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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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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.

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 sever-

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ity, 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

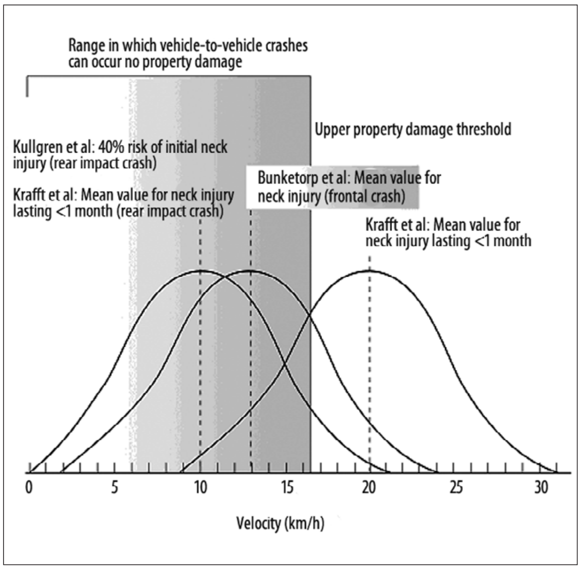

Figure 1. Note that curves were used here only for the purpose of illustration. Only the mean values (dashed lines) are known with confidence.

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.

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.

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