Ankle fracture patterns in drivers are associated with femoral fracture, higher BMI, and advanced age

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ABSTRACT

Objective: Despite advances in vehicle safety systems, motor vehicle crashes continue to cause ankle fractures. This study attempts to provide insight into the mechanisms of injury and to identify the at-risk population groups.

Methods: A study was made of ankle fractures patients treated at an urban level 1 trauma center following motor vehicle crashes, with a concurrent analysis of a nationally representative crash data set. The national data set focused on ankle fractures in drivers involved in frontal crashes. Statistical analysis was applied to the national data set to identify factors associated with fracture risk.

Results: Malleolar fractures occurred most frequently in the driver’s right foot due to pedal interaction. The majority of complex/open fractures occurred in the left foot due to interaction with the vehicle floor. These fractures occurred in association with a femoral fracture, but their broad injury pattern suggests a range of fracture causation mechanisms. The statistical analysis indicated that the risk of fracture increased with increasing driver body mass index (BMI) and age.

Conclusions: Efforts to reduce the risk of driver ankle injury should focus on right foot and pedal interaction. The range of injury patterns identified here suggest that efforts to minimize driver ankle fracture risk will likely need to consider injury tolerances for flexion, pronation/supination, and axial loading in order to capture the full range of injury mechanisms. In the clinical environment, physicians examining drivers after a frontal crash should consider those who are older or obese or who have severe femoral injury without concurrent head injury as highly suspicious for an ankle injury.

Background

Older studies of injuries produced in motor vehicle crashes found that ankle fractures account for a significant portion of lower extremity injuries, with malleolar fractures making up 24–56% of fractures below the knee in frontal car crashes (Lestina et al. 1992; Sherwood et al. 1999). In the middle to long term, the majority of ankle fractures will present a significant risk for pain and loss of function (Beckenkemp et al. 2014; Marsh et al. 2010), with most injured persons not returning to full pre-injury function. Lower extremity fractures due to motor vehicle crashes are associated with significant decreases in physical and general mental health function at 1 year post-injury (Read et al. 2004). Ankle fractures also pose a financial burden on the injured through lost work days due to weight-bearing and driving restrictions imposed for a mean of 9 weeks (Marecek and Schafer 2013). These injuries result in job loss for a reported 18% of those previously working and subsequent disability program enrollment for approximately half of those who lost employment (Thakore et al. 2015). In the midst of severe tibial fractures, such as those occasionally generated in a motor vehicle crash, ankle injuries may be overlooked (Stuermer and Stuermer 2008). Overlooked ankle injuries can result in posttraumatic instability, which contributes to the risk of osteoarthritis and functional loss in the ankle joint (Weatherall et al. 2013).

In considering motor vehicle crashes as a source of traumatic ankle fracture, studies indicate that drivers have the highest risk of fracture compared to other occupants (Chong et al. 2007; Estrada et al. 2004; Richter et al. 2001). The majority of drivers who suffer from ankle fractures sustained their injury in a frontal crash (Chong et al. 2007; Estrada et al. 2004). In vehicles with airbags, occupants who are unrestrained have an increased likelihood of lower extremity fracture (Estrada et al. 2004) versus those wearing seat belts. The added safety from the airbags may be contributing to increases in ankle fracture cases, because some occupants are presenting with these fractures who would not have survived in pre-airbag vehicles (Estrada et al. 2004).

The current study seeks to identify factors associated with ankle fracture risk in newer vehicles and broaden knowledge of ankle fracture mechanisms. A large national data set was utilized to study occupant and crash characteristics associated with ankle fracture in newer vehicles. A retrospective review of medical records and radiographs for vehicle occupants with ankle injuries who were treated at an urban level 1 trauma center was performed to identify the mechanism of ankle fractures and the fracture type.
Table 1. Study design.

| Study | Factors                  | Levels                  |
|-------|--------------------------|-------------------------|
| Data set | NASS/CDS (DOF1)          | 2008–2013               |
|       | Force direction (DOF1)   | 11:00–1:00              |
|       | Damage (GAD1)            | F (frontal)             |
|       | Rollover                 | 0 (none)                |
|       | Model year               | 2000–2013               |
|       | Vehicle type             | 2–6 (sedans), 14–16 (SUV), 20–21 (minivans), 30–31 (trucks) |
| Drivers | Seat position I1         |                         |
| Restraint | Manual belt use 4 = Lap and shoulder 0 = None used | |
| Injuries | No. of lateral malleolar fracture No. of medial malleolar fracture | |

Factors in regression

- Occupant factors: Height, Weight, BMI, Age, Seat track position
- Crash factors: Curb weight, Principle force direction (0–360°), Body type DV, total (crash speed)

The group that sustained malleolar injuries was less likely to have a concurrent moderate-to-severe head or chest injury than drivers without malleolar fracture (Figure 2). Approximately 30% of drivers who experienced at least one injury rated AIS 30% of drivers who experienced at least one injury rated AIS

**Methods**

In order to identify factors associated with the risk of ankle fracture in a large data set, frontal crash cases were obtained from a national sample of motor vehicle crashes in the United States NASS-CDS (NHTSA 2014) for the years 2008–2013. This data set includes approximately 5,000 crashes per year that are sampled from locations throughout the United States. It provides detailed crash and occupant information and allows users to estimate national frequencies for crashes included in the data set. Frontal crashes were identified as those that involved a primary damage location (NASS-CDS data element DOF1) of 11:00–1:00, involved a primary damage location (NASS-CDS data element GAD1) of frontal, and did not involve a rollover. Passenger vehicles with model years older than 2000 were excluded (Table 1).

In this data set, drivers were isolated and divided into “unrestrained” and “restrained” data sets. The restrained driver cases were identified using the NASS crash investigator codes for lap and shoulder belt restraint, because earlier work indicated that these were more reliable than the police-indicated restraint use (Viano and Parenteau 2009). The Abbreviated Injury Score (AIS 90) codes provided for each injured occupant in the NASS-CDS were utilized to identify drivers with malleolar fractures (Table 1). All drivers were then assigned an indicator variable (1 = positive for malleolar fracture, 0 = negative) for use in the statistical analysis.

Data analysis involved identification of crash and occupant variables associated with malleolar fracture. Only occupants who experienced a minor-to-severe injury (AIS 1–6) were considered, in order to focus the analysis on crashes that were likely to induce injury and to exclude very low-severity crashes. The statistical analysis was performed using the SURVEYLOGISTIC tool in SAS 9.0 (SAS Institute Inc., Cary, NC). The “survey” tool performs regression in complex sample designs, which, in this case, involved use of NASS-CDS sample stratification and weights. The weights in the NASS-CDS are intended to provide estimates for yearly occurrence rates on a national scale. Factors potentially associated with malleolar fracture were included in the initial logistic model and those with probabilities greater than 0.05 were eliminated in stepwise fashion beginning with the least probable factor (the one with the highest P value). Factors considered in the initial model described both occupant and crash characteristics, such as body mass index (BMI) and crash severity (delta V). These factors are listed in Table 1.

In order to study ankle fracture characteristics and mechanisms, a retrospective review of all ankle injury cases presenting at an urban level 1 trauma center over a 2-year period was performed. All work was carried out under protocols approved by the hospital’s institutional review board. All cases from March 2012 to March 2014 with International Classification of Diseases, Ninth Revision, codes of 823.0–824.9 were extracted from hospital records and reviewed to identify those that involved an ankle fracture (malleolar or pilon) (Buck 2013). The resulting cases were further reviewed to identify those attributed to occupants in motor vehicle crashes. Occupant age, anthropometry, and any information related to the crash were obtained from the chart. X-rays were reviewed by 2 orthopedic surgeons to classify the injuries using both Association for Osteosynthesis (AO) classification and the Lauge-Hansen mechanistic classification. Where there were discrepancies between the physician classifications, a secondary review was performed including a third reviewer and a final classification was agreed upon.

**Results**

The nationally representative data derived from the NASS-CDS frontal crash cases provided an estimated ankle fracture rate of 0.2% in restrained drivers in frontal crashes. It also indicated that there was no difference in the rate of malleolar fracture between female (48.8% of sample) and male (51.2%) drivers, which were both at 0.2%. The majority of fractures occurred in the right ankle (80.7% of all malleolar fractures), with 3% of cases involving bilateral ankle fractures. The majority of right-foot malleolar fractures were attributed to the foot controls (80.4%), whereas those in the left foot were attributed to the vehicle floor (93.2%). In restrained drivers in frontal crashes, bimalleolar fractures were most common, and left-foot fractures were more frequently open or complex (Figure 1), regardless of restraint condition.

The group that sustained malleolar injuries was less likely to have a concurrent moderate-to-severe head or chest injury than drivers without malleolar fracture (Figure 2). Approximately 30% of drivers who experienced at least one injury rated AIS...
2 or higher in a frontal crash but who had no ankle fracture had a moderate head injury; 23% also had a moderate chest injury. In comparison, only 12% of those with an ankle fracture had a similar head injury and 16% had a similar chest injury. However, femoral fractures were present in approximately 4% of drivers from both groups (3.2% for the no ankle fracture group and 5.0% for the other).

The logistic regression indicated that driver age and BMI were significant in a malleolar fracture risk model for restrained drivers, with increases in age and BMI associated with an increased risk of fracture (Table 2, Figure 3). Likewise, the regression for unrestrained drivers also showed increasing age increased malleolar fracture risk (Table 2). In both driver groups the crash severity, as described by the crash velocity difference (DV total), contributed to fracture risk at a similar level, as demonstrated by the similar odds ratios.

In the 2-year study period, the trauma center treated 18 individuals with 20 ankle fractures (2 drivers experienced bilateral ankle fractures) resulting from motor vehicle crashes. These cases accounted for 15.7% of the ankle fractures seen in the study period. Based on the number of cases at the trauma center and the records provided for the county in which the trauma center is located (Michigan Traffic Safety Crash Facts 2013), an estimated 0.38% of the injury crashes will have an ankle fracture. Based on the number of cases at the trauma center and the records provided for the county in which the trauma center is located (Michigan Traffic Safety Crash Facts 2013), an estimated 0.38% of the injury crashes will have an ankle fracture.

In the malleolar fracture cases, 33.3% of the injured (6 of 18) were obese, similar to the obesity rate for the state within which the trauma center is located (Anderson et al. 2009). In addition to obesity, notable comorbidities were diabetes mellitus (17% of patients) and smoking (61%). No case involved documented osteoporosis. There were no strong patterns in terms of the fracture classifications. There were similar numbers of Weber A, B, and C fibular fractures: 4, 3, and 5, respectively. The majority of fractures were classified as either 44-A or 44-B (Figure 4) under the AO classification system. There were nearly equal numbers of fractures attributed to a supination mechanism (6 of 20) as there were to pronation (5 of 20), but the largest category under the Lange-Hansen classification system was “not applicable,” with 10 of 20 in this category after review by the surgeons.

The fractures were treated as follows: 5 were treated nonoperatively, 4 were treated with external fixation, and the remainder underwent open reduction and internal fixation. There were no postoperative infections, nonunions, or other clinically significant complications in the ankle.

Table 2. Logistic regression fit to national data set.

| Restrained model | Significant factors | Wald’s $\chi^2$ | Odds ratio | 72.6% Concordant |
|------------------|---------------------|----------------|------------|-----------------|
| Age              | $P = .0010$         | 1.038          |            | 16.9% cases missing data |
| BMI              | $P = .0089$         | 1.162          |            | Raw numbers: 60 fracture cases; 2,370 no fracture cases |
| DVTotal          | $P = .0006$         | 1.058          |            | Weighted numbers: 7,688 fracture cases; 584,346 no fracture cases |
| Unrestrained model | Significant factors | Wald’s $\chi^2$ | Odds ratio | 77.8% Concordant; 0.8% cases missing data |
| Age              | $P = .0082$         | 1.029          |            | Raw numbers: 19 fracture cases; 632 no fracture cases |
| DVTotal          | $P < .0001$         | 1.058          |            | Weighted numbers: 1,246 fracture cases; 127,472 no fracture cases |
than the 0.39% rate reported by Bugler et al. (2015). The Bugler study used a percentage of all ankle fractures seen, which is higher than the rate of open cases in motor vehicle collisions (MVCs) that will capture the full range of injury-producing scenarios. Despite this, there was no strongly dominant fracture type. This suggests that it is unlikely that a single criterion for ankle loads will capture the full range of injury-producing scenarios.

The trauma center data indicate an overall rate of open ankle fractures at 20% (open cases in motor vehicle collisions [MVCs] as a percentage of all ankle fractures seen), which is higher than the 0.39% rate reported by Bugler et al. (2015). The Bugler study documented cases out of a center seeing all local adult orthopedic trauma, whereas the level 1 trauma center in the current study is likely to see more severe, polytraumatic cases. Urban et al. (2010) saw 1 open in 9 ankle fractures (11%) in a data set derived from trauma centers with significant injuries in a crash, which is a rate of open fractures more consistent with the data from the current study's trauma center. Open fractures are of special concern because they present a high risk of complication.

A number of factors have been previously associated with ankle fracture risk in motor vehicle crashes. Female gender and shorter height have been linked to an increase in foot and ankle fractures for occupants in crashes (Chong et al. 2007). This association has been attributed to shorter occupants sitting closer to the steering wheel, with other work suggesting that height is the true risk factor (Dishinger et al. 1995). The current study did not find a higher risk of malleolar fracture for female drivers or shorter occupants. The national data set studied here indicated that there was an increase in malleolar fracture risk with an increase in BMI. Similarly, a study of a small group of MVC patients at another trauma center found that a high proportion of persons with malleolar fractures were obese (Urban et al. 2010). In our trauma center data, the frequency of obesity in patients was similar to that seen in the local community. However, this community figure may not represent the local driving (exposed) population. The national data set also indicated an increased risk of fracture with increasing age. This may reflect changes to skeletal structure associated with age, such as osteoporosis, which plays a role in fracture risk in general. Ankle fracture fixation in osteoporotic bone presents a unique challenge. This might suggest that older drivers might pose a special concern; however, geriatric patients who experience ankle fracture due to a high-energy mechanism (i.e., motor vehicle crash) have complication rates and outcomes similar to those of younger patients (Herscovici and Scaduto 2012).

The trauma center group suggested other factors that may influence fracture risk. In the trauma center group the rate of smoking was 66%, higher than the 26.9% indicated for the local region (health outcomes study). Jaramillo et al. (2015) found that smoking was associated with low bone mineral density, thereby reducing loads required to fracture bone. The trauma center group also exhibited higher rates of diabetes than those in the local population (17 vs. 12.8%; Fussman 2014), which likely also reduces fracture load (Dede et al. 2014; Shah et al. 2015). These findings highlight the role of biovariability in considering fracture risk.

One of the challenges in efforts to prevent ankle fractures in MVCs is that there appears to be several paths to ankle fracture. Studies suggest that pronation, axial loading, and dorsiflexion can each produce medial malleolar fracture (Madeley et al. 2004; Rudd et al. 2004; Urban et al. 2010). Axial loading and combined loads can also produce bimalleolar fracture (Funk et al. 2012). It is therefore impossible to describe the occupant’s foot and ankle motion by review of the postinjury x-ray alone. The nonunique fracture patterns possible under the loads induced in a motor vehicle crash environment, as indicated in experimental work and in the current study, suggest that it is unlikely that a single measure such as tibial force will be successful in predicting the likelihood of ankle injury. Much of the experimental work appears to focus on the role of the brake pedal in producing malleolar fractures; however, in both the trauma data set and NASS-CDS, the more severe (open/comminuted/dislocated) ankle injuries occur more frequently in the driver’s left foot. The NASS-CDS investigators attribute injuries in the left foot to the vehicle floor. The NASS-CDS data cannot provide the pre-impact ankle position or the ankle movement during the impact. The trauma center data also do not provide this, and x-ray images provide only the local mechanism of fracture—that is, tension or bending—and not the joint position. It may be useful to study driver foot and ankle positions in normal driving and panic braking in order to better understand the positions of the feet and thereby have better insight into fracture mechanisms and injury prevention approaches for each foot.

There are several limitations to the present study. Though this study supports earlier work that indicates that malleolar fractures in drivers are the most frequent ankle fracture, it does not indicate a clear etiology for these fractures and therefore cannot make a recommendation for a method of injury prevention. Though the Lange-Hansen classification system used here has commonly been used to evaluate ankle fracture mechanisms, experimental studies have shown that it fails to describe appropriately the mechanisms in traumatic injuries (Madeley et al. 2010).
In addition, only drivers in frontal crashes were considered; however, earlier work indicated that this was the largest at-risk group (Chong et al. 2007; Read et al. 2004; Urban et al. 2010; Ivarsson et al. 2008). Factors associated with ankle fracture risk in other crash modalities may differ from those described here. Another limitation is that patients have not been followed to evaluate the long-term physical and psychological outcomes. Thakore et al. (2015) suggested that mobility challenges associated with ankle fracture in MVCs have a strong negative impact on quality of life.

Increased age and BMI were associated with an increased risk of ankle fracture in drivers involved in frontal crashes. The majority of fractures involved the driver’s right foot in contact with the pedal; however, higher severity fractures were seen in the left foot due to contact with the floor. This study suggests that drivers with femoral fractures who do not experience a concomitant moderate-to-severe head or chest injury should be carefully evaluated by surgeons to rule out ankle fracture or instability. Though bimalleolar fractures were common, a wide range of fractures can be produced in MVCs, complicating both treatment and prevention efforts.

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