you're asking the doctor to speculate.

....

Mr. Adelman: Then let the doctor answer.

Mr. Ripplinger: I will, but under—over an objection.

(The trial judge overruled the objection.)

Doctor Templer: You know, I—I don't know. I go on—based on what I'm told. I'm sure a lot of things could have happened. Maybe—to my knowledge, he was not in another car injury. Everything fits for a hyperflexion/hyperextension injury for whiplash syndrome. These can occur even at low speeds. This is well documented.

Q. But you don't know the extent of that hyperextension in this particular accident, do you?

A. No. There's absolutely no way to tell. He—we can go based on the objective findings, but there is no way to tell unless you have video footage of his neck snapping forward and backward. Even very low speed collisions can cause hyperflexion/hyperextension injuries. That's well documented. That's not just me saying that. Especially—he was rear-ended; correct?

Q. Doctor, I—you're the one who's testifying. Was he rear-ended?

A. Yes. Was—that was my question. That was my understanding, he was rear-ended, meaning that he was surprised when it happened, meaning that we're more likely to see these injuries.

Q. All right. And he told you that the estimated speed was 25 to 30 miles per hour; is—

A. That's—

Q. --that correct?

A. That's –that's what's written down. Yes.

Q. Okay. Now, Doctor, you testified that he had multiple abnormalities in part of your final diagnosis; is that correct?

A. Yes, it is.

Q. And you told—and you testified they could have been caused by this accident; isn't that correct?

A. Yes.

Q. It's also true that they might not have been caused by this accident; isn't that correct?

A. Yes. That's true. It might not have been caused by the accident.

Q. In fact, he had—before the accident he had degenerative disc disease in his spine—in his cervical spine; isn't that correct?

A. He had some mild facet disease that was—and I did review the images of his CT, which is going to be the best thing to see, were very minimal changes which were appropriate for our age.

Q. All right. And many of the objective findings that you found were as—were as a result of that degenerative disc disease; isn't that correct?

A. Were any of them?

Q. Many of them.

A. Some of them were the result of degenerative changes I think you could say, yes." Templer deposition, pp 48-51. SC C 83.

"Opinion testimony that is purely speculative in nature and based on guess, surmise or conjecture is inadmissible and is tantamount to no evidence at all. *Poulakis v. Taylor Rental Center, Inc.*, 209 Ill. App. 3d 378, 383, 568 N.E.2d 196, 199, 154 Ill. Dec. 196 (1991)" *DiCosola v. Bowman*, 342 Ill. App. 3d 530, 538, 276 Ill. Dec. 625, 632, 794 N.E.2d 875, 882 (2003). Defendant called no opinion witness to contradict the testimony of Dr. Templer. The doctor testified on direct examination that some of plaintiff's conditions of ill being were not caused by the collision. Dr. Templer was asked to speculate on other causes. There was no evidence of any other cause and the Doctor had previously testified that he was "absolutely" sure of the injuries that were proximately caused by the collision. The trial Court should have sustained the objection to this line of questioning and barred the defendant from arguing that the injuries were not from this collision as the Court did in *DiCosola*.

The only thing the parties disagreed on was the speed at impact and whether Peach's truck was pushed into the intersection by the force of the impact; two irrelevant facts.

Defendant's argument that the photos are relevant to question plaintiff's and his treating physician's credibility is strikingly similar to the argument made by defendant in *Baraniak:*

> "Defendant argues that the vehicle photographs were not admitted into evidence in order to support a connection between the amount of the property damage and the extent of plaintiff's injuries but were used to aid the jury in assessing plaintiff's credibility when she testified that the impact was "hard." To illustrate her point, defendant cites to defense counsel's closing argument, in which he stated: "When you take these photographs back into the jury room, you can use them to [the] issue of credibility. The plaintiff testified that this was a really hard or heavy impact. Now, since so much of what is going on here depends on her credibility, take a look at the photos and see whether it is credible that this is a hard or heavy impact or the defendant's testimony that this was a light impact, a fender bender impact, so to speak ***."During the trial, none of the medical expert witnesses testified that the amount of the damage to plaintiff's vehicle correlated to her injuries. Although plaintiff's credibility was an issue for the jury to determine, that is true in every case since it is axiomatic that it is the function of juries to determine the credibility of all of the witnesses who testify before them. If we were to accept defendant's reasoning, we would essentially be conducting an end run around the relevancy rule, and photographs of damaged vehicles would always be admissible in trials of this nature on the grounds that credibility is always an issue. The effect of such a ruling would be to allow parties to accomplish indirectly what the courts have already determined is improper absent expert testimony, i.e., to argue or even imply that there is a correlation between the extent of vehicular damage and the extent of a person's injuries caused by an accident. Therefore, upon retrial, absent expert testimony on the correlation between the vehicular damage and plaintiff's injuries, the photographs of the parties' damaged vehicles shall be excluded." *Baraniak v. Kurby*, 371 Ill. App. 3d 310, 317-18, 308 Ill. Dec. 949, 955-56, 862 N.E.2d 1152, 1158-59 (2007).

The holding of the Appellate Court in this case should be affirmed. The evidence, when viewed in its aspect most favorable to the defendant, so overwhelmingly favors plaintiff that no contrary verdict based on that evidence could ever stand.

III. Should This Court Determine That the Evidence Does Not Support Remand for a Trial on Damages Only, the Court Should Remand for a New Trial and Bar the Defendant from Use of the Photographs, Testimony Regarding Speed of Impact, Damage to the Vehicles and Asking the Doctor to Speculate on Other Causes for Plaintiff's Injuries

"...[O]n a motion for a new trial, a court will weigh the evidence and set aside the verdict and order a new trial if the verdict is contrary to the manifest weight of the evidence. *Maple*, 151 Ill. 2d at 454. A verdict is against the manifest weight of the evidence where the opposite result is clearly evident or where the findings of the jury are unreasonable, arbitrary, and not based on the evidence. *Maple*, 151 Ill. 2d at 454. A court's ruling on a motion for a new trial will not be reversed except in those instances where it is affirmatively shown that it clearly abused its discretion. *Maple*, 151 Ill. 2d at 455. In determining whether the trial court abused its discretion, the reviewing court should consider whether the jury's verdict was supported by the evidence and whether the losing party was denied a fair trial. *Maple*, 151 Ill. 2d at 455." *Jackson v. Seib*, 372 Ill. App. 3d 1061, 1068-69, 310 Ill. Dec. 502, 511, 866 N.E.2d 663, 672 (2007).

Plaintiff will not be repetitive and repeat the statement of the evidence recited in the previous argument. Suffice to say, if the facts of this case do not justify the Appellate Court's decision below, the jury's verdict was clearly not supported by the admissible evidence and Mr.

Peach was clearly denied a fair trial. Plaintiff requests this alternate relief if the Court does not believe the prior argument is valid.

~~ARGUMENT FOR CROSS RELIEF~~

Stricken by order 8-3-18

The Appellate Court Should Not Have Stricken the Secondary Authority Cited by Plaintiff and Included in the Appendix and This Court Should Consider Them and the Others Cited by Plaintiff in This Brief and Included In This Appendix

The Appellate Court struck from Plaintiff's brief and appendix the reference to and the copies of two scientific peer reviewed articles which are cited in this brief and are included in the Appendix to this brief: *Correlating crash severity with injury risk, injury severity, and long-term symptoms in low velocity motor vehicle collisions,* Croft and Freeman, Medical Science Monitor 2005, 11(10): RA316-321 (A1-6) and *Lack of Relationship Between Vehicle Damage and Occupant Injury*, Robbins M.C., SAE paper 970494, Society of Automotive Engineers, 1997;117-119. (A7-11) The Court held that since these articles were not presented to the trial court they constituted evidence that was not in the record and could not be so included, citing *People ex rel. Madigan v. Leavell*, 388 Ill. App. 3d 283, 287, 329 Ill. Dec. 11, 16, 905 N.E.2d 849, 854 (2009).

The article were not included in Plaintiff's Brief as evidence. They were cited as secondary authority to explain why the plaintiff challenged evidence, the vehicle photographs, and objected to Defendant's attorney's

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argument that there was a direct correlation between that damage to the vehicles and injury to their occupants.

In *People v. Schaap* (*In re Schaap*), 274 Ill. App. 3d 497, 501, 211 Ill. Dec. 274, 276, 654 N.E.2d 1084, 1086 (1995) the State moved to strike portions of respondent's brief which quoted medical texts to support his position that the trial court should not have ordered involuntary administration of psychotropic drugs for respondent. The Appellate Court held that: "A court of review must determine the issues before it based upon the evidence presented to the trial court. (People *v. Reimolds* (1982), 92 Ill. 2d 101, 106-07, 65 Ill. Dec. 17, 440 N.E.2d 872.) However, a reviewing court is entitled to rely on secondary authority where there is no controlling primary authority. (See *SK Handtool Corp. v. Dresser Industries, Inc.* (1993), 246 Ill. App. 3d 979, 986, 189 Ill. Dec. 233, 619 N.E.2d 1282.)."

The prior decisions have been without consistency and have required each trial court to make a decision about requiring expert testimony without any standard to guide them. The cases cited by Plaintiff and Defendant in this case make that clear. Where the courts have allowed an expert to opine on the issue, no basis except the fact that the witness is a doctor and claims to have such knowledge was given. No studies were cited or scholarly journals were introduced to support the expert's opinion. See for example the unsupported testimony

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~~in *Fronabarger v. Burns*, 385 Ill. App. 3d 560, 563-564 (5th Dist., 2008) and *Jackson v. Seib*, 372 Ill. App. 3d 1061, 1066-1067(5th Dist., 2007)~~

~~These articles clearly show that there is no possible way to justify such a correlation without expert testimony and even with it, there is no scientific justification to make such a correlation. They were and are submitted to interpret the evidence and testimony, not to be evidence and submitted as such as was approved in *People v. Wilhoite*, 228 Ill. App. 3d 12, 23(1st Dist., 1991) where the DSM-III-R was used to explain doctors' testimony. "...[W]e may consider scholarly authority referred to by the parties in interpreting the evidence. (People v. Garrett (1975), 62 Ill. 2d 151, 339 N.E.2d 753.)"~~

~~The Appellate Court erred in striking the articles, plaintiff requests this Court to allow their citation and take them into consideration in ruling in this case.~~

CONCLUSION

Wherefore, for the foregoing reasons, Plaintiff respectfully requests that this Court affirm the judgment of the Appellate Court of Illinois Fifth Judicial District and remand this case for a trial on damages. This Court should further order that testimony regarding speed of the vehicles at impact or damages to the vehicles after impact and photographs of the damage to the vehicles after impact should not be admissible.

In the alternative, Plaintiff respectfully requests that this Court affirm the judgment of the Appellate Court of Illinois Fifth Judicial District and remand this case for trial. This Court should further order that testimony regarding speed of the vehicles at impact or damages to the vehicles after impact and photographs of the damage to the vehicles after impact should not be admissible.

~~As to the Request for Cross Relief, Plaintiff prays that the order of the Appellate Court, Fifth Judicial District, granting Defendant's motion to strike the academic publications from Plaintiff's Brief and Appendix be reversed.~~ stricken by order

Respectfully submitted,

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CERTIFICATE OF COMPLIANCE

Under penalties as provided by law pursuant to Section 1-109 of the Code of Civil Procedure, the undersigned certifies that this Appellee/Cross Appellant's Brief conforms to the requirements of Rule 341(a) and (b). The length of this Brief, excluding the pages contained in the Rule 341(d) cover, the Rule 341(h)(1) statement of points and authorities, the Rule 341(c) certificate of compliance, the certificate of service, and those matters to be appended to the brief under Rule 342(a), is 30 pages.

/s/ George R Ripplinger

PROOF OF SERVICE

The undersigned certifies that on the 6th day of July, 2018, he caused the foregoing Appellee/Cross Appellant's Brief to be electronically filed with the Supreme Court of Illinois by using Odyssey EfileIL system, and a copy of the Appellee/Cross Appellant's Brief to be served electronically by the Odyssey EfileIL System upon counsels for the defendant eadelman@grlawstl.com and mmorrissey@reedarmstrong.com.

Under penalties as provided by law pursuant to Section 1-109 of the Code of Civil Procedure, the undersigned certifies that the statements set forth in this instrument are true and correct.

/s/ George R Ripplinger

A1 thru A26 stricken by order of 8/3/18 and any argument in appellee's brief

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Correlating crash severity with injury risk, injury severity, and long-term symptoms in low velocity motor vehicle collisions

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Source of support: Self financing

Summary

Background: Auto insurers use a variety of techniques to control their losses, and one that has been widely employed since the mid-1990's is the Minor Impact Soft Tissue (MIST) segmentation strategy. MIST protocol dictates that all injury claims resulting from collisions producing US$1000 or less in damage be "segmented," or adjusted for minimal compensation.

Material/Methods: Multiple databases were searched for studies comparing any of three dependent variables (injury risk, injury severity, or duration of symptoms) with structural damage in motor vehicle crashes of under 40 km/h (25 mph).

Results: A limited correlation between crash severity and injury claims was found. We could not determine, however, whether this relationship held across all crash severities. Other studies provided conflicting results with regard to acute injury risk, but both found no statistically significant correlation between crash severity and long-term outcome.

Conclusions: A substantial number of injuries are reported in crashes of little or no property damage. Property damage is an unreliable predictor of injury risk or outcome in low velocity crashes. The MIST protocol for prediction of injury does not appear to be valid.

key words: crash severity • property damage • whiplash • Minor Impact Soft Tissue (MIST) • motor vehicle crash

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Background

In the mid-1990s, a set of guidelines was published by a leading U.S. auto insurer for claims adjustors concerning the handling of certain types of crash-related injury claims [1]. This training manual identified injury claims resulting from motor vehicle crashes with US$1000 or less in claimant's vehicle property damage as those that should be categorized, or "segmented," separately from all other injury claims. Claims adjustors were instructed that, as a general precept, crashes with minimal damage are unlikely to-or cannot-cause significant or permanent injury. Thus, any claim for injury in the presence of minimal vehicle property damage was to be handled as a type of fraudulent claim and claims adjustors were instructed that, regardless of medical evidence of injury, the injury should not or could not have occurred because of the nature of the crash, and the claim goal was to close without payment. The MIST claims segmenting protocol continues to be used up to the present time, and many other insurers have adopted similar claims handling practices based on an assumed lack of relationship between vehicle property damage below a certain monetary level and the potential for injury.

The MIST protocol uses vehicle property damage as a construct for injury presence rather than probability, as all injury claims in the presence of <$US1000 vehicle property damage are considered to be false, while crashes with >$US1000 vehicle property damage are considered as possibly injury producing, with the medical records used as the determinant of injury presence and severity.

The purpose of the present study is to synthesize the published literature for evidence that allows for validation of a system that can accurately predict injury presence, severity, or duration based solely on vehicle property damage levels.

Within the epidemiological and clinical literature, authors have traditionally described injuries occurring in motor vehicle crashes in various ways: on a nominal scale such as acute injury vs. no injury; on an ordinal scale of severity of injury; or on an interval scale of time for prolonged symptoms. Crash severity has also been variously described in terms of crash velocities, component crush (property damage or structural damage), total repair costs, or tow-away status. The hypothesis we endeavored to assess in this best evidence synthesis is that property damage following low velocity frontal or rear impact motor vehicle crashes can be shown to be quantitatively related to any of three injury metrics: initial injury presence, injury severity, or symptom duration. Given that vehicle property damage levels are not used by insurers as a means to predict injury but rather as a determinant that injury is not present, the validity of MIST segmentation protocol can be judged by the level of specificity of the technique (defined as the percentage of cases not injured that are identified correctly), and negative predictive value of the technique (defined as the percentage of cases identified by MIST as not possibly injured that are truly uninjured). We conducted a comprehensive best evidence synthesis of the existing medical and engineering literature to investigate the relationship between vehicular structural damage and occupant injury in motor vehicle crashes.

Material and Methods

We conducted literature searches of MEDLINE, CINAHL, WebDex, Road Safety Library, and the Transportation Library literature databases for years 1970 to 2005, inclusively, using a variety of search terms designed to identify studies correlating occupant injury occurring in motor vehicle crashes to some measure of crash severity. This search was augmented by studies previously known to the authors as well as by supplemental studies identified within the papers reviewed. Because side impact and roll-over crashes are associated with higher levels of property damage and significantly higher risks for occupant injury or fatality, these crash types were excluded to avoid confounding effects and only crashes defined as chiefly frontal (from 11 o'clock to 1 o'clock) or rear (from 5 o'clock to 7 o'clock) were considered in this synthesis. Reports focusing on high velocity crashes of 40 km/h (25 mph) or more were excluded since more than 95% of rear impact injury crashes are reported to occur below this speed [2] and because this is one of the most prevalent and expensive injury mechanisms in motor vehicle trauma, with an estimated annual comprehensive cost in the U.S. of $42.9 billion [3].

Only papers published in peer reviewed journals were considered acceptable. We included only those studies in which the authors correlated the resulting vehicle property damage with at least one measure of injury risk. Only studies in which some reliable methodology of damage assessment was identified, such as investigation by trained crash investigators, crash reconstructionists, or insurance investigators was deemed suitably robust for this analysis.

In addition to literature satisfying our inclusion criteria, we identified a number of studies in which the authors described crash severity only in terms of crash velocity. This material was considered as supplemental to the structural damage studies because structural damage is related to crash velocity and allows some assumptions to be made about structural damage.

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Results

Sixteen citations were discovered initially. Of these, 12 were later excluded based on exclusion criteria described above. In the largest study reviewed, the authors examined all rear impact property damage liability claims across 38 states from 1993 through 1996. From a total of 32,904 eligible claims from State Farm Mutual Automobile Insurance Company, 5083 claims were included [4]. Vehicles studied were restricted to a subset of those judged to be approximately similar in size and weight to each other and did not differ significantly in design from those of model year 1995. Damage to the vehicle was coded as *minor* if only the bumper, bumper cover, rear body panel, or tail lamp were repaired; *moderate* if repairs were made to the bumper reinforcement, bumper energy absorber (isolator), deck lid, or quarter panels; and *severe* if either the trunk floorpan or frame were repaired, or if the car was declared a total loss. Data for each stratum were weighted by the reciprocal of the sampling probability to obtain estimated neck injury rates across all claims and statistical testing was preformed. Logistic regression was used to model neck injury risk on the basis of sex, age, direction of impact, crash location, repair cost, damage severity, and the head restraint rating of the Insurance Institute for Highway Safety (IIHS) for that particular vehicle. Neck injuries were found to be more likely among drivers of directly rear-struck cars, vs. those struck in a rear corner, and also in more severe crashes. Controlling for other factors in the logistic regression, head restraints rated "good" conveyed a 24% reduction in risk.

In tort and add-on tort liability states, 30% of female drivers and 23% of male drivers reported neck injury. On the basis of property damage, the risk of injury claim increased with increasing severity. However, injuries were common even in the minor category and the differences in injury claims between categories was not large (20% for minor property damage; 27% for moderate property damage; 41% for severe property damage). Significant differences were reported when comparing minor to severe property damage for both males and females, and when comparing moderate to severe for males. No comparative data were provided comparing minor to moderate damage-information that would be necessary to examine the entire continuum of this relationship. On the basis of repair cost, the reported proportion of claims with neck injury increased incrementally with increasing repair cost, although the differences between the lowest category, <$500, and the next category, $500–999, was only 2% for males and 4% for females, and no significance figures were provided. In their logistic regression, when property damage was dichotomized between *more than $1000 damage* and *less than $1000 damage*, the authors reported that the results were significant, but only for females.

A smaller study was conducted by Olsson et al. [5]. Twenty-six rear impact crashes with 33 front seat occupants were followed longitudinally for 12 months. All were Volvo vehicles that had crashed in 1987–1988 in Gothenburg, Sweden. None of the cars would have been equipped with the Volvo Whiplash Protection Seat (WHIPS), which became available only a decade later. A detailed crash investigation and subject interview was conducted. Crash severity from deformation of the vehicle was converted into energy equivalent speed (EES) based on barrier crash tests. The authors further characterized the crashes as either *soft* or *stiff* depending on whether or not the rear side member was activated (struck or permanently deformed) or not. The authors also estimated the head restraint geometry in terms of the horizontal distance between the head and head restraint. This dimension is also known as the *backset*. Data were subjected to logistic regression analysis.

Of the 33 subjects in the study, 88% were initially injured. At 12 weeks, 39% continued to be symptomatic. At 12 month follow-up, 36% continued to have symptoms. Symptoms were significantly prolonged when backset distance exceeded 10 cm. The calculated EES was less than 10 km/h (6.2 mph) for six subjects and between 10 km/h and 20 km/h (10.4 mph) for 20 occupants. It was more than 20 km/h for seven cases. No correlation was found between either EES or *soft* vs. *stiff* crash characteristic and the duration of neck symptoms or type of neck symptoms. Notably, of the four subjects in the study who were not injured, all had damage to the side members of their cars which the authors defined as *stiff* crashes. Of the crashes described as *soft* (e.g., less property damage), 60% of the subjects had symptoms exceeding 12 months compared to only 32% of those injured in *stiff* collisions, suggesting a paradoxic relationship between crash severity and injury severity within this crash range.

A similar sized study was conducted in Australia [6]. The authors recruited 32 subjects from the offices of physiotherapists and general medical practitioners, as well as through radio station and newspaper ads. Subjects were interviewed and examined. The subjects' vehicles were inspected as were crash partner vehicles when possible. In addition to crash severity, independent variables considered by the authors included head orientation at time of the crash and awareness of the impending crash. Crashes included rear impacts (68.8%), frontal impacts (15.6%), side impacts (12.5%), and 3.1% unknown. Most crashes were reported as being relatively minor with velocity changes calculated to be between 10 km/h (6.2 mph) and 19 km/h (11.8 mph). Maximum deformation was 0–49 mm in 25%, 50–100 mm in 21.9%, >100 mm in 37.5%, and unknown in 15.6%. The authors applied correlational statistical analysis. They found a statistically significant correlation between maximum deformation and both the subjects' severity rating and examiners' severity rating for all crashes and for rear impact crashes considered in subset analysis. The authors reported that, "in a few cases, there was almost no vehicle damage."

These authors followed this group of subjects for 6 months and reported their findings in a subsequent paper reporting no statistically significant associations between crash severity and the 6-month injury status [7], although they found that persons who were unaware of the impending crash were significantly more likely to have persistent symptoms. In total, 66% of the 29 subjects followed at 6 months continued to have symptoms attributable to their crashes. No statistically significant relationships existed between measures of crash severity in terms of calculated velocity change or maximum deformation and long-term symptoms.

SUPPLEMENTAL LITERATURE

Some relationship between crash velocity and structural damage can be safely assumed. The quantitative correspondence, in low velocity crashes, between structural damage and crash velocity is not linear, however. Most passenger cars are capable of absorbing bumper to bumper contacts without appreciable damage at low speeds. We searched for supplemental literature describing damage tolerances or thresholds for rear or frontal crashes. Seven studies were found in which the thresholds for structural damage could be determined [8–16]. Reported damage thresholds ranged from closing velocities from 7.7 km/h (4.8 mph) to 16.3 km/h (10.1 mph) and delta Vs ranging from 12.9 km/h (8.0 mph) to 19.3 km/h (12.0 mph). The latter figures imply slightly higher closing velocities based on principles of physics. In many cases, multiple crashes were conducted in this crash speed range before structural damage was reported. These results can then be compared to real world crash statistics.

In a study of rear impact crash injuries which were recorded with on-board crash pulse recorders, the reported mean delta V was 10.0 km/h (6.2 mph) for injuries lasting less than one month and 20.0 km/h (12.4 mph) for those lasting longer than one month [17]. In another real world

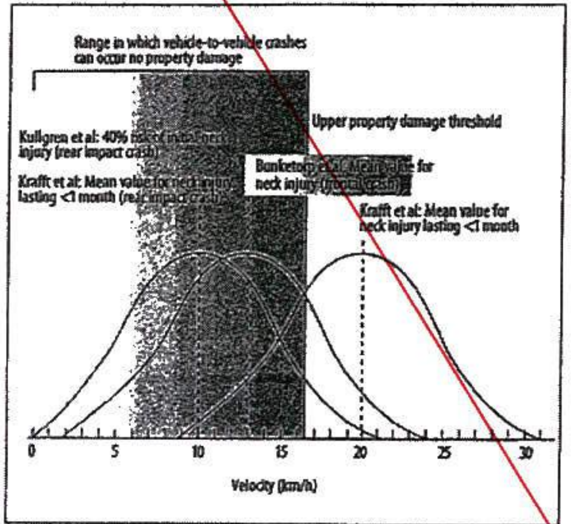

Figure 1. Note that curves were used here only for the purpose of illustration. Only the mean values (dashed lines) are known with confidence.

study employing crash pulse recorders, the risk of initial neck injury in a rear impact collision was 40% at a delta V of 10 km/h (6.2 mph) [18]. For frontal crashes, the mean injury delta V has been reported to be somewhat higher at 13.0 km/h (8.1 mph) [19]. In an analysis of whiplash injuries, the majority of which occurred in rear impact crashes, 24% were reported to occur in crashes with delta Vs of 0–5 km/h (0–3.1 mph); another 49% were reported in crashes of 5.0–10.0 km/h (3.1–6.2 mph) [20].

One can safely assume that any distribution of crash velocities producing mean values of 10.0–20.0 km/h and 13.0 km/h will also include crashes at lower speeds. A proportion of these would fall well below the structural damage thresholds reported above. According, it is logical to assume that injuries are not uncommon in crashes with minimal or no structural damage, Figure 1.

DISCUSSION

In the Farmer et al. [4] study, the majority of claims had some degree of property damage, and we could not determine what proportion of people with no property damage had injuries from this study design. The main limitations to the study were that the subjects' medical and other records were reviewed only by claims adjustors and no questionnaires or contacts were made with claimants to verify injury type, severity, duration, or persistence. When dichotomizing repair cost to under vs. over $1000, significance was found only for females and the authors did not report a comparison between minor vs. moderate property damage, which limits the conclusions that can be drawn since the lower part of this crash severity vs. injury risk continuum cannot be evaluated. The study has strength from the standpoint of its size, but is limited in its retrospective record review design and missing correlative range.

In the Olsson et al. [5] study, there were apparently no non-injured persons and a potential self-selection bias existed. It is not clear whether there were any crashes with zero property damage. From the standpoint of the occupant's physical experience in a given crash, a more plastic deformation of the car's structural components can provide the occupants with some degree of ride down. Thus, the authors' designation of soft and stiff may be misleading in terms of injury risk. One other potential problem concerns external validity. There was a disproportionately large male make-up of this group (88%). Females, however, are injured with twice the frequency than males [21,22].

In the Ryan et al. [6,7] studies, crash severity was found to correlate with injury severity as judged by both the subjects themselves and the examining therapist in the acute phase, but this significance did not persist at the 6-month follow-up period. These studies, like the Olsson et al. [5] study, while small, have the advantage of a prospective design and more valid injury assessment than the Farmer et al. [4] study. In both longitudinal studies, no significant correlations were found between crash severity and long-term symptoms [7,23]. These findings are summarized in Table 1.

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Our supplemental literature review demonstrates that passenger cars can collide with one another in a collinear fashion at low speeds without sustaining appreciable damage and that at or below these crash speeds, epidemiological studies demonstrate that a substantial injury risk exists in frontal and rear impact crashes. Coupled with the report in the four studies mentioned that property damage was often of a very minor nature in cases with reported injuries, it seems clear that property damage in low velocity motor vehicle crashes does not provide a reliable means of assessing the validity of injury claims and, considering the two longitudinal studies we reviewed, provides no reliable means of prognosticating long-term outcome. It is likely that other factors, such as being aware of an impending impact [7] and relative head restraint rating [4] or geometry [5] are competing, and perhaps stronger, determinants of injury risk than property damage in low velocity crashes of this type.

CONCLUSIONS

In our comprehensive literature review, we found only four papers that compared property damage resulting from low velocity motor vehicle crashes to any of three injury categories (injury risk, injury severity, or duration of symptoms) which were conducted using acceptable scientific rigor and statistical assessment of the results. Two of the papers reviewed in this analysis followed the same group of 32 subjects. Another study followed only 26 subjects. In the largest dataset (n=5083 claims) the authors did not interview or examine the subjects. They reported injury claims and, in cases in which the records allowed them to determine it, symptoms exceeding 6 months. These claims were apparently not all verified and no information was available regarding injury severity or long-term symptoms outside of retrospective claims review of insurance files by non-physician claims persons. Damage assessment was made on the basis of repair costs and did show a positive correlation between increasing costs and property damage. However, it was not clear whether a continuous relationship existed across all crash severity categories, since differences between the two lowest ranges were marginal and since one comparison group was omitted from analysis without ex-

Table 1. Studies Correlating Crash Severity and Injury.

Study	n	Type (class of evidence)	Outcome measure	Correlation between crash severity and outcome measure?	Strengths of study	Limitations of study
Farmer et al. [4]	5083	Retrospective file review (class III)	Injury claim; symptom duration more than 6 months. Repair records for property damage	Yes, in damage severity and in repair costs in some categories	Large dataset covering 38 states	Weak outcome assessment. No subject examination or follow-up. Weighted toward property damage only claims
Olsson et al. [5]	33	Longitudinal cohort (class II)	Examination by physician. Reconstruction of crash provided EES value and characterized as either stiff or soft	No correlation between symptom duration and either character or EES of crash	Longitudinal design. Strong outcome assessment methods	Weighted towards injured subjects and males overrepresented in sample
Ryan et al. [6]	32	Longitudinal cohort (class II)	Examination by therapist. Severity assessment by subjects and examiners. Measurement of crush depth	Significant correlation between property damage and both severity ratings	Longitudinal design. Strong outcome assessment methods	All subjects were injured. Potential self-selection bias
Ryan et al. [7]	29*	Longitudinal cohort (class II)	Examination by therapist. Severity assessment by subjects and examiners. Measurement of crush depth	No significant correlation between measured crush depth and 6-month outcome	Longitudinal design. Strong outcome assessment methods	All subjects were injured. Potential self-selection bias

* Same subjects as reference 15.

planation. Selection bias in the other two studies tended to exclude persons who were not injured. As a result, none of the studies can be used to develop risk tables regarding property damage and injury risk, injury severity, or injury duration or persistence.

Our best evidence synthesis demonstrates that while there appears to be some relationship between property damage and injury risk or severity, this may only be true when considering a wider property damage range (e.g., minor vs. severe or moderate vs. severe) but this metric does not hold for males nor does it correlate significantly with long-term symptoms for persons of either sex. A substantial number of injuries are reported in crashes of severities that are unlikely to result in significant property damage. Thus, property damage is neither a valid predictor of acute injury risk nor of symptom duration. Other factors, such as head restraint geometry, awareness of the impending crash, sex, and prior injury are likely to impose competitive or stronger outcome effects, particularly as regards long-term outcome. Based upon our best evidence synthesis, the level of vehicle property damage appears to be an invalid construct for injury presence, severity, or duration. The MIST protocol for prediction of injury does not appear to be valid.

References:

1. Koehler K, Freeman MD: Litigating Minor Impact Soft Tissue Cases. Philadelphia: Thomson West Publishers, 2001
2. Burnett R, Carter J, Roberts V, Myers B: The influence of seatback characteristics on cervical injury risk in severe rear impacts. Accid Anal Prev, 2004; 36: 591–601
3. Zaloshnja E, Miller T, Council F, Persaud B: Comprehensive and human capital crash costs by maximum police-reported injury severity within selected crash types. In 48th Annual Proceedings of the Association for the Advancement of Automotive Medicine Sept 13–15; Key Biscayne, Fl, 2004; 251–64
4. Farmer CM, Wells JK, Werner JV: Relationship of head restraint positioning to driver neck injury in rear-end crashes. Accid Anal Prev, 1999; 31: 719–28
5. Olsson I, Bunketorp O, Carlsson G et al: An in-depth study of neck injuries in rear end collisions. In International IRCOBI Conference September 12–14; Lyon, France, 1990; 269–80
6. Ryan GA, Taylor GW, Moore VM, Dolinis J: Neck strain in car occupants. The influence of crash-related factors on initial severity. Med J Aust, 1993; 159: 651–56
7. Ryan GA, Taylor GW, Moore VM, Dolinis J: Neck strain in car occupants: injury status after 6 months and crash-related factors. Injury, 1994; 25: 533–37
8. West D, Gough J, Harper T: Low speed collision testing using human subjects. Accid Reconstruct J, 1993; 5: 22–26
9. Wolley R, Strother C, James M: Rear stiffness coefficients derived from barrier test data. SAE International Congress, , Detroit, MI, 1991; 910120
10. Szabo T, Welcher J: Dynamics of low speed crash tests with energy absorbing bumpers. SAE Tech Paper Series, 1992; 921573: 1–9
11. Bailey M, Wong B, Lawrence J: Data and methods for estimating the severity of minor impacts. SAE Tech Paper Series, 1995; 950352: 1339–74
12. Szabo T, Welcher J: Human subject kinematics and electromyographic activity during low speed rear impacts. 1996, SAE paper 962432: 295–315
13. Siegmund G, King D, Lawrence J et al: Head/neck kinematic response of human subjects in low-speed rear-end collisions. 1997, SAE Technical Paper, 973341: 357–85

14. Croft AC, Herring P, Freeman MD, Haneline MT: The neck injury criterion: future considerations. Accid Anal Prev, 2002; 34: 247–55
15. Cipriani AL, Bayan FP, Woodhouse ML et al: Low speed collinear impact severity: a comparison between full scale testing and analytical prediction tools with restitution analysis. Accident Reconstruction, 2002; 2002: 23–37
16. Croft AC, Haneline MT, Freeman MD: Low speed frontal crashes and low speed rear crashes: is there a differential risk for injury? In 46th Annual Proceedings of the Association for the Advancement of Automotive Medicine; Tempe, AZ, 2002; 79–91
17. Krafft M, Kullgren A, Ydenius A, Tingvall C: Influence of Crash Pulse Characteristics on Whiplash Associated Disorders in Rear Impacts-Crash Recording in Real Life Crashes. Traffic Injury Prevention, 2002; 3: 141–49
18. Kullgren A, Eriksson L, Bostrom O, Krafft M: Validation of neck injury criteria using reconstructed real-life rear-end crashes with recorded crash pulses. In Proceedings 18th International Technical Conference on the Enhanced Safety of Vehicles (ESV) May 19–22; Nagoya, Japan, 2003
19. Bunketorp O, Jakobsson L, Norin H: Comparison of frontal and rear-end impacts for car occupants with whiplash-associated disorders: symptoms and clinical findings. In International IRCOBI Conference September 22–24; Graz, Austria, 2004; 245–56
20. Schuller E, Eisenmenger W, Beier G: Whiplash injury in low speed car accidents: Assessment of biomechanical cervical spine loading and injury prevention in a forensic sample. Journal of Musculoskeletal Pain, 2000; 8: 55–67
21. Dolinis: Risk factors for 'whiplash' in drivers: a cohort study of rear-end traffic crashes. Injury, 1997; 28: 173–79
22. Jakobsson L, Norin H, Svensson MY: Parameters influencing AIS 1 neck injury outcome in frontal impacts. Traffic Inj Prev, 2004; 5: 156–63
23. Olsson I, Bunketorp O, Carlsson G: An in-depth study of neck injuries in rear end collisions. In 1990 International IRCOBI Conference September 12–14; Bron, Lyon, France, 1990; 1–15

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Lack of Relationship Between Vehicle Damage and Occupant Injury

Malcolm C. Robbins
Robbins & Assocs.

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Lack of Relationship Between Vehicle Damage and Occupant Injury

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ABSTRACT

A common misconception formulated is that the amount of vehicle crash damage due to a collision, offers a direct correlation to the degree of occupant injury. This paper explores this concept and explains why it is false reasoning. Explanations with supporting data are set forth to show how minor vehicle damage can relate or even be the major contributing factor to occupant injury. Mathematical equations and models also support these findings.

INTRODUCTION

A common concept formulated is that the amount of motor vehicle crash damage offers a direct correlation to the degree of occupant injury. This paper explores this concept and explains why it is false reasoning. This false reasoning is often applied by insurance adjusters, attorneys and physicians and frequently results in costly unjustified litigation. Due to this litigation process, the injured parties often are not compensated, resulting in unjustified hardship to the party who has already been injured.

The object of this paper is to present a clear understanding of vehicle body performance when it is subjected to crash dynamics and the relationship to occupant dynamic responses and resulting injury.

THEORY

One of the major factors relating to occupant injury due to a collision is the G force to which the occupant is subjected. [1][2] Even with seat belts air bags and other measures, severe injury and fatality occurs when a vehicle is subject to a collision. [3][4][5][6] This is a rather complex subject to answer in a single paper, but fundamentally even when seat belts are used, the G force sustained by the vehicle beyond the crush zone or arresting distance is transferred to the occupant.

Galileo Galilei formulated an equation that can be used to demonstrate the G force an occupant will receive, assuming a "fixed" seated position. If an object starts from rest, Galilei's equation states: [1]

$$V = \sqrt{2as} \qquad (1)$$

where V = Velocity of object
a = acceleration rate
s = distance moved by object.

Rearranging Equation 1 to get deceleration, we have:

$$a = \frac{V^2}{2s} \qquad (2)$$

where s = arresting or crush distance
V = Velocity at time of impact
a = deceleration

Applying this formula (2) to the scenario of a pole vaulter. If a pole vaulter jumps 6.5 meters (20 feet), his speed when reaching a 1.5-meter (5-foot) safety mat can be calculated thus, using Equation 1:

$$V = \sqrt{2as} \qquad (1)$$

where $s = 6.5 - 1.5 = 5$ meters
$a = 9.81$ m/sec^2

hence: V = 11.29 m/sec or 40 km/hr (25 mph)

The resulting G force to which the pole vaulter is exposed can be calculated to be as follows, using Equation 2:

$$a = \frac{V^2}{2s} \qquad (2)$$

where V = 11.29 m/sec
s = 1.5 - 0.5 = 1 meter

hence: a = 63.7 m/ sec^2 (6.5 Gs)

If the vaulter impacted a concrete surface, the results would be clearly different. It is the amount of crush in the safety padding that prevents injury to the pole vaulter.

Applying the formula to vehicles which impact a solid brick wall:

First Scenario: Vehicle Green is traveling at a velocity of 12 meters/second (25 mph) and crushes 1 meter (3.1 feet) while impacting a solid brick wall. Using equation (2) above, then V = 8 m/sec (25 mph), s = 1 m (3.1 feet) and deceleration is:

$$a = \frac{12^2}{2} = 72m/\sec^2 = 7G$$

Second Scenario: Vehicle Red undertakes same velocity as Vehicle Green but crushes only 0.2 meters while impacting the solid brick wall. Deceleration is:

$$a = \frac{12^2}{0.2} = 360m/\sec^2 = 37G$$

The results show that the greater the crush distance of the vehicle, the less the G force received by the occupant.

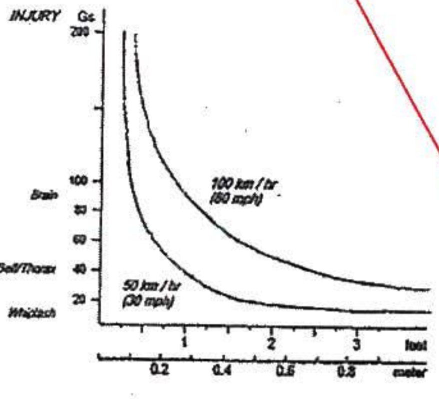

Figure 1

The graph shown in Figure 1 demonstrates the effect a vehicle's crushing distance has on the G force with a fixed collision speed.

DISCUSSION

The average force an occupant of a motor vehicle experiences with normal driving is in the range of 0.2 to 0.5 G. Under these conditions motor vehicle occupants can readily change direction or speed with the vehicle. Some braking will impose a resulting force of 0.9 G, which may cause unrestrained occupants to be thrown forward in the occupant area. The limiting factor is the amount of coefficient of friction available between tire and road for braking and steering. Injury has been known to result due to severe braking, typically when occupants did not have time to brace themselves and were restrained.

If a motor vehicle impacts an object, loads on occupants can rise to very high values. When this takes place, the unrestrained occupant cannot keep pace with the vehicle's change in speed or direction. Hence the unrestrained occupant continues to move within the interior passenger compartment, colliding with the compartment surfaces such as steering wheel, windshield or dashboard. The introduction of seat belts is an attempt to keep the occupant restrained and moving along with vehicle speed and direction. Air bags and padded interior surfaces are provided to cushion the occupant's limbs and head, which contact with occupant interior surfaces.

While the amount of crush a vehicle sustains does not relate to occupant injury, provided no penetration occurs to the occupant compartment, the amount of crush does relate to the impact velocity or speed in the event of a collision with another vehicle or object. In fact, evaluation of occupant injury when related to vehicle damage can only be made when several factors are taken into account. Some of these factors are the following:

Dynamics of force applied to occupant.

- Velocity of vehicle or objects on impact.
- Crushing or arresting distance of vehicle or object. [7][8]
- Ability of vehicle or objects to dissipate the energy of the impact.
- Combination of above factors will establish the dynamics of force applied to occupant.
- Initial positioning of occupant in relation to safety devices such as seat belts or air bags.

Physical condition of occupant.

- Degree of muscular stimulation at the time of impact, i.e., was impact anticipated by occupant?
- Structural strength of occupant, i.e., sex, age, bone mineral content and joint strength. [9]
- Geometric dimensions, i.e., height, weight.

One main factor for determining the dynamics of occupant injury due to a motor vehicle collision is the amount of crush or arresting distance, known as value "s" and previously discussed. This value can vary a great deal from vehicle to vehicle and its location on the vehicle. If we examine a soft drink extruded aluminum can and liken it to a motor vehicle body, several observations can be made:

- Firstly, force applied on the top of the can downwards meets a greater resistance than a force applied to the sides. Clearly the type of structure of the can plays a major part in the deformation resistance.
- Secondly, if a force is applied to the top, a relative great deal of resistance is initially met, then slowly, as the can is crushed, the amount of resistance deteriorates and the can yields.

Likewise, on a vehicle with a chassis, no serious visual deformation may occur even though it is subjected to relatively high speeds of impact. Classically, we see this in the case of pickup trucks or all-terrain vehicles that are traditionally fitted with a solid bumper-to-bumper chassis. Many of these types of vehicles are subjected to relatively severe impacts with little or no resulting damage to their bodies and bumpers. The classic whiplash injury associated with a great deal of litigation is most likely founded on the reasoning that if there was little or no vehicle damage, no injury can result. Motor vehicle bodies or bumper-to-bumper chassis offer little or no crushing effect on arresting obstacles when impacted; thus, relatively high G forces can be experienced by occupants when rear-ended, resulting in whiplash injury. The use of stiff motor vehicle bodies and chassis will also produce a spiked G force loading to occupants, even if little damage occurs to vehicle body or chassis.

Spike loading is a result of a non-linear yielding of a vehicle body, as previously discussed in the scenario of the tin can. In actual practice, deceleration rates during an automobile collision are rarely uniform, especially when chassis, drive trains and mounting panels are involved in the collision.

It is not uncommon to see a motor vehicle that has experienced mass destruction and damage, yet the occupants sustained little or no injuries. This is often a prime example of a situation in which the vehicle or vehicles have absorbed the dissipating kinetic energy of the collision. The occupants are thus not subjected to severe G forces. It is for this very reason that racing cars, when seen in a collision, appear to almost shed their body structure. Wheels are seen detaching and the body structure is seen to dissipate and crush almost in every direction. High-performance racing cars as seen on the Grand Prix circuit are designed with state-of-the-art crash engineering. The main outside structure of these racing cars is designed to allow for crushing and to dissipate energy in the event of a collision. The driver is protected by a rigid enclosure and is also very effectively restrained. These design factors in high-performance crash engineering account for the low driver-injury rates, even though the collisions involve very high speeds. So here we see heavy vehicle-body damage and relatively low occupant injury rates. i.e., the body of the racing car is sacrificed to prevent driver injury or death.

SUMMARY

The amount of crush or damage received by a motor vehicle in a collision is an indication of velocities involved when the stiffness of the motor vehicle and object or objects is known. However, the crush damage does not relate to the expected occupant injury, i.e., the more vehicle damage, the more chance that the occupant is injured, is not a conclusion that can be made. In fact, it is more likely the reverse. If the occupant is decelerated over a greater time/distance due to a large crush/arresting distance, then the likelihood of injury is reduced.

This conclusion has been demonstrated by both mathematical expression and practical examples. The first example is that of the pole vaulter who survives his 5-meter (16-foot) drop by the crush of the padding or mat. It is this crush which breaks the vaulter's fall and hence allows for increased stopping distance and time. The second practical example is that of the high-performance racing car which makes use of a rigid driver compartment for protection. However, the compartment is surrounded by a body which is designed to allow for crush or deformation due to a collision. The result is a reduced number of injuries or fatalities.

REFERENCES

1. Malliaris, A. C., R. Hitchcock and M. Hansen, "Harm Causation and Ranking in Car Crushes," SAE paper 850090, 1985.
2. Malliaris, A. C., R. Hitchcock and J. Hedlund, "A Search for Priorities in Crash Protection," SAE paper 820242, 1982.
3. Huelke, Donald, et al. "Upper Extremity Injuries Related to Air Bag Deployment," Journal of Trauma Injury, Injection & Critical Care, Vol. 38, No. 4 (April 1995): pp. 469-75.
4. Parmley, F. F., W. C. Marion and T. W. Mattingly. "Non-penetrating Traumatic Injury of the Heart," Circulation 18:376, 1958.
5. Hossack, D. W. "The Pattern of Injuries Received by 500 Drivers and Passengers Killed in Road Accidents," Medical Journal, pp. 193-95.
6. Leung, T. C., C. Tarriere. Et al. "Submarining Injuries of Three Belted Occupants in Frontal Collisions," SAE paper 921158, 1982.
7. Wood, D. P., S. Mooney, M. Doody and S. O'Riordain, "The Influence of Car Crush Behavior on Frontal Collision Safety and on the Car Size Effect," SAE paper 930893-SP-975.
8. Ibid.
9. Nahum, A.M. and J. W. Melvin, Accidental Injury, Springer-Verlag, pp. 460-489.

Further references:

1. Watts, A. J., D. R. Atkinson and C. J. Hennessy, Low Speed Automobile Accidents, Lawyers & Judges Publishing Co.
2. Fricke, L. B., Traffic Accident Reconstruction, Vol. 2, Northwestern University Traffic Institute.

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Deceleration during 'real life' motor vehicle collisions – a sensitive predictor for the risk of sustaining a cervical spine injury?

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Abstract

Background: The predictive value of trauma impact for the severity of whiplash injuries has mainly been investigated in sled- and crash-test studies. However, very little data exist for real-life accidents. Therefore, the predictive value of the trauma impact as assessed by the change in velocity of the car due to the collision (ΔV) for the resulting cervical spine injuries were investigated in 57 cases after real-life car accidents.

Methods: ΔV was determined for every car and clinical findings related to the cervical spine were assessed and classified according to the Quebec Task Force (QTF).

Results: In our study, 32 (56%) subjects did not complain about symptoms and were therefore classified as QTF grade 0; 25 (44%) patients complained of neck pain: 8 (14%) were classified as QTF grade I, 6 (10%) as QTF grade II, and 11 (19%) as QTF grade IV. Only a slight correlation ($r = 0.55$) was found between the reported pain and ΔV. No relevant correlation was found between ΔV and the neck disability index ($r = 0.46$) and between ΔV and the QTF grade ($r = 0.45$) for any of the collision types. There was no ΔV threshold associated with acceptable sensitivity and specificity for the prognosis of a cervical spine injury.

Conclusion: The results of this study indicate that ΔV is not a conclusive predictor for cervical spine injury in real-life motor vehicle accidents. This is of importance for surgeons involved in medicolegal expertise jobs as well as patients who suffer from whiplash-associated disorders (WADs) after motor vehicle accidents.

Trial registration: The study complied with applicable German law and with the principles of the Helsinki Declaration and was approved by the institutional ethics commission.

Background

Whiplash injuries remain a barely understood phenomenon. The economic damage caused by whiplash amounts to some 10 billion Euros a year in Europe [1] and 29 billion US Dollars a year in the USA [2]. As whiplash occurs as a result of motor vehicle accidents (MVAs), questions inevitably arise regarding who is liable for these costs.

Biomechanical considerations have been based on the assumption that damage to a given material only occurs when the energy that acts on this material is high enough. Thus, energy doses below a defined threshold have been considered harmless [3,4]. In this context, the parameter delta v (ΔV), which describes the velocity change of a motor vehicle during a collision with another vehicle, has become a widely accepted criterion for the energy that acts on the vehicle during a collision [5].

In numerous sled or car crash-test studies, volunteers were subjected to acceleration forces in order to define a threshold below which a cervical spine injury could be excluded [6-15]. The results of these studies are rather inconclusive and sometimes contradictory. Thus the scientific community has not yet reached consensus regarding the threshold value for cervical spine injuries after whiplash. Nonetheless, ΔV threshold values were adopted very early in the history of insurance law as a criterion to accept or deny the claim settlement for whiplash-associated disorders (WADs) [16].

Up until now, all volunteer crash-test studies precisely defined the subject's sitting position. While waiting for the collision, the subjects maintained an upright body and head position, with an optimally adjusted headrest. It is obvious that the real-life sitting position in traffic may significantly differ from this laboratory position in one or several points. Furthermore, an increased risk of injury has been observed for various factors such as the seat and headrest settings [11,17-20], the distance between head and headrest [21-23], the head rotation, and the collision type [24]. The inherent variability of these factors makes it unclear how easily the results from laboratory crash tests can be transferred to real-life accident situations. In order to elucidate these issues, this study analyzes the correlation between ΔV and cervical spine injuries in real-life accidents and questions whether ΔV is a valid predictor for cervical spine injuries following whiplash.

Methods

The study included 57 patients after a car collision. The patients were recruited either by an engineer's office for vehicle damage assessment and claims adjustment (n = 46) or by the first consultation of an emergency room (n = 11). We obtained the approval of the local independent ethics board and all patients gave their written informed consent to participate in the study.

Clinical Data

The clinical data were collected within 48 h after occurrence of the accident. Neck pain was determined on a visual analog scale (VAS) ranging from 0 (no pain) to 100 (maximal pain). The neck disability index (NDI) was used to assess disability problems related to neck pain. The NDI includes 10 items that attempt to describe the impact of neck pain: pain intensity, personal care, lifting, reading, headaches, concentration, work, driving, sleeping and recreation [25]. Subjects are requested to choose for each item, the statement that best describes their current situation; the statements represent different grades of severity. A total score which ranges from 0 to 50 was finally derived as the sum of the ten items.

All subjects who reported neck pain were physically and radiologically examined. The physical examination included investigation of the cranial nerves as well as of the motor and sensory function of spinal nerves C5–C8. Areas that were painful upon application of pressure were also examined. Furthermore, the range of motion (ROM) of the cervical spine in flexion/extension, rotation and lateral flexion was measured. In addition, X-rays of the cervical spine were taken in two planes. A CT scan was additionally taken if pathological findings were noted. The clinical and radiological findings were used to classify the whiplash injury according to the Quebec Task Force (QTF) system [26] (Table 1). The medical investigator was blinded concerning the technical data. Patients were informed of all results from the clinical examination excluding the QTF values.

Technical Data

In addition to the clinical findings, the ΔVs of their respective accident vehicles were determined for all patients. The damage on all vehicles involved in the accidents was examined by a certified engineer who was experienced in the assessment of such damage. The ΔV and the collision type (frontal, rear-end, side collision, multiple collisions, rollovers) were determined on the basis of the damage sustained by the vehicles. Depending on the available data, the ΔV was analyzed either by calculation and graphic illustration [27] or with the EES method [28]. The engineer was blinded concerning the clinical examination results.

Statistics

Descriptive analysis was performed for all parameters. Pearson's correlation coefficient was determined for the correlation between the pain score (VAS) and ΔV and for the correlation between the NDI and ΔV. The correlation between QTF classification and ΔV was described by

Table 1: Clinical classification of whiplash-associated disorders according to the Quebec Task Force

QTF Grade	Clinical Symptoms
0	**No complaint** about the neck, no physical signs
I	Neck complaint of pain, stiffness or tenderness only, **no physical signs**
II	Neck complaint and **musculoskeletal signs** *
III	Neck complaint and **neurological signs** **
IV	Neck complaint and **fracture or dislocation**

* Musculoskeletal signs include decreased range of motion and point tenderness; ** Neurologic signs include decreased or absent deep tendon reflexes, weakness and sensory deficits; Symptoms and disorders that can be manifest in all grades include deafness, dizziness, tinnitus, headache, memory loss, dysphagia and temporomandibular joint pain

Spearman's correlation coefficient. The specificity and sensitivity were calculated for the hypothesis that no cervical spine injuries occur below a particular ΔV threshold and that injuries can occur above this threshold. P-values below 0.05 were considered significant.

Results

We enrolled 57 individuals (25 males and 32 females) in the study; these individuals had been the occupants of 51 cars (Table 2). The median age was 33 (range 3 to 90 years) for the males and 30 (range 18 to 59 years) for the females.

A total of 25 (44%) patients complained about pain in the neck. VAS pain scores of 7 to 96 (median = 71) were reported. Fifteen patients reported an immediate onset of pain, four individuals reported a time to onset of minutes to hours, and four patients reported a time to onset of hours to one day. The Pearson's correlation coefficient of $r = 0.55$ indicated a moderate correlation between the pain that was subjectively reported and ΔV (Fig. 1).

A total of 25 (44%) patients complained pain related neck disability. NDI scores of 4 to 49 (median = 24) were reported. The Pearson's correlation coefficient of $r = 0.46$ indicated no relevant correlation between the NDI and ΔV (Fig. 2).

Thirty-two patients (56%) were classified as QTF grade 0. Eight patients (14%) presented with QTF grade I, 6 patients (10%) with QTF grade II, and 11 patients (19%) with QTF grade IV. No QTF grade III injuries were scored. The Spearman's correlation coefficient of $r = 0.45$ indicated no relevant correlation between ΔV and the QTF grade of cervical spine injury (Fig. 3).

Rear-end collision (n = 21, 36%) was the most frequent collision type, followed by side collisions (n = 19, 33%) and front collisions (n = 13, 23%); there were also three multiple collisions and one rollover. For the rear-end collisions, individuals with and without cervical spine injuries were found in a ΔV range between 9 km/h and 37 km/h. This range was 15 km/h to 28 km/h for frontal collisions and 9 km/h to 36 km/h for side collisions. Within these ranges, the percentage of false-positive and false-negative results varied greatly, depending on the predefined cut-off values (Tables 3, 4 and 5). Therefore, for all collision types it was impossible to define a ΔV value that excluded the occurrence of cervical spine injury with acceptable sensitivity while simultaneously predicting the occurrence of cervical spine injury with acceptable specificity.

Discussion

This study provides evidence that, in real-life accidents, cervical spine injuries may occur at low ΔV values, while it is possible to escape unscathed from collisions with high ΔV values. In particular, the correlation between ΔV and the occurrence of WADs was very low for any of the collision types. Therefore it is impossible to make meaningful statements about the existence of WAD based solely on assessment of the ΔV value. This finding might be of importance for the surgeon's assessment and patient's safety after a car accident. Diagnostic and therapeutic management should not be based solely on information related to trauma impact.

The results of the present study support the findings of numerous sled and car-crash experiments. In those experiments, neck problems were noted after rear-end collisions with ΔVs as low as 7 km/h [14,29-31]. In four other studies [8,32-34], neck problems occurred at a ΔV < 10 km/h. The neck problems were defined as QTF grade I and QTF grade II, persisting from hours to several weeks in all studies. In contrast, four studies reported rear-end collisions with ΔV values of 13.1 km/h to 50 km/h where the occupants escaped without any signs of injury [4,9,35,36]. In other crash-test studies, frontal impacts at ΔV less than 12 km/h caused no injuries [34]. However, different findings were obtained in our study and in a study that performed a retrospective analysis of 24 real-life frontal collisions [37]. In that study, 18 of the 24 subjects were classified as QTF grade II. It is noteworthy that 8 of these had neck problems for more than one year. The ΔVs in these cases ranged from 3 km/h to 23 km/h. The authors also reported that one subject suffered a prolapsed disk at

Table 2: Collision type, delta V, sex, age, QTF grade, pain score, neck disability index (NDI) and description of injury in cases of QTF grade IV in all studied subjects.

No.	Collision	Delta V	Sex	Age	QTF	Pain score	NDI	Injury
1	Frontal	8	♂	30	0	0	0	
2	Frontal	11	♂	19	0	0	0	
3	Frontal	15	♂	21	0	0	0	
4	Frontal	16	♀	33	0	0	0	
5	Frontal	17	♂	38	0	0	0	
6	Frontal	17	♂	24	0	0	0	
7	Frontal	24	♂	56	0	0	0	
8	Frontal	25	♀	20	0	0	0	
9	Frontal	28	♂	-	0	0	0	
10	Frontal	18	♀	26	1	49	17	
11	Frontal	15	♀	37	4	91	44	Fracture at C7 with dislocation at C6/7
12	Frontal	32	♀	20	4	89	40	Fracture at C5 with dislocation at C5/6, paraplegia at C7
13	Frontal	50	♂	20	4	89	36	Fracture at C5 with dislocation at C4/5
14	Rear	3	♀	39	0	0	0	
15	Rear	6	♀	40	0	0	0	
16	Rear	8	♂	-	0	0	0	
17	Rear	9	♀	27	0	0	0	
18	Rear	9	♂	20	0	0	0	
19	Rear	11	♂	23	0	0	0	
20	Rear	11	♀	31	0	0	0	
21	Rear	12	♀	31	0	0	0	
22	Rear	13	♀	36	0	0	0	
23	Rear	15	♀	59	0	0	0	
24	Rear	15	♂	27	0	0	0	
25	Rear	24	♂	53	0	0	0	
26	Rear	37	♂	42	0	0	0	
27	Rear	9	♂	31	1	70	10	
28	Rear	9	♀	26	1	51	18	
29	Rear	11	♀	31	1	36	4	
30	Rear	23	♀	19	1	50	5	
31	Rear	24	♀	58	1	44	17	
32	Rear	58	♀	19	1	26	8	
33	Rear	15	♀	23	2	49	14	
34	Rear	20	♀	31	2	55	16	
35	Side	4	♀	23	0	0	0	
36	Side	7	♀	39	0	0	0	
37	Side	9	♂	34	0	0	0	
38	Side	10	♂	54	0	0	0	
39	Side	10	♀	30	0	0	0	
40	Side	10	♂	51	0	0	0	
41	Side	11	♂	56	0	0	0	
42	Side	14	♂	42	0	0	0	
43	Side	18	♀	22	0	0	0	
44	Side	36	♀	29	0	0	0	
45	Side	9	♀	55	2	7	16	
46	Side	10	♀	59	2	61	20	
47	Side	10	♂	33	4	83	35	Zygapophyseal joint fracture at C4
48	Side	16	♂	90	4	94	46	Fracture at C7 with dislocation at C6/7
49	Side	32	♀	29	4	86	33	Zygapophyseal joint fracture at C2
50	Side	50	♂	33	4	81	47	Fracture at C5 with dislocation at C5/6, paraplegia at C6
51	Side	52	♀	34	4	92	34	Bony rupture of the alar ligaments
52	Side	58	♂	3	4	96	49	Atlantoaxial dislocation
53	Side	59	♀	39	4	87	48	Bony rupture of the alar ligaments
54	Multiple	46	♀	18	1	69	21	
55	Multiple	33	♀	32	2	67	38	
56	Multiple	46	♀	19	2	85	24	
57	Rollover	15	♀	30	4	94	42	Dens axis fracture Anderson 2

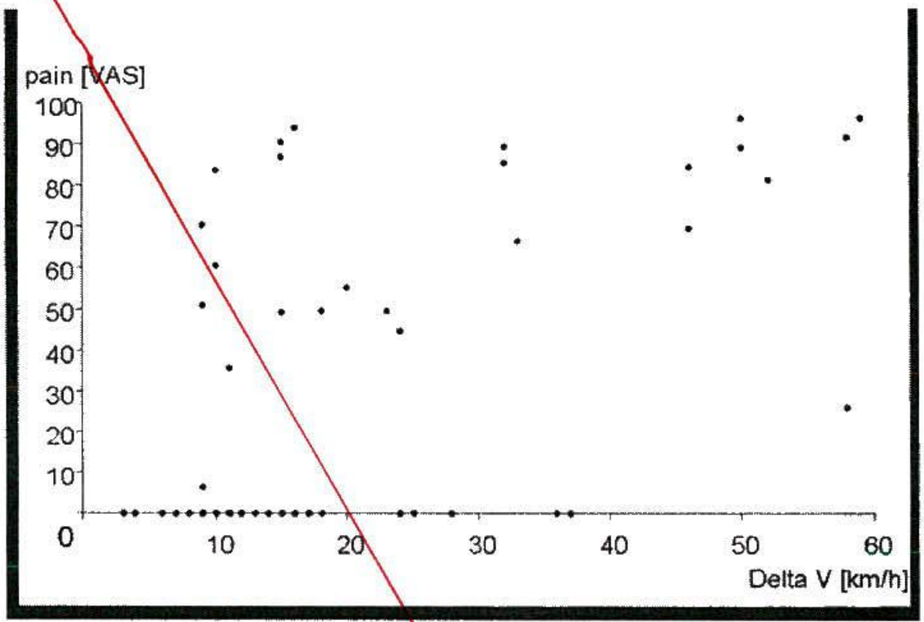

Figure 1
Pain score (VAS) for all subjects (n = 57) as a function of delta V (km/h).

C5/6 at a ΔV of 11–15 km/h. The occupant had not been wearing his seat belt and the airbag had deployed. He also had a frontal laceration as a sign of direct head impact. It was assumed that these factors caused the structural injury of the cervical spine at a low ΔV. The occurrence of structural injuries at ΔV values of less than 20 km/h had been considered improbable in expert discussions. However, we also observed a luxation fracture at C5/6 resulting from a frontal collision at a ΔV of 15 km/h and a facet joint fracture at C4 due to a side collision at a ΔV of 10 km/h (Table 1). Both occupants had been wearing their seat belts, there had been no head contact, and the airbag

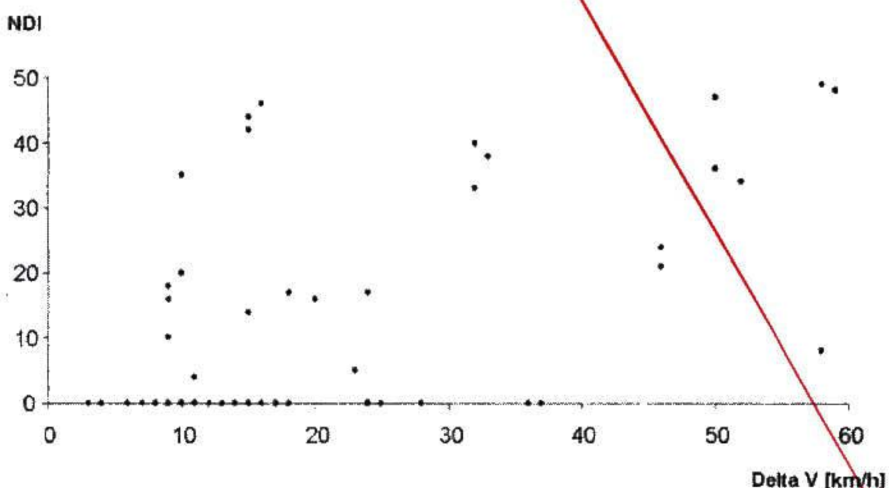

Figure 2
Neck disability index (NDI) for all subjects (n = 57) as a function of delta V (km/h).

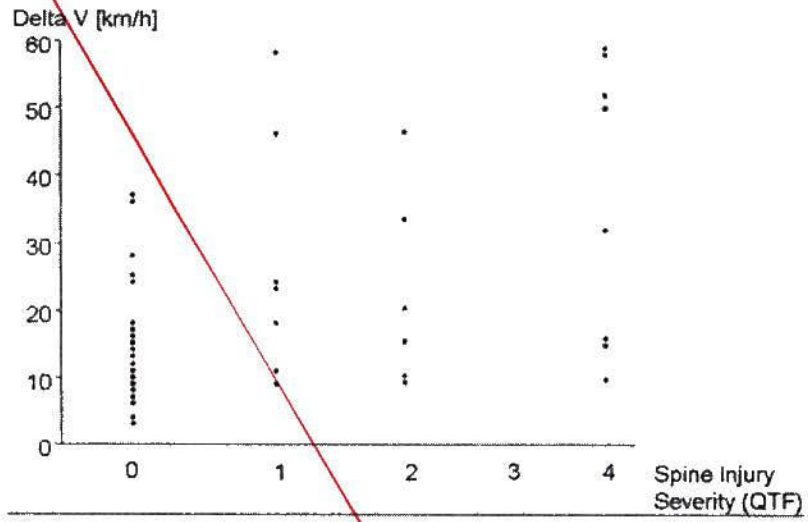

Figure 3
Delta V for all subjects (n = 57) as a function of the spine injury severity (QTF grade) (QTF 0: n = 32, QTF I: n = 8, QTF II: n = 6, QTF IV: n = 11).

had not deployed. In both cases, it is unclear which factors, either alone or in combination, were responsible for these structural injuries at considerably low ΔV. In accordance with other studies mentioned below, these results are indicative that multiple factors may influence the risk of injury in each individual case. Due to the additive effects of various protective factors, high-energy impacts may be absorbed without injury, while the additive effects of unfavorable factors could explain injuries sustained in low-energy impacts. Some factors have been described to influence the risk of injury, such as sex [38,39], head position [40], sitting position [24,41], distance between head and headrest [21-23] and seat construction [11,17-19]. The duration of the crash pulse is also thought to significantly contribute to the risk of cervical spine injury. These authors stated that an earlier acceleration peak during deformation of the colliding cars was correlated with a higher probability of cervical spine injury [24]. However, it remains unclear to what extent each one of these factors influences the risk of cervical spine injury.

The current data exclude the assumption of a linear correlation between ΔV and the risk of suffering a whiplash injury. It is tempting to speculate that the development of a cervical spine injury after whiplash is more like a complex system such as those described in chaos theory [42]. Complex systems cannot be simplified into linear correlations. Even small variations of the initial conditions can affect the end result so that it is no longer predictable, such as in the case of the "butterfly effect": the flapping of a butterfly's wings can ultimately result in a different weather pattern [43]. Taken together, it can be concluded that ΔV is an irrelevant predictive value for cervical spine injury after a MVA. Nevertheless further studies will be necessary to evaluate the development of pain chronifica-

Table 3: Specificity and sensitivity for specific delta V threshold values in frontal collisions (n = 13).

Delta V [km/h]	Sensitivity	Specificity
8	0%	100%
15	33%	75%
20	67%	50%
35	100%	25%

Table 4: Specificity and sensitivity for specific delta V threshold values in rear-end collisions (n = 21).

Delta V [km/h]	Sensitivity	Specificity
4	0%	100%
10	38%	75%
15	85%	50%
25	92%	13%
40	100%	13%

Table 5: Specificity and sensitivity for specific delta V threshold values in side collisions (n = 19).

Delta V [km/h]	Sensitivity	Specificity
4	0%	100%
10	60%	67%
20	90%	56%
35	100%	44%
60	100%	0%

tion in dependence of the ΔV to investigate its possible predictive value as "long-term" parameter.

Conclusion

The ΔV value as measured in the trauma impact does not represent a conclusive predictor for cervical spine injury in real-life motor vehicle accidents. This could be important for surgeons and patients in their medicolegal assessment of WADs.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

ME drafted the manuscript and performed the medical examination. MK participated in the study coordination and helped in the medical examination. MHL helped to draft the manuscript. EH participated in the study design and its coordination. CD performed the statistical analysis and helped to draft the manuscript. All authors read and approved the final manuscript.

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References

1. Radanov B, Dvorak J, Valach L: **Cognitive deficits in patients after soft tissue injury of the cervical spine.** *Spine* 1992, **17**:127-131.
2. Freeman MD, Croft AC, Rossignol AM, Weaver DS, Reiser M: **A review and methodologic critique of the literature refuting whiplash syndrome.** *Spine* 1999, **24**:86-96.
3. Niederer P, Walz F, Muser M, Zollinger U: **Was ist ein "schwerer", und was ist ein "leichter" Verkehrsunfall?** *Schweizerischen Aerztezeitung* 2001, **82**:1535-1539.
4. Meyer S, Hugemann W, Weber M: **Zur Belastung der Halswirbelsäule durch Auffahrunfälle – Teil I.** *Verkehrsunfall und Fahrzeugtechnik* 1994, **32**:15-21.
5. Becke M, Castro WHM: **Zur Belastung von Fahrzeuginsassen bei leichten Seitkollisionen. Teil II.** *Verkehrsunfall und Fahrzeugtechnik* 2000, **12**:225-228.
6. Rosenbluth W, Hicks L: **Evaluating low-speed rear-end impact severity and resultant occupant stress parameters.** *J Forensic Sci* 1994, **39**:1393-1424.
7. Davidsson J, Flogard A, Lövsund P, Svensson MY: **BioRid P3-Design and Performance Compared to Hybrid III and Volunteers in Rear Impacts at Delta V = 7 km/h.** *SAE Paper* 1999, **99SC16**:253-256.
8. Kaneoka K, Ono K, Inami S, Ochiai N, Hayashi K: **The human cervical spine motion during rear-impact collisions: a proposed cervical facet injury mechanism during whiplash trauma.** *Journal of Whiplash & Related Disorders* 2002, **1**:85-97.
9. Blouin JS, Descarreaux M, Belanger-Gravel A, Simoneau M, Teasdale N: **Attenuation of human neck muscle activity following repeated imposed trunk-forward linear acceleration.** *Exp Brain Res* 2003, **150**:458-464.
10. Siegmund GP, Sanderson DJ, Myers BS, Inglis JT: **Awareness affects the response of human subjects exposed to a single whiplash-like perturbation.** *Spine* 2003, **28**:671-679.
11. Watanabe Y, Ichikawa H, Kayama O, Ono K, Kaneoka K, Inami S: **Influence of seat characteristics on occupant motion in low-speed rear impacts.** *Accident Analysis & Prevention* 2000, **32**:243-250.
12. Kumar S, Narayan Y, Amell T: **Role of awareness in head-neck acceleration in low velocity rear-end impacts.** *Accident Analysis & Prevention* 2000, **32**:235-241.
13. Magnusson ML, Pope MH, Hasselquist L, Bolte KM, Ross JS, Goel VK, Lee JS, Spratt K, Clark CR, Wilder DG: **Cervical electromyographic activity during low-speed rear impact.** *European spine journal* 1999, **8**:118-125.
14. Matsushita T, Sato TB, Hirabayashi K, Fujimura S, Asazuma T, Takatori T: **X-Ray study of the human neck motiondue to head inertia loading.** In *Proceedings of the 37th Stapp Car Crash Conference; Fort Lauderdale, USA SAE technical paper series SoAE*; 1994:55-64.
15. Ono K, Kaneoka K, Wittek A, Kajzer J: **Cervical injury mechanism based on the analysis of human cervical vertebrae motion and head-neck-torso kinematics during low speed rear impacts.** *Proceedings 41st Stapp Car Crash Conference; November 13–14; Lake Buena Vista, USA* 1997:339-356.
16. Ayasse H: **Ayasse, H., 1992. Das Schleudertrauma der Halswirbelsäule aus der Sicht der Schadenssachbearbeitung.** *Zeitschrift für Versicherungsrecht, Haftungs- und Schadensrecht* 1992, **28**:1185-1202.
17. Svensson MY, Lovsund P, Haland Y, Larsson S: **The influence of seat-back and head-restraint properties on the head-neck motion during rear-impact.** *Accident Analysis & Prevention* 1996, **28**:221-227.
18. Welcher JB, Szabo TJ: **Relationships between seat properties and human subject kinematics in rear impact tests.** *Accident Analysis & Prevention* 2001, **33**:289-304.
19. Eichberger A, Geigl BC, Moser A, Fachbach B, Steffan H: **Comparison of different car seats regarding head-neck kinematics of volunteers during rear end impact.** *Proceedings of the International Conference on the Biomechanics of impacts; Dublin* 1996:153-164.
20. Muhlbauer M, Eichberger A, Geigl B, Steffan H: **Analysis of Kinematics and acceleration behavior of the head and neck in experimental rear-impact collisions.** *Neuro-Orthopedics* 1999, **25**:1-17.
21. Farmer CM, Wells JK, Werner JV: **Relationship of head restraint positioning to driver neck injury in rear-end crashes.** *Accident Analysis & Prevention* 1999, **31**:719-728.
22. Jakobsson L, Norin H, Jernström C, Svensson S, Johnsen P, Isaksson-Hellman I, Svensson M: **Analysis of different head and neck responses in rear-end car collisions using a new humanlike mathematical model.** *SAE* 1994, **13-0007**:.
23. Song D, Uriot J, Trosseille P, Mack C, Tarriere C, Got C, Domont A: **Modelling and Analysis of Interactions between occupant, seatback and headrest in rear impact.** *Proceedings of the International Conference on the Biomechanics of Impact (IRCOBI); Dublin, Ireland* 1996:165-185.
24. Kullgren A, Krafft M, Nygren A, Tingvall C: **Neck injuries in frontal impacts: influence of crash pulse characteristics on injury risk.** *Accid Anal Prev* 2000, **32**:197-205.
25. Vernon HT, Mior S: **The Neck Disability Index: a study of reliability and validity.** *J Manipulative Physiol Ther* 1991, **14**:409-415.
26. Spitzer WO, Skovron ML, Salmi LR, Cassidy JD, Duranceau J, Suissa S, Zeiss E: **Scientific monograph of the Quebec Task Force on Whiplash-Associated Disorders: redefining "whiplash" and its management [see comments] [published erratum appears in Spine 1995 Nov 1;20(21):2372].** *Spine* 1995, **20**:1S-73S.
27. Appel H, Krabbel G, Vetter D: **Unfallrekonstruktion.** In *Unfallforschung, Unfallmechanik und Unfallrekonstruktion* Kippenheim: Informations Ambs GmbH; 2002:143-183.
28. Zeidler F: **Erfahrungen aus 25 Jahren Unfallforschung bei Merzedes-Benz. Methodik, Maßnahmen, Effizienz.** *Verkehrsunfall und Fahrzeugtechnik* 1995, **33**:246-250.

29. Brault JR, Wheeler JB, Siegmund GP, Brault EJb: **Clinical response of human subjects to rear-end automobile collisions.** *Arch Phys Med Rehabil* 1998, **79**:72-80.
30. Eichberger A, Steffan H, Geigl BC, Svensson MY, Boström O, Leinzinger P, Darok M: **Evaluation of the applicability of the neck injury criterion (NIC) in rear end impacts on the basis of human subject test.** *Proceedings of the International Conference on the Biomechanics of impacts* 1998:1-14.
31. McConnell WE, Howard RP, Guzman HM, Bomar JB, Raddin JH, Benedict JV, Smith HL, Hatsell CP: **Analysis of human test subject kinematic responses to low velocity rear end impacts.** In *Proceedings of the 37th Stapp Car Crash Conference; San Antonio, USA* series Stp; 1998:21-30.
32. Anderson RD, Welcher JB, Szabo TJ, Eubanks JJ, Haight WRR: **Effect of Braking on Human Occupant and Vehicle Kinematics in Low Speed Rear-End Collisions.** *16th International Technical Conference on the Enhanced Softy of Vehicles* 1998, **Paper No. 980298**:1-13.
33. Szabo TJ, Welcher JB: **Human subject kinematics and electromyographic activity during low speed rear impacts.** In *Proceedings of the 40th Stapp Car Crash Conference; Albuquerque, USA* SAE; 1996:295-315.
34. Nielsen G, Gough J, Little D, West D, Baker V: **Repeated Low Speed Impacts with Utility Vehicles and Humans.** *Accident Reconstruction Journal* 1996, **9**:24-38.
35. Ewing CL, Thomas DJ, Lustick L, Muzzy WH III, Willems G, Majewski PL: **The Effect of Duration, rate of onset and peak sled acceleration on the dynamic response of the human head and neck.** *Proceedings of the 20st Stapp Car Crash Conference; Dearborn, USA* 1976:3-41.
36. West DH, Gough JP, Harper GTK: **Low speed rear-end collisions testing using human subjects.** *Accident Reconstruction Journal* 1993, **5**:22-26.
37. Jakobsson L, Norin H, Bunketorp O: **In-depth study of whiplash associated dissorders in frontal impacts: influencing factors and consequences.** *Proceedings of the International Conference on the Biomechanics of impacts* 2002:1-12.
38. Evans L: **Ade Dependence of Female To Male Fatality Risk From the Same Crash: An Independent Reexamination.** *43rd Annual Proceedings of the Asssociation for the Advancement of Automotive Medicine Conference; Barcelona, Sitges* 1999:225-238.
39. Garces GL, Medina D, Milutinovic L, Garavote P, Guerado E: **Normative database of isometric cervical strength in a healthy population.** *Med Sci Sports Exerc* 2002, **34**:464-470.
40. Winkelstein BA, Nightingale RW, Richardson WJ, Myers BS: **Cervical facet joint mechanics: Its Application to whiplash injury.** *Proceedings of the 43rd Stapp Car Crash Conference; San Diego, USA* 1999:243-252.
41. Sturzenegger M, Radanov BP, Di Stefano G: **The Effect of accident mechanisms and initial findings on the long-term course of whiplash injury.** *Journal of Neurology* 1996, **242**:443-449.
42. Gleick J: **Chaos: The Amazing Science of the Unpredictable.** London: Vintage Random House; 1998.
43. Lorenz E: **Deterministic Nonperiodic Flow.** *Journal of the Atmospheric Sciences* 1963, **20**:130-141.

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BIOMECHANICAL FEATURES

The Influence of Morphology on Cervical Injury Characteristics

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Study Design. Review of peer-reviewed literature.

Objective. Outline the effects of neck and cervical spine morphology on soft tissue injury Potential during low velocity automotive rear impacts.

Summary of Background Data. Automotive rear impacts are mechanical events and the response of the human head–neck complex can be thought of in biomechanical terms. This manuscript reviews evidence from peer-reviewed studies implicating occupant-related factors in the onset and severity of cervical spine soft-tissue injury.

Methods. Effects of anatomical characteristics, head–neck and spine orientation, facet joints, and neck muscles were reviewed.

Results. On the basis of existing biomechanically based research, the following occupant-related characteristics can influence the response of the cervical spine during automotive rear impacts: anatomical dimensions of the cervical spine, head–neck and cervical spine orientation at the time of impact, facet joint orientation, and neck muscle size and orientation.

Conclusion. The response of the cervical spine to rear impacts can be described using biomechanical concepts. This review has identified occupant-related factors that can influence injury susceptibility and cited biomechanically related research to outline the method by which those factors affect the overall head–neck and cervical spine response in such a way as to increase the susceptibility or severity of injury for a given rear impact event.

Key words: biomechanics, cervical spine, gender, whiplash. **Spine 2011;36:S180–S186**

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CONTEXT

Automotive rear impacts are mechanical events and the response of the head–neck complex can be thought of in biomechanical terms. As such, geometry, orientation, boundary conditions, material properties, and loading are known to affect the response of the cervical spine to these dynamic events. Clinical literature has identified a number of biomechanical factors that may influence injury potential or severity during automotive rear impacts. Perhaps the most common occupant-based factor is gender. With regard to gender, females were consistently shown to be more susceptible to whiplash trauma.[1–10] Females were also associated with increased susceptibility for long-term (chronic) symptoms.[3,7,9,11] Higher injury rates may be attributed to biomechanical, psychological, sociological, or anthropometric considerations. This chapter will focus on defining the method by which biomechanical factors influence response of the cervical spine to rear impacts with a focus on outlining possible underlying mechanisms for greater injury susceptibility for specific populations, such as females.

BIOMECHANICS OF THE CERVICAL SPINE

From a mechanical standpoint, the cervical spine can be viewed as a column that transmits loads from the head to the body. The ability to transmit loads without experiencing a sudden change in shape (*i.e.*, buckling) is a phenomenon known in mechanics as *stability*. Although column mechanics and stability are typically concerned with axial loads (*i.e.*, compression), the cervical column is also exposed to a variety of other loading modes including flexion/extension, lateral bending, axial rotation, tension, and shear during both physiologic and traumatic loading scenarios. During low speed automotive rear impacts, anteriorly directed shear loads are transmitted from the seatback to the base of the cervical spine. This results in inertial loading as the base of the spine displaces anteriorly relative to the head, which temporarily remains stationary because of its inertia. The stability of the cervical spine during this type of loading is dependent upon several intrinsic factors including spinal geometry, head–neck orientation, neck muscle sizes and relative locations, and the orientation of cervical facet joints. This article will focus on the contribution of these factors to the stability of the cervical spine during rear impacts.

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Dynamic stability of the cervical spine can influence the potential or severity of injury. This article will not focus directly on soft tissue injuries in terms of mechanical tolerance or associated pain symptoms. Rather, the article will provide a brief overview of factors that affect spinal stability and the mechanisms that influence injury potential and severity. To do so, four assumptions have been made. First, motions of the cervical vertebrae result in distortion of the interconnecting soft tissues including ligaments, intervertebral discs, and joints. Greater intervertebral motion results in greater tissue distortions. Each tissue has specific tolerances for subfailure, wherein the tissue remains intact but is structurally weakened, or catastrophic failure, resulting in loss of the load carrying capacity for the tissue. Increasing motions of the cervical spine transition from the physiologic to the traumatic realm, eventually resulting in subfailure or catastrophic failure of one or more tissues. Second, for a given external load, decreased stability of the spine will lead to greater motions and, therefore, increased distortion of soft tissues. Third, from an injury standpoint, increased soft tissue distortion results in either an increased potential of injury or a higher severity of injury. Given interpersonal differences in tissue mechanical tolerance, increasing the level of tissue distortion will increase the potential that a specific individual will sustain an injury. Likewise, once injured, increasing tissue distortion beyond that level will lead to a more severe injury. Finally, higher subfailure injury severity will result in greater chronicity of symptoms for the affected individual because of the greater extent of tissue damage and the higher level of associated repair and healing. The following contributing factors are discussed under these four assumptions.

ANATOMICAL CONCEPTS

In the most basic function, the cervical spine is a column that is responsible for supporting the mass of the head and facilitating physiologic motions of the head and neck. As such, column-related metrics can be used to assess spinal stability. According to column mechanics, stability is dependent upon length and cross-sectional area with the ratio of those two quantities describing the *slenderness*. In anatomical terms, column length is the superior–inferior distance from the cranio–vertebral junction to the base of the cervical spine. From a compressive stability standpoint, the cross-sectional area of the ligamentous spine consists of the axial plane projection of the intervertebral discs and facet joints. Stability of the cervical column is increased for shorter and thicker spines and decreased for slender spines. Although the biomechanical implications of column length are fairly straightforward, the implications of cross-sectional area are less clear because of the orientation of the facet joints and differing contributions of cross-sectional dimensions depending on the direction of loading. In the case of anteriorly directed shear force, such as that experienced during automotive rear impacts, the anterior–posterior contribution to cross-sectional area is more important in the column resistance to bending. This describes a property of beams that is mechanically termed second moment of area or area moment of inertia, and represents a column's resistance to bending. Therefore, the distance from the anterior of the intervertebral disc to the posterior of the facet joints is a relevant quantity for spinal stability during whiplash loading.

Recent literature has identified the importance of cross-sectional dimensions on cervical column stability and reported these data for C2 to C6 spinal levels as derived from CT scans of young volunteers.[12,13] Focusing on the effect of gender for cervical column stability, those studies identified a significantly decreased anterior–posterior dimension from the anterior aspect of the vertebral body to the posterior aspect of the facet joints in females for composite populations of males and females size matched on the basis of the head circumference or sitting height (Figure 1). Lateral vertebral width was also significantly greater in male volunteers, indicating that both dimensions responsible for the area moment of inertia were significantly greater in males. Therefore, given equal column length, results of those studies indicate greater cervical column stability during rear impacts for males compared to size-matched females. In the general population, wherein females are typically anthropometrically smaller, these differences may be accentuated. Given that females have historically been identified as being more susceptible to soft tissue cervical spine injury,[3,14,15] the differences

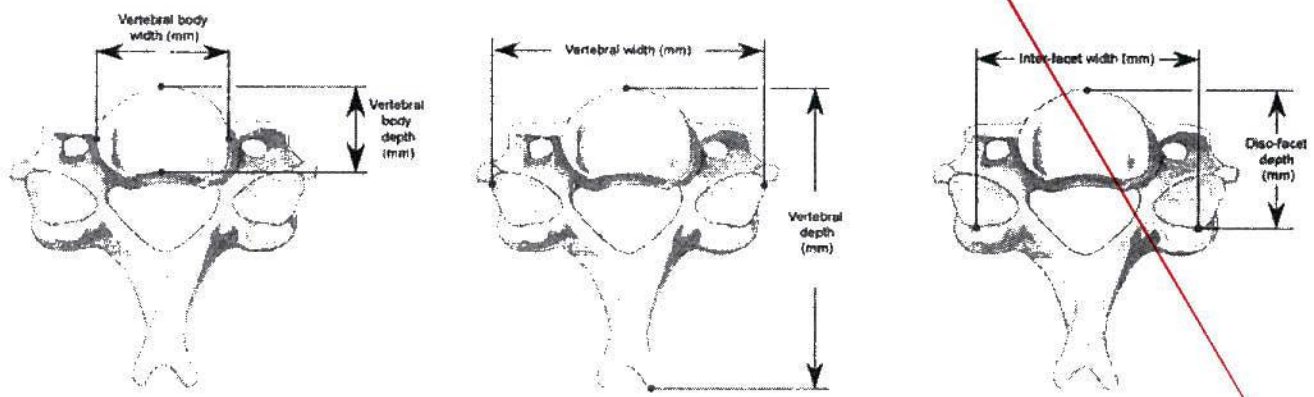

Figure 1. Geometrical dimensions of cervical vertebrae. All geometrical measures were greater in men for two subsets of younger size-matched volunteers. Vertebral width and disc-facet depth were significantly greater ($P < 0.05$) in men. Obtained pending permission from Stemper *et al.* Spine 2008.

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SUBMITTED - 1396744 - Amanda Isom - 7/6/2018 1:31 PM in column stability identified in those studies may partially explain increased female susceptibility identified in clinical and epidemiological literature.

Other studies have recognized the importance of cross-sectional geometry in cervical column stability[16] and anatomical investigations have reported similar metrics,[17–21] albeit using different population characteristics. Previous studies generally focused on vertebral body metrics, including lateral width and anterior–posterior depth. Although populations were not sized matched, those studies also identified greater dimensions in males, which were particularly evident in the anterior–posterior dimension.[17,18] One study quantified vertebral metrics in a population of size matched males and females.[22] That study reported significantly increased anterior–posterior vertebral body dimensions in males at C2 to C7 levels. Vertebral body to spinous process length was also significantly greater in males at C5 to C7 levels. However, vertebral body dimensions only partially contribute to cervical column bending stability and the spinous process contributes to stability primarily during flexion. Nonetheless, these studies identified anatomical differences between males and females that likely contribute to column stability and may partially explain greater rates of whiplash injury and pain chronicity in women after automotive rear impacts.

HEAD–NECK AND SPINE ORIENTATION

Similar to anatomical characteristics, cervical spine orientation can also influence head–neck response to automotive rear impacts, as well as the likelihood and severity of injury. Spine orientation can refer to the inherent cervical curvature or the position of the head–neck complex at the time of impact. The normal shape of the cervical spine is represented by lordosis, which forms an anteriorly convex curvature in the sagittal plane. The magnitude of the lordotic curvature is distributed consistently between each spinal segment from C2 to C3 through C6 to C7,[23] with the overall magnitude of curvature varied between individuals. The lordotic curvature of the spine can be affected by the aging process (*i.e.*, spinal degeneration),[24] traumatic events,[25,26] or surgical intervention.[27–29] Because curvature influences the load carrying capacity of the spine, abnormal cervical curvatures may increase the likelihood or severity of soft tissue injury.[16,30–32] Clinical literature supports this hypothesis and has correlated abnormal cervical curvatures with higher rates of injury and postinjury degenerative changes in the spine.[11,33] Although not investigated in human subjects, the biomechanical effect of abnormal curvatures on the response of the cervical spine to rear impacts was delineated using a validated head–neck computational model (Figure 2).[34] That study identified increased facet joint capsular ligament stretch for straight and kyphotic curvatures, which can be associated with an increased potential or severity of injury. Kyphotic curvature increased facet joint ligament elongations by 73% at the C5 to C6 level compared to elongations sustained in the normal lordotic spine. Therefore, clinical, experimental, and computational studies outlined in this section have demonstrated that cervical spinal curvature can influence the likelihood and chronicity of injury.

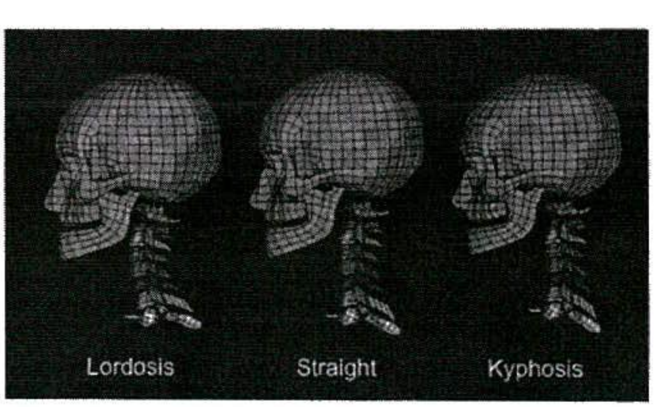

Figure 2. Normal lordotic curvature (left) and abnormal curvatures (middle, right) computationally simulated for their effect on facet joint ligament elongations during dynamic rear impacts. Obtained pending permission from Stemper *et al.* J Biomech 2005.

Cervical spine orientation can also refer to the position of the head–neck complex at the time of rear impact. With regard to influencing injury suceptibility, clinical and epidemiological reports have identified that occupants with their head rotated at the time of impact have sustained higher frequency of multiple injuries and remained symptomatic for a longer duration of time.[7,35,36] In addition, one study reported that occupants with head rotated at the time of impact had a higher rate of high-grade MRI abnormalities of the alar and transverse ligaments than occupants looking forward at the time of impact.[37] The explanation for this increased susceptibility has been hypothesized to be increased prestrain on cervical spine ligaments because of axial rotation of the spine. Biomechanical studies have attempted to prove this hypothesis using experimental testing and computational modeling. Using isolated cervical segments and quasi-statically applied shear loading, one study identified increased capsular ligament strains for axially rotated segments compared to segments with neutral initial position.[38] Strains were greatest on the ipsilateral side. Other studies investigating the effect of axially rotated head positions at the time of impact using isolated cervical spines demonstrated increased potential of ganglion compression and vertebral artery injury, although those injury mechanisms remain outside of the traditional concept of whiplash injury.[39,40] More recently, the effect of axial head rotation at the time of dynamic impact on capsular ligament strains was parametrically investigated using a validated computational model.[41] That study reported increased ligament strains for simulations incorporating axial head rotation, with greater strain increases for greater magnitudes of axial rotation. Similar to the previous study incorporating quasi-static loading, strains were greatest on the ipsilateral side. These studies have clearly demonstrated that prestrain on cervical spine soft tissues because of axial rotation can increase the potential and severity of injury during low velocity rear impacts.

ROLE OF FACET JOINTS

Cervical facet joints have been studied primarily as the site of injury during automotive rear impacts, but also play a levels were described using cylindrical coordinates.[54] That study incorporated a unique protocol and obtained data on neck muscle positions using upright MRI scans of six younger male volunteers. Upright MRI has the benefit of obtaining images with the volunteer in the seated position and allowing the head to load the cervical spine and structures of the neck.[55] More relevant to the study of cervical spine stability, one study reported statistically significantly different neck muscle sizes and positions between male and female volunteers.[56] Male neck muscles demonstrated greater cross-sectional areas and were positioned at a greater distance from the cervical spine (Figure 4). Specifically, sternocleidomastoid cross-sectional areas were 81% greater in males than in females. Greater cross-sectional areas are associated with maximum contractile force, whereas muscles located further from the cervical spine have a higher moment generating capacity. A recent study by Yoganandan *et al*,[57] reported only 26% greater head mass in males (3.66 kg for males compared to 2.89 kg for females). Therefore, according to muscle size and locations, male neck muscles have a greater ability to stabilize the cervical spine

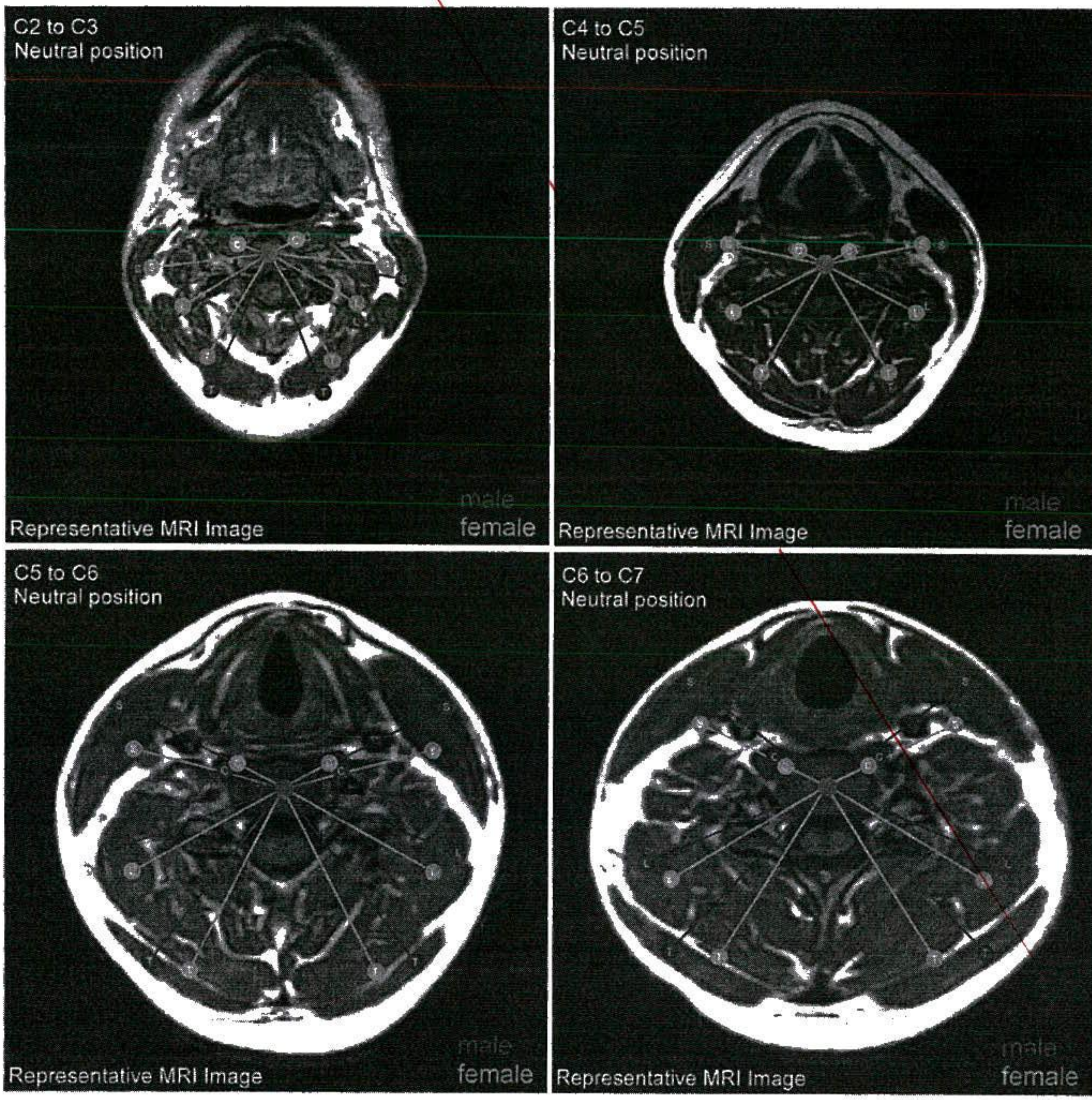

Figure 4. Neck muscle centroid positions for C2 to C3, C4 to C5, C5 to C6, and C6 to C7 levels. S: sternocleidomastoid, C: longus colli, L: levator scapulae, T: trapezius.

under dynamic loading, given the slightly greater head mass in that population. Once again, this finding is supported by clinical studies demonstrating higher incidence of whiplash injuries in females.

Moment generating capacity can also be directly measured in human volunteers or cadaveric specimens. One study incorporating the tendon excursion method in human cadavers identified that neck muscle moment arms were dependent upon the plane of loading (*i.e.*, flexion/extension, lateral bending, or axial rotation), spinal level, and involved muscle,[58] which highlights the importance of morphology on the ability of a specific neck muscle to influence intervertebral motion and prevent soft tissue injury. Studies directly quantifying moment generating capacity have all reported greater sagittal plane moments in male volunteers compared to female volunteers.[59–61] These findings of decreased muscle strength in females compared to males can be used as a validation of morphometric studies described above. As with the other metrics described above, the morphometry of neck muscles can influence maximum contractile force and moment generating capacity which can alter the stability of the head–neck complex and influence the potential or severity of injury during a specific rear impact scenario.

SUMMARY/FUTURE RESEARCH DIRECTIONS

Vehicle safety research is often concerned with crash-related factors when determining the likelihood of injury for a specific impact scenario. Although factors such as impact velocity are important for the outcome of a vehicle collision, this article has highlighted several occupant-related factors that may also influence the injury potential and chronicity of symptoms after low velocity rear impact. Continuing safety research should consider interpersonal variability in terms of anatomical morphology of the ligamentous cervical spine and head–neck complex. This highlights the importance of computational and statistics-based parametric modeling in future research endeavors, where anthropometric models of a single geometry were incorporated in the past. The foundation of these computational models includes accurate material properties and validation data, which must continue to be developed using experimental biomechanics research. Additionally, tolerance criteria that relate biomechanical measures to specific soft tissue injuries must be proposed.

➢ Key Points

- ❑ Slender female cervical spines may be more susceptible to bending for a given rear impact.
- ❑ Straight and kyphotic cervical curvatures can increase facet joint ligament stretch during rear impacts.
- ❑ Axial rotation of the head at the time of rear impact increases ipsilateral facet joint ligament strains.
- ❑ Different sizes and relative orientations of the neck muscles between men and women may explain differing injury susceptibility between those populations.

References

1. Pobereskin LH. Whiplash following rear end collisions: a prospective cohort study. *J Neurol Neurosurg Psychiatry* 2005;76:1146–51.
2. Suissa S. Risk factors of poor prognosis after whiplash injury. *Pain Res Manag* 2003;8:69–75.
3. Cassidy JD, Carroll LJ, Côté P, et al. Effect of eliminating compensation for pain and suffering on the outcome of insurance claims for whiplash injury. *N Engl J Med* 2000;342:1179–86.
4. Hildingsson C, Toolanen G. Outcome after soft-tissue injury of the cervical spine. A prospective study of 93 car-accident victims. *Acta Orthop Scand* 1990;61:357–9.
5. Jonsson H, Jr, Cesarini K, Sahlstedt B, Rauschning W. Findings and outcome in whiplash-type neck distortions. *Spine (Phila Pa 1976)* 1994;19:2733–43.
6. Mayou R, Bryant B. Outcome of 'whiplash' neck injury. *Injury* 1996;27:617–23.
7. Radanov BP, Sturzenegger M, Di Stefano G. Long-term outcome after whiplash injury. A 2-year follow-up considering features of injury mechanism and somatic, radiologic, and psychosocial findings. *Medicine (Baltimore)* 1995;74:281–97.
8. Cote P, Hogg-Johnson S, Cassidy JD, et al. Initial patterns of clinical care and recovery from whiplash injuries: a population-based cohort study. *Arch Intern Med* 2005;165:2257–63.
9. Guez M, Hildingsson C, Nilsson M, Toolanen G. The prevalence of neck pain: a population-based study from northern Sweden. *Acta Orthop Scand* 2002;73:455–9.
10. Sterner Y, Toolanen G, Gerdle B, Hildingsson C. The incidence of whiplash trauma and the effects of different factors on recovery. *J Spinal Disord Tech* 2003;16:195–9.
11. Hohl M. Soft-tissue injuries of the neck in automobile accidents. Factors influencing prognosis. *J Bone Joint Surg Am* 1974;56:1675–82.
12. Stemper BD, Derosia JJ, Yogananan N, et al. Gender dependent cervical spine anatomical differences in size-matched volunteers. *Biomed Sci Instrum* 2009;45:149–54.
13. Stemper BD, Yoganandan N, Pintar FA, et al. Anatomical gender differences in cervical vertebrae of size-matched volunteers. *Spine (Phila Pa 1976)* 2008;33:E44–9.
14. Spitzer WO, Skovron ML, Salmi LR, et al. Scientific monograph of the Quebec Task Force on Whiplash-Associated Disorders: redefining "whiplash" and its management. *Spine (Phila Pa 1976)* 1995;20:1S–73S.
15. Harder S, Veilleux M, Suissa S. The effect of socio-demographic and crash-related factors on the prognosis of whiplash. *J Clin Epidemiol* 1998;51:377–84.
16. Liu YK, Dai QG. The second stiffest axis of a beam-column: implications for cervical spine trauma. *J Biomech Eng* 1989;111:122–7.
17. Francis CC. Dimensions of the cervical vertebrae. *Anat Rec* 1955;122:603–9.
18. Katz PR, Reynolds HM, Foust DR, Baum JK. Mid-sagittal dimensions of cervical vertebral bodies. *Am J Phys Anthropol* 1975;43:319–26.
19. Gilsanz V, Boechat MI, Gilsanz R, et al. Gender differences in vertebral sizes in adults: biomechanical implications. *Radiology* 1994;190:678–82.
20. Frobin W, Leivseth G, Biggemann M, Brinckmann P. Vertebral height, disc height, posteroanterior displacement and dens-atlas gap in the cervical spine: precision measurement protocol and normal data. *Clin Biomech (Bristol, Avon)* 2002;17:423–31.
21. Panjabi MM, Duranceau J, Goel V, et al. Cervical human vertebrae. Quantitative three-dimensional anatomy of the middle and lower regions. *Spine (Phila Pa 1976)* 1991;16:861–9.
22. Vasavada AN, Danaraj J, Siegmund GP. Head and neck anthropometry, vertebral geometry and neck strength in height-matched men and women. *J Biomech* 2008;41:114–21.
23. Takeshima T, Omokawa S, Takaoka T, et al. Sagittal alignment of cervical flexion and extension: lateral radiographic analysis. *Spine (Phila Pa 1976)* 2002;27:E348–55.
24. Gore DR, Sepic SB, Gardner GM. Roentgenographic findings of the cervical spine in asymptomatic people. *Spine (Phila Pa 1976)* 1986;11:521–4.

25. Abel MS. Roentgenographic aspects of post-traumatic arthritis, instability and disk deterioration following occult fractures of cervical spine. *Clin Orthop* 1962;24:49–60.
26. Vaccaro AR, Silber JS. Post-traumatic spinal deformity. *Spine (Phila Pa 1976)* 2001;26:S111–18.
27. Baisden J, Voo LM, Cusick JF, et al. Evaluation of cervical laminectomy and laminoplasty. A longitudinal study in the goat model. *Spine (Phila Pa 1976)* 1999;24:1283–8; discussion 1288–9.
28. Batzdorf U, Batzdorff A. Analysis of cervical spine curvature in patients with cervical spondylosis. *Neurosurgery* 1988;22:827–36.
29. Butler JC, Whitecloud TS, 3rd. Postlaminectomy kyphosis. Causes and surgical management. *Orthop Clin North Am* 1992;23:505–11.
30. Maiman DJ, Yoganandan N, Pintar FA. Preinjury cervical alignment affecting spinal trauma. *J Neurosurg* 2002;97:57–62.
31. Maiman DJ, Sances A Jr, Myklebust JB, et al. Compression injuries of the cervical spine: a biomechanical analysis. *Neurosurgery* 1983;13:254–60.
32. Yoganandan N, Sances A Jr, Maiman DJ, et al. Experimental spinal injuries with vertical impact. *Spine (Phila Pa 1976)* 1986;11:855–60.
33. Norris SH, Watt I. The prognosis of neck injuries resulting from rear-end vehicle collisions. *J Bone Joint Surg Br* 1983;65:608–11.
34. Stemper BD, Yoganandan N, Pintar FA. Effects of abnormal posture on capsular ligament elongations in a computational model subjected to whiplash loading. *J Biomech* 2005;38:1313–23.
35. Sturzenegger M, DiStefano G, Radanov BP, Schnidrig A. Presenting symptoms and signs after whiplash injury: the influence of accident mechanisms. *Neurology* 1994;44:688–93.
36. Jakobsson L, Isaksson-Hellman I, Lindman M. WHIPS (Volvo cars' Whiplash Protection System)—the development and real-world performance. *Traffic Inj Prev* 2008;9:600–5.
37. Kaale BR, Krakenes J, Albrektsen G, Wester K. Head position and impact direction in whiplash injuries: associations with MRI-verified lesions of ligaments and membranes in the upper cervical spine. *J Neurotrauma* 2005;22:1294–302.
38. Siegmund GP, Davis MB, Quinn KP, et al. Head-turned postures increase the risk of cervical facet capsule injury during whiplash. *Spine (Phila Pa 1976)* 2008;33:1643–9.
39. Ivancic PC, Ito S, Tominaga Y, et al. Effect of rotated head posture on dynamic vertebral artery elongation during simulated rear impact. *Clin Biomech (Bristol, Avon)* 2006;21:213–20.
40. Tominaga Y, Maak TG, Ivancic PC, et al. Head-turned rear impact causing dynamic cervical intervertebral foramen narrowing: implications for ganglion and nerve root injury. *J Neurosurg Spine* 2006;4:380–7.
41. Storvik SG, Stemper BD. Axial head rotation increases facet joint capsular ligament strains in automotive rear impact. *Med Biol Eng Comput*. 2011;49:153–61
42. Denis F. The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. *Spine (Phila Pa 1976)* 1983;8:817–31.
43. Pal GP, Routal RV, Saggu SK. The orientation of the articular facets of the zygapophyseal joints at the cervical and upper thoracic region. *J Anat* 2001;198:431–41.
44. Panjabi MM, Oxland T, Takata K, et al. Articular facets of the human spine. Quantitative three-dimensional anatomy. *Spine (Phila Pa 1976)* 1993;18:1298–310.
45. Goel VK, Clausen JD. Prediction of load sharing among spinal components of a C5-C6 motion segment using the finite element approach. *Spine (Phila Pa 1976)* 1998;23:684–91.
46. Teo EC, Ng HW. Evaluation of the role of ligaments, facets and disc nucleus in lower cervical spine under compression and sagittal moments using finite element method. *Med Eng Phys* 2001;23:155–64.
47. Raynor RB, Pugh J, Shapiro I. Cervical facetectomy and its effect on spine strength. *J Neurosurg* 1985;63:278–82.
48. Chancey VC, Nightingale RW, Van Ee CA, et al. Improved estimation of human neck tensile tolerance: reducing the range of reported tolerance using anthropometrically correct muscles and optimized physiologic initial conditions. *Stapp Car Crash J* 2003;47:135–53.
49. Van Ee CA, Nightingale RW, Camacho DL, et al. Tensile properties of the human muscular and ligamentous cervical spine. *Stapp Car Crash J* 2000;44:85–102.
50. Vasavada AN, Lasher RA, Meyer TE, Lin DC. Defining and evaluating wrapping surfaces for MRI-derived spinal muscle paths. *J Biomech* 2008;41:1450–7.
51. De Loose V, Van den Oord M, Keser I, et al. MRI study of the morphometry of the cervical musculature in F-16 pilots. *Aviat Space Environ Med* 2009;80:727–31.
52. Elliott JM, Jull GA, Noteboom JT, et al. Magnetic resonance imaging study of cross-sectional area of the cervical extensor musculature in an asymptomatic cohort. *Clin Anat* 2007;20:35–40.
53. Conley MS, Stone MH, Nimmons M, Dudley GA. Specificity of resistance training responses in neck muscle size and strength. *Eur J Appl Physiol Occup Physiol* 1997;75:443–8.
54. Stemper BD, Baisden JL, Yoganandan N, et al. Determination of normative neck muscle morphometry using upright MRI with comparison to supine data. *Aviat Space Environ Med* 2010;81:878–82.
55. Jinkins JR, Dworkin JS, Damadian RV. Upright, weight-bearing, dynamic-kinetic MRI of the spine: initial results. *Eur Radiol* 2005;15:1815–25.
56. Stemper BD, Yoganandan N, Baisden JL, et al. Biomechanical implications of gender-dependent muscle locations. ASME 2008 Summer Bioengineering Conference. Marco Island, FL; 2008.
57. Yoganandan N, Pintar FA, Zhang J, Baisden JL. Physical properties of the human head: mass, center of gravity and moment of inertia. *J Biomech* 2009;42:1177–92.
58. Ackland DC, Merritt JS, Pandy MG. Moment arms of the human neck muscles in flexion, bending and rotation. *J Biomech*. 2011;44:475–86.
59. Vasavada AN, Li S, Delp SL. Three-dimensional isometric strength of neck muscles in humans. *Spine (Phila Pa 1976)* 2001;26:1904–9.
60. Jordan A, Mehlsen J, Bülow PM, et al. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine (Phila Pa 1976)* 1999;24:1343–8.
61. Moroney SP, Schultz AB, Miller JA. Analysis and measurement of neck loads. *J Orthop Res* 1988;6:713–20.