Renal Injury Mechanisms of Motor Vehicle Collisions: Analysis of the Crash Injury Research and Engineering Network Data Set

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Purpose: Injury prevention requires efficient diagnosis and management, and knowledge of collision kinematics may allow first responders to triage victims earlier based on crash scene assessment. We identified possible collision patterns and vehicle interior components that may have a role in kidney injury following motor vehicle collision.

Materials and Methods: A total of 115 cases (131 renal injuries) were identified in the multicenter Crash Injury Research and Engineering Network database. For each case a crash investigation was performed, identifying vehicle kinematic characteristics, vehicle damage profile and an assessment of the interior compartment to determine points of occupant contact and restraint system use. A multidisciplinary team reviewed each case to establish a probable mechanism for all injuries sustained. Review of the medical record was performed to identify subject demographics and injury characteristics. Cases were analyzed based on frontal vs side impact.

Results: Of the subjects 52% were male. Mean age was 36.1 years and median injury severity score was 33. Overall injuries were low grade in 72.5% of patients, 30% were unrestrained and 47.6% of collisions were side impact. No difference was observed between frontal and lateral collisions with respect to renal injury severity. For frontal impact the seat belt was the source in 26 of 29 renal injuries (90%) and 12 of 15 unrestrained cases (80%) were due to direct impact with the steering column. Of 131 side impact injuries 62 were attributable to impact with lateral compartment elements. Side impact injuries were associated with lateral door panel impact (41 of 61) with the armrest accounting for 22. The mean lateral compartment intrusion was 29.6 cm. No grade V injuries occurred when vehicle intrusion was less than 30 cm. The mean change in velocity for frontal and lateral collisions was 24.0 and 31.5 mph, respectively ($p < 0.05$). In frontal collisions the change in velocity for kidney injuries sourced to the steering wheel vs seat belt injuries was statistically greater (41.5 vs 28.4 mph, $p = 0.05$).

Conclusions: Renal injury in frontal and side impact collisions appears to occur after direct impact from objects in the vehicle compartment. For frontal crashes occupant acceleration into the seat belt or steering wheel seems to result in renal injuries. Side impact injuries occur when the vehicle side panel intrudes into the compartment, striking the occupant. Further collision evaluation in larger data sets is required to substantiate our findings.

Key Words: kidney; wounds and injuries; accidents, traffic; automobiles; biomechanics

Motor vehicle collision remains a major cause of morbidity and mortality in the United States, and renal injury occurs in 1% to 3% of blunt mechanism injuries with an incidence of 4.9/100,000 population.[1–3] WHO predicted that the incidence of road traffic accidents would increase to the third leading contributor of disability adjusted life years lost by 2020, behind ischemic heart disease and unipolar major depression.[4]

For blunt trauma MVC remains the predominant source of injury to the kidney. The ability to prevent such injuries and decrease the morbidity associated with them requires a multifaceted approach. Great progress has been made in diagnosis, imaging and nonoperative management. Remaining areas for significant progress include injury prevention, improved triage and transfer, efficient diagnosis and implementation of management. To achieve these goals knowledge is required of the collision kinematics and occupant interaction with the vehicle interior compartment leading to injury.

Anatomically the kidney is protected in the retroperitoneum by the perinephric fat, abdominal wall musculature and visceral structures (spleen, liver and bowel). Direct renal injury is related to the direct transmission of kinetic energy and it is frequently associated with other organ injuries. A second type of injury due to deceleration forces occurs at points of anatomical fixation, such as the renal hilum or ureteropelvic junction. The contribution of these attachments to injury mechanism has been difficult to model in a laboratory setting. Studies of the ex vivo renal tissue response to external forces suggest that different injury patterns result from various types of blunt forces (compres-

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sive, tensile and shearing). Our current understanding of renal injury biomechanics is derived from ex vivo unilaminar and bilaminar models. These experimental data suggest that kidney density is in the range of 0.8 to 1.2 gm/cc, the injury threshold (specific energy density for rupture) is inversely proportional to impact speed and parenchymal injury occurs at the point of maximal weakness as kinetic energy is absorbed beyond a threshold, as determined by tissue composition.[5,6] This information is helpful for understanding the tissue response to injury but it is imperfect since it is unable to completely model the complex multilaminar geometry of the kidney or the multiple destructive forces and protective elements that are present during collision.

Data exist to suggest that vehicle collision kinematic patterns (side/lateral or frontal) predispose vehicle occupants to patterns/clusters of injuries and mechanisms.[7–10] However, little is know about the collision factors related to kidney injury and in general renal trauma is crudely classified as penetrating or blunt in mechanism. We identified possible collision patterns and vehicle interior components that may have a role in kidney injury following MVC. Thus, we analyzed the association between crash parameters and renal injury in men and women enrolled in the CIREN study, a multicenter cohort of patients involved in severe MVCs.

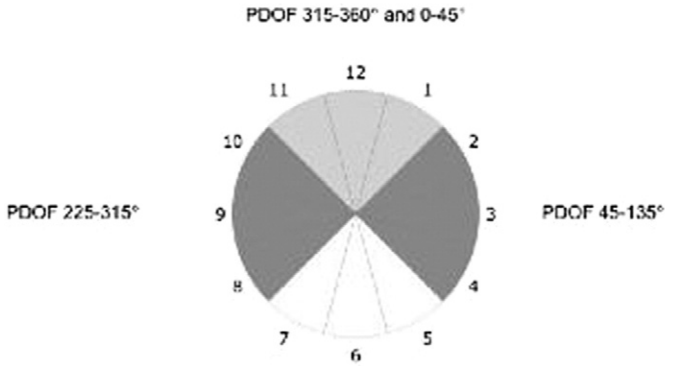

FIG. 1. PDOF noted on clock

MATERIALS AND METHODS

The motor vehicle crash information included in this study was collected from the Harborview Injury Prevention and Research Center, which is 1 of 8 CIREN (NHTSA) teams, and cases from all sites are included in this analysis. Crashes in the CIREN database are sampled based on the fulfillment of several criteria. These criteria include the facts that the occupant must have been restrained or have air bag deployment and an injury of AIS 3 or greater must have occurred. A multidisciplinary team consisting of a crash investigator, a bioengineer, a research nurse and the treating physicians reviewed each case. The crash investigator for the team is certified in vehicle crash reconstruction and data collection through the training program given by the Transportation Safety Institute NASS. Each crash scene and vehicle investigation done at CIREN centers follow the data collection format established by NASS. After the crash information was analyzed, and the injuries and hospital course documentation were obtained the crash was reviewed by the multidisciplinary team to establish a probable mechanism for the injuries sustained.

Crash Investigation

Each crash site had scaled documentation of the roadway, traffic controls, road surface type, and conditions and road grade at pre-impact and post-impact locations. Physical evidence such as tire skid marks were located and referenced to establish the heading angle and post-impact trajectory of the colliding vehicles. A scaled drawing with impact and final rest positions was completed to assist in calculating the speed and force at impact. Exterior inspections of the vehicle were performed, including detailed measurements of direct and induced damage. With a contour gauge a damage crush profile was collected from the damage plane and a specific Classification Deformation Code,[11] which includes PDOF, was assigned (fig. 1). Collisions with a PDOF of 315 to 360 or 0 to 45 degrees are defined as frontal collisions and are noted at the 11, 12 and 1 o'clock positions. Lateral collisions are defined by a resultant vector of 45 to 135 or 225 to 315 degrees, noted as the 2 to 4 and 8 to 10 o'clock positions, respectively. These measurements were entered into Win SMASH crash analysis software to calculate the ΔV of the vehicle during impact and the energy dissipated during the crash event.[12] ΔV is the primary metric used to describe crash severity. It measures the change in velocity during deceleration.

An inspection of the interior of the vehicle from which the injured person had been removed was performed to determine points of contact and restraint system use. The exact locations and all evidence of contact by the occupant were documented, especially the abdomen and pelvis contacts for this group.

Case Selection

Case selection was based on AISs for kidney injury (54161–54164 and 54169)[13,14] and the crashes selected involved frontal and side impacts (fig. 1). Review of the medical record was performed to identify American Association for the Surgery of Trauma organ injury grade, injury laterality, MAIS and ISS.[15] Statistical analysis with Smith's Statistical Package, version 2.75 (Pomona College, Claremont, California) was performed using Student's t test, the chi-square test for categorical data and ANOVA for comparison of means. Statistical significance was considered at $p < 0.05$. Institutional review board approval was obtained for this study.

RESULTS

Of the cases in CIREN 115 with renal injury were identified. Of the subjects 52.2% were male. Mean age was 36.1 years. Overall injury severity was high with a median ISS of 33 (range 5 to 75) and median MAIS of 4 (range 2 to 6). Statistically significant differences were observed for ISS and MAIS when low and high grade kidney injuries were compared (American Association for the Surgery of Trauma I and II vs III to V) (table 1).

In the 115 subjects a total of 131 renal injuries were identified. Table 2 shows the association between restraint use and PDOF related to renal injury grade. Of the observed injuries 72.5% were low grade. Almost 30% of subjects did not use any form of seat belt restraint, whereas 61.8% were restrained with the lap and shoulder belt, and the remaining