Steering Wheel Deformity and Serious Thoracic or Abdominal Injury Among Drivers and Passengers Involved in Motor Vehicle Crashes

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Study objective: We assess the relationship between steering wheel deformity and serious thoracic or abdominal injury among drivers and front seat passengers involved in motor vehicle crashes, while adjusting for important crash factors.

Methods: This was a national population-based cohort of adults involved in motor vehicle crashes from 1995 to 2002 and included in the National Automotive Sampling System Crashworthiness Data System database. Participants were front seat occupants aged 16 years or older involved in motor vehicle crashes with collision. Outcome measure was serious thoracic or abdominal injury, defined as an Abbreviated Injury Scale score greater than or equal to 3 in these body regions.

Results: There were 42,860 persons involved in motor vehicle crashes and seated in the driver or front passenger seat whose data were available for analysis. Five hundred fifty-four (1.3%) persons had serious thoracic injuries, and 169 (0.4%) persons had serious abdominal injuries. In multivariable logistic regression models that adjusted for important crash factors and the National Automotive Sampling System Crashworthiness Data System sampling design, increasing steering wheel deformity was associated with serious thoracic injury in drivers (odds ratio [OR] for each 5-cm increase in steering wheel deformity 1.28, 95% confidence interval [CI] 1.04 to 1.59) and front seat passengers (OR 1.77, 95% CI 1.26 to 2.49). Increasing steering wheel deformity was associated with serious abdominal injury in front seat passengers (OR 1.45, 95% CI 1.11 to 1.89) but not in drivers (OR 0.95, 95% CI 0.79 to 1.15).

Conclusion: Steering wheel deformity is an independent predictor of serious thoracic injury in drivers and front seat passengers and is associated with serious abdominal injury among front seat passengers. For these occupants, the risk of these injuries increases incrementally with increasing steering wheel deformity. [Ann Emerg Med. 2005;45:43-50.]

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INTRODUCTION

Background

Steering wheel deformity has been suggested as a predictor of thoracic injury, abdominal injury, and overall injury severity among persons involved in motor vehicle crashes. Although the association between steering wheel deformity and injury has been described primarily with drivers, it has been suggested that steering wheel deformity may also represent a marker of injury severity for all occupants by serving as a surrogate measure of crash severity. It remains unclear whether the steering wheel itself causes certain injuries (eg, thoracic and abdominal) or whether it is simply a marker of a severe crash that may not be important after other measures of crash severity are accounted for. In addition, the role of a bent steering wheel as a predictor of specific injury patterns in passengers is unknown. It is also possible that air bag deployment and restraint use modify the potential association between steering wheel deformity and serious injury.
Editor’s Capsule Summary

What is already known on this topic
Steering wheel deformity has been associated with thoracic injuries, although it is not known whether this correlation is related to crash severity or mechanism of injury.

What question this study addressed
This study assesses whether the amount of steering wheel deformity was associated with increasing risk of thoracic and abdominal injury in drivers and front seat passengers. This study was conducted on a probability sampled, national data set of persons involved in motor vehicle crashes.

What this study adds to our knowledge
The risk of thoracic injuries (among drivers and passengers) and abdominal injuries (among passengers) increases incrementally with the amount of steering wheel deformity. In addition, air bag deployment was also associated with thoracic injury in drivers and abdominal injury in front seat passengers.

How this might change clinical practice
Emergency physicians should have a high level of clinical suspicion for thoracoabdominal injuries in patients who were involved in motor vehicle crashes with steering wheel deformity. In addition, emergency medical services should be encouraged to collect information about the amount of deformity of the steering wheel regardless of air bag deployment.

Importance
An association between steering wheel deformity and certain injuries may have relevance to the practicing clinician during the evaluation of persons involved in motor vehicle crashes, and the degree of steering wheel deformity may be an important surrogate measure of crash severity, particularly when the calculation of change in velocity (ΔV) or other more direct measures of crash severity is not possible.

Goals of This Investigation
In this study, we sought to assess whether increasing steering wheel deformity is associated with increased risk of serious thoracic and/or serious abdominal injury among drivers and front seat passengers involved in motor vehicle crashes, while adjusting for important crash factors in a national, population-based sample.

MATERIALS AND METHODS
Theoretical Model of the Problem
There is a large amount of potentially useful information communicated about a motor vehicle crash from out-of-hospital personnel, including information about the vehicle, the scene, and the occupant(s). Such information is clinically useful only to the extent that it has been researched and understood and is applicable to patient care and the prevention of injury. One of the many variables that can be assessed at the scene of a motor vehicle crash is steering wheel deformity and the extent of this deformation. It would be useful to establish whether such a finding is related to specific injuries that may occur during a crash and whether these associations are different for occupants exposed directly (ie, drivers) and indirectly (ie, passengers) to the steering wheel.

Study Design
We used observational data on the retrospective cohort of persons included in the National Automotive Sampling System Crashworthiness Data System database from 1995 through 2002 for the study.

Setting
The National Automotive Sampling System Crashworthiness Data System database is a probability sampled, population-based, nationally representative cohort of persons involved in motor vehicle crashes that is collected using a 3-stage sampling of crashes from specific regions throughout the United States to ensure national generalizability of the data. The National Automotive Sampling System Crashworthiness Data System database includes crashes in which at least 1 vehicle was towed because of damage (and was thus available for crash investigation). The 8-year period was selected because data collection changes for air bags were instituted for the National Automotive Sampling System Crashworthiness Data System in 1995. The study was approved by the institutional review boards of our hospitals.

Selection of Participants
A national, population-based sample of front seat occupants (drivers and front seat passengers) of national driving age (≥16 years) involved in motor vehicle crashes with passenger vehicles and light trucks (including sport utility vehicles), as included in the National Automotive Sampling System Crashworthiness Data System database, were included in the analysis. Occupants seated in the middle seat were excluded because they formed a very small portion of front seat occupants (<1%) and have variable exposure to air bag deployment. We also excluded children because there was a low incidence of serious abdominal and thoracic injuries in children included in the National Automotive Sampling System Crashworthiness Data System database and because adults involved in motor vehicle crashes have a higher risk of injury or death compared with children, even after controlling for important crash characteristics. We restricted the sample to front seat occupants to allow the assessment of direct (drivers) and indirect (front seat passengers) exposure to the steering assembly, while controlling for other potentially important crash factors (eg, air bag deployment and seat position). To simplify discussion in the article, we will refer...
Methods of Measurement

Steering wheel deformity was coded as a 4-level, ordered, discrete variable (none, 1 to 5 cm, 6 to 10 cm, >10 cm) according to the degree of steering rim deformation measured during crash investigation for the National Automotive Sampling System Crashworthiness Data System database. Information on telescoping of the steering column is not provided in the database and was not included in this analysis. Steering wheel deformity was categorized into comparable increments of deformity (5 cm) that allowed an adequate number of subjects in each category and that provided increments of deformity that could be potentially distinguished by out-of-hospital personnel. We also tested categoric and quadratic variables for steering wheel deformity. Additional analyses and discussion of different methods of coding used for the steering wheel term are available in Appendix E1 (available at http://www.mosby.com/AnnEmergMed).

Variables were selected on the basis of known associations with injury and crash severity, as well as factors identified a priori as potentially mediating thoracic or abdominal injury in motor vehicle crashes. Sixteen variables were included in the analysis: age (years), sex, pregnancy (any duration of gestation), Glasgow Coma Scale (GCS) score (GCS scores of 14 and 15 were grouped together for the highest score category), police-reported alcohol presence, ΔV (change in velocity), rollover with collision, passenger space intrusion (<15 cm, 15 to 29 cm, 30 to 45 cm, 46 to 60 cm, >60 cm), restraint use (manual lap, lap and shoulder belt, or automatic lap and shoulder belt system versus none), entrapment, ejection, air bag deployment (separated by driver-side or passenger-side deployment), steering wheel deformity (described above), vehicle weight (>3,870 pounds was the highest vehicle weight group), vehicle model year, and direction of impact (frontal, left lateral, or right lateral, with a reference group of rear, undercarriage, and top crashes). In crashes with multiple impacts, impact type was coded as the primary impact site (ie, the impact with the highest ΔV).

ΔV, age, GCS score, vehicle weight, passenger space intrusion, and steering wheel deformity were analyzed as continuous variables, and the additional 10 variables were included as categoric variables. Restraint use was categorized as restrained or unrestrained because the number of occupants with different types of restraint configurations (eg, manual lap belt, shoulder belt only, automatic shoulder and manual lap belt) was too small to allow for different restraint variables in the models. Air bag deployment was used instead of air bag presence in the vehicle to reflect crash information as it would be communicated by emergency medical services personnel. However, presence of an air bag (ie, a vehicle equipped with an air bag in the respective seat position) was also tested in the models to further assess the association between air bags and thoracic or abdominal injury. Noncollision crashes and pure rollovers were excluded to allow for the appropriate use of ΔV to control for crash severity because ΔV can be calculated only in crashes in which a fixed object or another vehicle is struck.

In this article, we use the term “risk” synonymously with odds because the outcomes (thoracic or abdominal injury) were rare (ie, <2% of the sample).

Outcome Measures

Serious thoracic and abdominal injury was defined as an Abbreviated Injury Scale score greater than or equal to 3 in these body regions. The Abbreviated Injury Scale for a given injury ranges from 1 (minor) to 6 (nonsurvivable). A score of 3 or more represents a “serious” injury. Because the diagnostic assessment and clinical management of serious thoracic and serious abdominal injury differs, all analyses were carried out separately on thoracic and abdominal injury as the outcome measure. We also analyzed a third outcome, serious thoracic or serious abdominal injury, to represent any serious injury to the torso.

Primary Data Analysis

After exclusion of noncollision crashes, pure rollovers, persons with missing injury information, and persons with missing steering wheel information, there were 42,860 adult front seat occupants in the 1995 to 2002 National Automotive Sampling System Crashworthiness Data System database. We stratified the analysis into drivers (n=33,733) and passengers (n=9,127) to allow the assessment of steering wheel deformity by direct (driver) and indirect (passenger) exposure.

To allow the inclusion of all adult front seat occupants contained in the National Automotive Sampling System Crashworthiness Data System database during this period and to preserve the original weighting scheme of the database, we used multiple imputation to impute missing values. Information for clusters, strata within clusters, and year were included as fixed effects in the imputation process to preserve the complex design features of the database.

We assessed the association between steering wheel deformity, thoracic injury, and (separately) abdominal injury through multivariable logistic regression models that accounted for the complex sample design (strata, clusters, and weighting) of the database. Further adjustment of estimates based on clustering within vehicles did not change the results. Variables that did not contribute to either model (ie, assessing thoracic and abdominal injury separately) at a level of P value less than .10, that did not change the association between steering wheel deformity and injury, and that were not otherwise thought to be important confounders were removed from the model in a nonautomated, stepwise, backward selection process. The final model included 14 variables. Identical multivariable analyses were repeated after restricting the sample to occupants with at
least 1 injury of any severity (ie, maximum Abbreviated Injury Scale score in any body region ≥1) to simulate a patient population likely to seek evaluation in an emergency department after a motor vehicle crash.

After creation of the model, we assessed specific interaction terms (steering wheel deformity × restraint use, steering wheel deformity × air bag deployment), considering steering wheel deformity to be the focal independent variable and restraint use or air bag deployment as effect modifiers.\(^{25}\) Interaction terms that suggested the presence of an effect modifier were further assessed through stratified analyses. Additional discussion of interaction terms is provided in Appendix E2 (available at http://www.mosby.com/AnnEmergMed).

Database management was performed using SAS software (SAS 8.1, SAS Institute, Inc., Cary, NC). SAS-callable IVWare (Survey Methodology Program, Survey Research Center, Institute for Social Research, University of Michigan, Ann Arbor, MI) was used for multiple imputation, multivariable analyses, and the calculation of rates, accounting for the complex sample design of the National Automotive Sampling System Crashworthiness Data System database and ensuring appropriate variance calculations in all analyses. The jackknife repeated replication technique was used to estimate logistic regression parameter variances.\(^{26}\)

**Sensitivity Analyses**

To explore the effects of multiple imputation and different potential patterns of missing data, we conducted sensitivity analyses of the imputation models.

**RESULTS**

**Characteristics of Study Subjects**

We studied 42,860 front seat occupants (age 16 to 97 years), representing a national population of 21,155,926 occupants involved in motor vehicle crashes during the 8-year period. Of this group, 33,733 persons were drivers and 9,127 were front seat passengers. Five hundred fifty-four (1.3%) occupants had serious thoracic injuries, including 135 fatalities (24% of persons with serious thoracic injuries), and 169 (0.4%) occupants had serious abdominal injuries, including 42 fatalities (25% of persons with serious abdominal injuries). Eighty-five persons had serious thoracic and abdominal injuries. Occupant and vehicle characteristics are presented in Table 1.

In multivariable logistic regression models that adjusted for crash severity, important crash factors, and the National Automotive Sampling System Crashworthiness Data System sample design, steering wheel deformity was independently associated with thoracic injury (odds ratio [OR] for each 5-cm increase in steering wheel deformity 1.28, 95% confidence interval [CI] 1.04 to 1.59) but not abdominal injury (OR 0.95, 95% CI 0.79 to 1.15) among drivers (Table 2). For the combined outcome of serious thoracic or serious abdominal injury among drivers, increasing steering wheel deformity was associated with any serious torso injury (OR for each 5-cm increase in steering wheel deformity 1.19, 95% CI 1.01 to 1.41).

When the sample was restricted to occupants with at least 1 injury of any severity (74% of the original sample), the results for steering wheel deformity were qualitatively similar (for thoracic injury, OR 1.19, 95% CI 0.96 to 1.48; for abdominal injury, OR 0.88, 95% CI 0.73 to 1.06). Vehicle model year and pregnancy did not contribute substantially to the analysis and were omitted from the final models.

For drivers, air bag deployment did not modify the relationship between steering wheel deformity and thoracic injury (interaction term: steering wheel deformity × air bag deployment, \(P=0.99\)) or abdominal injury (\(P=0.66\)). However, the presence of a deployed air bag was independently associated with thoracic injury (OR 1.53, 95% CI 1.07 to 2.18). When the air bag variable was assessed as presence of an air bag (whether or not the air bag deployed), there was no association with either injury type among drivers.

The association between steering wheel deformity and thoracic injury was not modified by restraint use (interaction term: steering wheel deformity × restraint use, \(P=0.45\)), although there was substantial interaction between restraint use and steering wheel deformity with abdominal injury (\(P=0.01\)). Further analyses, stratified by steering wheel deformity, suggested that restraints were less protective against abdominal injury when there was steering wheel deformity (restraint use OR 0.68, 95% CI 0.43 to 1.08) compared with no deformity (restraint use OR 0.25, 95% CI 0.13 to 0.50).

Similar to results from the multivariable models, the crude rate of serious thoracic (but not abdominal) injury increased incrementally with increasing steering deformity among drivers (Figure 1). The rate of serious thoracic injury was notably higher than the rate of abdominal injury at all levels of steering wheel deformity.

In identical multivariable logistic regression models, including front seat passengers only, steering wheel deformity was independently associated with thoracic injury (OR for each 5-cm increase in steering wheel deformity 1.77, 95% CI 1.26 to 2.49) and abdominal injury (OR 1.45, 95% CI 1.11 to 1.89) (Table 2). Steering wheel deformity was also associated with serious torso injury (combined outcome of thoracic or abdominal injury) among passengers (OR for each 5-cm increase in steering wheel deformity 1.80, 95% CI 1.29 to 2.51). When restricted to occupants with at least 1 injury of any severity (74% of the original sample), these results did not qualitatively change (for thoracic injury, OR 1.61, 95% CI 1.11 to 2.36; for abdominal injury, OR 1.37, 95% CI 1.05 to 1.78).

In contrast to drivers, the relationship between steering wheel deformity and injury appeared to be modified by air bag deployment among passengers (interaction term: steering wheel deformity × air bag deployment, for thoracic injury \(P=0.02\), and for abdominal injury \(P=0.07\)). Further analyses, stratified by steering wheel deformity, did not demonstrate a relationship between air bag deployment and thoracic injury. However, in crashes without steering wheel deformity, air bag deployment...
was associated with higher odds of serious abdominal injury (passenger air bag deployment, OR 2.36, 95% CI 1.08 to 5.15). When the air bag variable was coded as presence of an air bag (rather than deployment), there was no association with either injury type among passengers. The association between steering wheel deformity and injury was not modified by restraint use (interaction term: steering wheel deformity and injury was not modified by restraint use; for passenger air bag deployment, OR 2.36, 95% CI 1.08 to 5.15).

For passengers, the crude rate of serious thoracic and, to a lesser extent, abdominal injury increased incrementally with increasing steering wheel deformity (Figure 2). The rate of serious thoracic injury was generally higher than the rate of abdominal injury across all levels of steering wheel deformity, although this effect was not as pronounced as among drivers.

Sensitivity Analyses
There were no qualitative differences or indication of systematic bias in the results of sensitivity analyses using different patterns of missing data. Detailed results and further discussion of sensitivity analyses are provided in Appendix E3 (available at http://www.mosby.com/AnnEmergMed).

LIMITATIONS
We acknowledge some limitations in this study. The National Automotive Sampling System Crashworthiness Data System data set contains missing values for some variables, which required the use of multiple imputation to allow analysis of the full data set. Because it is not possible to know the pattern of missing data in the original data set, we conducted sensitivity...
analyses with varying patterns of missing data for variables with greater than 5% missing data. We found no indication of systematic bias or qualitative change in the results with differing patterns of missing data.

We used $D_V$ and passenger space intrusion as surrogate measures of crash severity. Both variables had a strong, independent association with injury in these analyses. Although these measures offer an improved means of adjusting for crash severity, they necessitate exclusion of persons involved in crashes where $D_V$ cannot be calculated (ie, pure rollovers and noncollision crashes) and may not completely control for the severity of the crash. Although a matched-pairs analysis (ie, 2 occupants in the same vehicle) is ideal to control for the variety of confounders in motor vehicle crashes, we elected not to use this type of model because it would have substantially reduced the sample size and would have prevented analysis stratified by individual seat position, which was necessary to address the relationship between steering wheel deformity and injury for occupants exposed directly and indirectly to the steering wheel.

Because the outcomes of interest were relatively rare (<2%), the precision of our estimates was reduced, especially in instances in which the number of persons within a given category was small (eg, cell size for persons with steering wheel deformity >10 cm and abdominal injury). However, the sampling design of the National Automotive Sampling System Crashworthiness Data System provides for oversampling of serious crashes (and thus seriously injured persons) and then underweights these same crashes to represent the national population. For this reason, the cell size may appear small but actually represents a much larger number of sampled persons (Table 1). In addition, because the database uses a complex sample design, we were unable to assess regression diagnostics for the multivariable models.

Steering wheel deformity was coded as a 4-level, ordered, discrete variable for the logistic regression models. The logistic regression analysis assessed the linear relationship between increasing levels of steering wheel deformity and injury over all levels of deformity (including no deformity) in a logit model, analyzing steering wheel deformity as a continuous variable that

<table>
<thead>
<tr>
<th>Model Covariates</th>
<th>Drivers (n=33,733), OR (95% CI)</th>
<th>Front Seat Passengers (n=9,127), OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serious Thoracic Injury (AIS ≥3)</td>
<td>Serious Abdominal Injury (AIS ≥3)</td>
<td>Serious Thoracic Injury (AIS ≥3)</td>
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<tr>
<td>Serious Abdominal Injury (AIS ≥3)</td>
<td></td>
<td>Serious Abdominal Injury (AIS ≥3)</td>
</tr>
<tr>
<td>$D_V$ (per km/h)</td>
<td>1.06 (1.05–1.08) *</td>
<td>1.07 (1.04–1.09) *</td>
</tr>
<tr>
<td>Passenger space intrusion (per 15 cm)</td>
<td>1.54 (1.28–1.85) *</td>
<td>1.27 (0.97–1.66) *</td>
</tr>
<tr>
<td>Age (per decade)</td>
<td>1.44 (1.23–1.68) *</td>
<td>1.70 (1.55–1.87) *</td>
</tr>
<tr>
<td>GCS score (per unit decline)</td>
<td>1.22 (1.13–1.33) *</td>
<td>1.26 (1.14–1.39) *</td>
</tr>
<tr>
<td>Vehicle weight (per 500-lb decline in weight)</td>
<td>1.19 (0.98–1.45)</td>
<td>1.28 (1.01–1.62) *</td>
</tr>
<tr>
<td>Ejection</td>
<td>5.81 (3.25–10.4) *</td>
<td>7.47 (2.19–25.5) *</td>
</tr>
<tr>
<td>Entrapment</td>
<td>2.77 (1.50–5.12) *</td>
<td>3.06 (1.29–7.25) *</td>
</tr>
<tr>
<td>Restraint use</td>
<td>0.43 (0.20–0.63) *</td>
<td>0.55 (0.34–0.90) *</td>
</tr>
<tr>
<td>Ethanol intoxication</td>
<td>1.96 (1.16–3.31) *</td>
<td>1.10 (0.48–2.54) *</td>
</tr>
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<td>Male sex</td>
<td>0.86 (0.53–1.40) *</td>
<td>0.91 (0.48–1.75) *</td>
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<tr>
<td>Rollover</td>
<td>2.21 (1.35–3.61) *</td>
<td>3.74 (1.69–8.24) *</td>
</tr>
<tr>
<td>Air bag deployment</td>
<td>1.53 (1.07–2.18) *</td>
<td>1.36 (0.68–2.72) *</td>
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<tr>
<td>Frontal crash</td>
<td>1.74 (0.89–3.38) *</td>
<td>5.38 (0.42–68.7) *</td>
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<tr>
<td>Right lateral crash (passenger side)</td>
<td>3.18 (1.77–5.73) *</td>
<td>28.0 (2.20–356) *</td>
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<td>Left lateral crash (driver side)</td>
<td>9.62 (5.64–16.4) *</td>
<td>70.3 (0.58–85.3) *</td>
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<tr>
<td>Steering wheel deformity (per 5 cm)</td>
<td>1.28 (1.04–1.59) *</td>
<td>1.77 (1.26–2.49) *</td>
</tr>
</tbody>
</table>

*CIs that do not cross 1.

*When including presence of an air bag rather than air bag deployment in the models, there was no association between presence of an air bag and either injury type.

Table 2. Adjusted odds of injury outcome using multivariable logistic regression models, stratified by drivers versus front seat passengers involved in motor vehicle crashes.

Figure 1. Rates of serious thoracic and abdominal injury among drivers, with an increasing extent of steering wheel deformity (n=33,733). Error bars represent the 95% CI around each estimate.
smoothes out potential differences linearly over all levels of deformity. We explored additional options for coding steering wheel deformity (ie, categoric variables for each incremental increase in deformity, and using a quadratic term); however, these covariate types did not demonstrate an advantage over the continuous term in assessing the relationship between steering wheel deformity and injury.

Finally, although we demonstrate a strong relationship between steering wheel deformity and certain injury patterns (thoracic and abdominal), this study was not designed to assess the clinical utility of steering wheel information on patient care. Inquiring about steering wheel deformity may prove clinically useful in those persons involved in motor vehicle crashes who do not have an apparent thoracic or abdominal injury on initial evaluation, but demonstrating such utility will require prospective research. In addition, the interrater reliability among out-of-hospital providers for assessing the extent of steering wheel deformity and the validity of these measurements when compared with a professional crash investigation team will need to be assessed.

**DISCUSSION**

In this study, we demonstrate an association between steering wheel deformity and specific injury patterns among drivers and front seat passengers. Specifically, increasing steering wheel deformity was associated with an increasing risk of serious thoracic (but not abdominal) injury among drivers. Among passengers, increasing steering wheel deformity was associated with serious thoracic and serious abdominal injury.

Air bag deployment was associated with thoracic injury among drivers (regardless of steering wheel deformity) and with abdominal injury among passengers (in the subset of crashes without steering wheel deformity). It is unclear whether the associations with air bag deployment represent findings inherent to more severe frontal crashes (ie, those crashes in which an air bag is likely to deploy) or are due to the air bag itself because results using presence of an air bag did not offer supportive results. The finding that air bag deployment did not counterbalance the harmful associations between steering wheel deformity and injury suggests that information on steering wheel status may provide useful information even in the subset of crashes with air bag deployment. Restraint use was protective for both injury types, yet this protective effect diminished for abdominal injury in the presence of steering wheel deformity.

The relationship between steering wheel deformity and injury persisted for drivers and passengers after adjustment for 2 measures of crash severity ($\Delta V$ and passenger space intrusion) and multiple other important crash factors, suggesting that steering wheel deformity is an independent predictor of specific injury types among occupants involved in motor vehicle crashes. Although steering wheel deformity has been suggested to be a causal factor in thoracic injury among drivers by direct contact, it is interesting to note an equally strong association with thoracic injury among passengers not directly contacting the steering assembly in the crash. We did not find an association between steering wheel deformity and abdominal injury among drivers, as has been suggested in a previous study. However, there was a strong relationship between steering wheel deformity and abdominal injury among passengers. These results suggest that a bent steering assembly may cause injury by direct impact through thoracic loading with relative sparing of abdominal structures among drivers, but may serve as a general measure of crash severity among front seat passengers, resulting in an increased risk of thoracic and abdominal injury.

Our results may be applicable in the clinical setting by providing additional risk factor information for thoracic and abdominal injury to clinicians evaluating persons involved in motor vehicle crashes. Steering wheel information (ie, the presence and extent of deformity) may have a role in the evaluation of persons without obvious thoracoabdominal injury, although this question will require additional research. Out-of-hospital providers should be encouraged to assess the steering wheel for drivers and passengers involved in motor vehicle crashes, regardless of air bag deployment.

In conclusion, steering wheel deformity is an independent predictor of serious thoracic injury among drivers and front seat passengers involved in motor vehicle crashes and is associated with serious abdominal injury among front seat passengers. For these occupants, the risk of these injuries increases incrementally with increasing steering wheel deformity. Air bag deployment was associated with thoracic injury in drivers (regardless of steering wheel deformity) and abdominal injury in passengers (in the subset of crashes without steering wheel deformity). Restraint use is protective against thoracic and abdominal injury. Out-of-hospital providers should be encouraged to collect information about the condition of the steering wheel for persons involved in motor vehicle crashes.
Author contributions: CDN conceived the study and designed the analysis. RJL and JFK provided important guidance, comments, and suggestions throughout the project. CDN performed all database management, data coding, and statistical analyses. CDN drafted the manuscript, and all authors contributed substantially to its revision. All authors take responsibility for the paper as a whole.


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