University of Maryland
National Study Center for Trauma and EMS
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CIREN Program Report

The Mechanism of Lower Extremity Injuries in Real-World Crashes

Real-world crashes provide important insights into the mechanism(s) of lower extremity injury. These injuries are frequent, disabling, and costly. Many of these injuries are sustained in crashes with little or no intrusion. Accident investigations, crash test data, and simulation results suggest that factors such as vehicles' change in velocity and rate and timing of intrusion must be considered in examining mechanisms of injury to the lower extremities.

Introduction

Motor vehicle crashes are a major cause of lower extremity injuries. These injuries are costly, frequently result in lifetime impairments, and are preventable. Although current information on the biomechanics of these injuries is still insufficient, it is known that they occur most often in frontal and offset frontal collisions, that seatbelts may be ineffective with respect to their prevention, and that vehicular intrusions of the toepan and instrument panel have been implicated as possible causes [1]. Many collisions resulting in these injuries occur at delta v's well within the purview of current regulatory standards. With the increasing availability of airbags and resultant decrease in life-threatening head and thoracic injuries, the relative importance of lower extremity injuries will increase.

Data from NHTSA's National Accident Sampling System (NASS) reveal that lower extremity injuries account for 32% of all AIS>2 injuries for belted occupants (24% for unbelted). Injuries to the ankle/foot complex account for 33% of the AIS>2 injuries for belted occupants (24% for unbelted), and are the most prevalent lower extremity injury [2]. Among patients admitted to trauma centers following motor vehicle crashes, approximately 20% of drivers had at least one lower extremity fracture; the highest incidence rate for a specific fracture is 5.7% for ankle injuries [3]. Surveys suggest that foot and ankle injuries account for 8-12% of all moderate-to-serious injuries sustained by motor vehicle occupants involved in frontal collisions [4-6]. In a study of the one-year treatment charges for persons hospitalized in Maryland with motor vehicle-related injuries, lower extremity injuries accounted for 40% of the treatment charges [7].

Lower extremity injuries sustained in car crashes tend to be high-energy injuries, which have a poorer prognosis than comparable low-energy injuries caused by slips and falls [8]. Because they involve weight-bearing surfaces and joints, knee and ankle fractures often result in prolonged reductions in mobility. Proximal foot fractures (talus, calcaneus) involve the complex weight-bearing joints of the ankle and hindfoot and may also result in long-term impairment and disability. However, their low scores on injury severity scales, which are usually designed to reflect threat to life, not to predict nonfatal outcomes, do not reflect the disabling nature of these injuries.

In a follow-up study of patients admitted to trauma centers, it was noted that, among individuals with moderate or severe injuries to the extremities, only 58% had returned to work at one year [9]. Another study of functional outcomes after lower extremity fracture revealed that a significant

proportion of patients hospitalized for treatment of a unilateral fracture of the lower extremity remained physically impaired at 6 months after discharge from the hospital. Most affected was the ankle joint: 55% of the patients had evidence of abnormal dorsi/plantar flexion [10]. At 12 months, half of the patients still reported minor to moderate disabilities. Six- to 12-month improvements were noted for patients with both single and multiple metaphyseal or shaft fractures in one limb. Patients with foot fractures, however, showed no improvement. Measures of patient-oriented functional outcomes were worse for persons with three or more fractures to the same extremity and for fracture patterns typical of high energy forces [11].

With increasing survival rates among drivers in high-speed crashes, as a result of the availability of both seatbelts and airbags, it is anticipated that there will be a relative increase in serious lower extremity injuries among people who previously would have died of multiple trauma, including head, thoracic, abdominal, and lower extremity injuries [12]. From in-depth crash reconstruction studies, it is possible to learn more about the mechanism of these injuries and thus, working with biomechanics experts, address scientific strategies for prevention [13].

We present data on 1,345 cases studied as part of NHTSA's Crash Injury Research and Engineering Network (CIREN), 751 (56%) of which received at least one lower extremity fracture (table 1).

Table 1 summarizes the comparison of injury severity scores and delta v for CIREN cases with and without lower extremity fractures (LEF). It is apparent that, compared to those not resulting in LEF, LEF crashes occur at significantly higher delta v's. Thus, injured occupants with LEF also have, on average, higher injury severity scores. Additionally, the median total charges were double for those with lower extremity fractures compared to those without such fractures.

Table 1. Median Injury Severity Score (ISS), and Delta V by Lower Extremity Fractures (1345 cases)

	Lower Ext. Fracture (n=751)	No Lower Ext. Fracture (n=594)	P-value
ISS (25%–75%)	17 (10–29)	14 (9–26)	<0.001
Total Delta V (25%–75%)	43 (31–57)	33 (24–45)	<0.001
Total Charges	$41,042	$19,569	<0.001

A total of 1,754 lower extremity fractures were documented for these 1,345 cases. The frequencies of individual fractures are listed in Table 2. Pelvic fractures were most common (26%), followed by tibia/fibula fractures (23%) and femur fractures (21%).

Table 2. Distribution of Fracture Type (1754 cases)

Pelvic	26%
Tibia/Fibula*	23%
Femur	21%
Ankle/Hindfoot	13%
Tarsal/Metatarsal	7%
Patella	4%
Other	7%

*Excluding ankle/hindfoot

Table 3 identifies the injury source associated with a particular fracture type. For pelvic and femur fractures, the major source of injury was the instrument panel. Tibia/fibula fractures were associated with the instrument panel and toepan, while ankle/foot fractures were primarily attributed to the toepan and foot controls.

Post-trauma Outcomes

Despite the low AIS scores associated with injuries to the lower extremities, many patients who survive these high-energy crashes experience physical and psychological problems. Difficulties such as depression, post-traumatic stress, behavioral and cognitive changes can impede recovery and a return to pre-injury functional status. Results from the Short Form Health Survey (SF36) presented in the 2001 annual report clearly indicated a decline in both physical and psychological functioning at 6 months post trauma, with gradual improvement at one year, but significantly lower functional status than at baseline for all patients. This report will discuss only a few LEI outcomes as they pertain to patients with ankle/foot fractures and those with mild brain injury.

Table 3. Most Common Injury Source by Fracture Type						
Rank	**Pelvic**	**Tibia/ Fibula**	**Femur**	**Ankle/ Hind Foot**	**Tarsal/ Metatarsal**	**Patella**
1	Knee bolster	Floor/ toe pan	Knee bolster	Floor/ toe pan	Floor/ toe pan	Knee bolster
2	Left side interior surface	Left instrument panel	Left instrument panel	Foot controls	Foot controls	Left instrument panel
3	Left side interior surface	Knee bolster	Glove compartment door	Non-contact injury source	Unknown injury source	Glove compartment door
4	Right side interior surface	Foot controls	Center instrument panel	Right side interior surface	Non-contact injury source	Steering column
5	Left instrument panel	Center instrument panel	Right instrument panel	Left instrument panel	Right side interior surface	Center instrument panel

At the Maryland CIREN center, a clinical interview is conducted with the patient and family shortly after admission to the trauma center to obtain pre-injury information, and at 6 months and 1 year post trauma in order to assess cognitive, economic, physical and psychosocial outcomes of injury. A total of 90 patients have completed the interview process through one year. Of those, 65 patients (72%) sustained lower extremity injuries. Lower extremity injuries were defined as a fracture of the pelvis or lower limbs, including femur, patella, tibia fibula and bones of the ankle and foot (International Classification of Diseases 9th Revision [ICD-9] codes 808.0-808.9, 820.0-829.9). Using CDC criteria, traumatic brain injuries were defined as fracture of the vault or base of the skull; other and unqualified and multiple fractures of the skull; and intracranial injury, including concussion, contusion, laceration, and hemorrhage (ICD-9 codes 800.0-801.9, 803.0-804.9, and 850.0-854.1) as reported at the scene by paramedics and recorded in the medical record and by the patient when total amnesia to the event and /or loss of consciousness was indicated.

Analysis of 65 Maryland CIREN Cases

Crash and injury characteristics of 65 patients with lower extremity injury are displayed in Table 4. Most (91%)of the patients were drivers, of whom 69% were deemed culpable for their crash according to the crash investigation review. The majority were involved in frontal crashes (89%) and were belted, with airbag deployment (80%). Fifty-five percent of the patients suffered an ankle or foot fracture, and 37% sustained fractures to both lower extremities.

In addition to the lower extremity fractures, 28% had an associated traumatic brain injury (TBI) even though most of the patients (88%) had an admission Glasgow Coma Score (GCS) of 15.

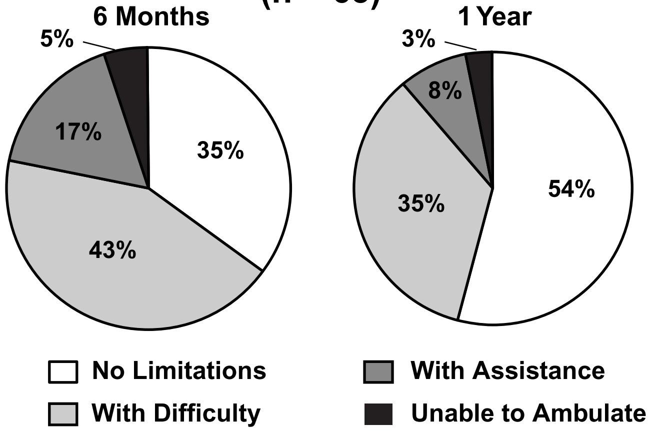
Following acute care hospitalization, many patients with LEI were discharged to an inpatient rehabilitation facility (44%) where they remained, on average, three weeks for intensive therapy. Additional outpatient therapy lasted approximately 12 weeks. At 6 months post-trauma, the majority of patients reported serious problems with ambula-

Table 4. Crash and Injury Characteristics of Patients With Lower Extremity Injury* (N = 65)

	n	**%**
Drivers	59	91
Culpable	41	69
Restraint Use		
Airbag with Seatbelt	52	80
Airbag Only	9	14
Seatbelt Only	3	5
Point of Impact		
Frontal	57	89
Lateral	6	9
Injuries		
Left LEI Fracture	33	56
Right LEI Fracture	45	76
Bilateral Fractures	22	37
Ankle/Foot Fracture	36	55
Maximum AIS for LEI = 2	42	65
Associated TBI	18	28
Admission GCS		
3–8	4	6
9–12	4	6
14–15	57	88

*due to ‘other’ responses, numbers may not add to 65 tion due to a slow, uneven, or painful gait, foot drag or limp, often requiring assistance such as a cane, walker or use of a wheelchair. One-year following injury, 35% continued to have difficulty walking, 8% required the aid of a walker or cane and 3% were unable to walk (Figure 1).

Figure 1. Ambulation (n = 65)



Patients who sustain ankle or foot fractures or bilateral extremity injury report significant ambulation problems and are less likely to return to work or activities, such as driving, compared to those without such injuries (Table 5). Among those who worked full time prior to the crash, only 58% of patients with ankle/foot injuries were back to full time work at one year compared to 87% of patients without ankle/foot injuries. (This was similar to the group with bilateral fractures). Over half of those with ankle/foot fractures or bilateral injuries experienced interfering pain, limited range of motion and more pronounced gait abnormalities, compared with 34% of those without such injuries at one year following injury.

Table 5. Ankle/foot Fracture vs. No Ankle/foot Fracture

	A/F Fracture (N=36)		No A/F Fracture (N=29)	
	n	%	n	%
Cannot return to driving				
6 months	15	42	6	21
1 year	9	25	4	14
Cannot return to work				
1 year	8	22	1	3
*p<0.05				

Additional injury, such as mild traumatic brain injury (TBI) also influences long term outcome and frequently exacerbates the recovery process, especially for patients with LEI who must endure multiple surgeries and lengthy rehabilitation. Although the majority of LEI patients who sustained a TBI had a Glasgow Coma Score of 14 /15 (89%) on admission, 28% had an associated TBI as evidenced by follow-up interviews at six months. Some of the consequences of TBI include physical problems (headaches, dizziness, balance); emotional or behavioral concerns (altered mood, increased irritability, depression); and cognitive problems (slowed ability to process information, memory, concentration). Of those who sustained a TBI, 44% exhibited behavioral problems at one year compared to 9% of those not diagnosed with such injury (Figure 2). At one year, 61% of the TBI group reported cognitive problems versus 15% of the non-TBI group (Figure 3). Depression remained high for all patients at one year but especially for the TBI group (56%) vs. 30% for the non-TBI patients.

Figure 2. TBI vs. No TBI Behavioral Changes

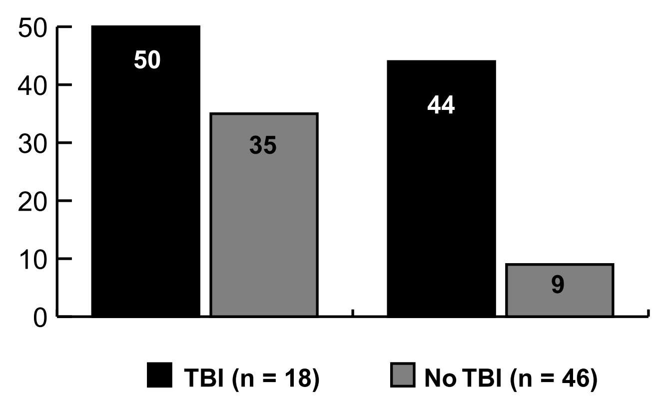
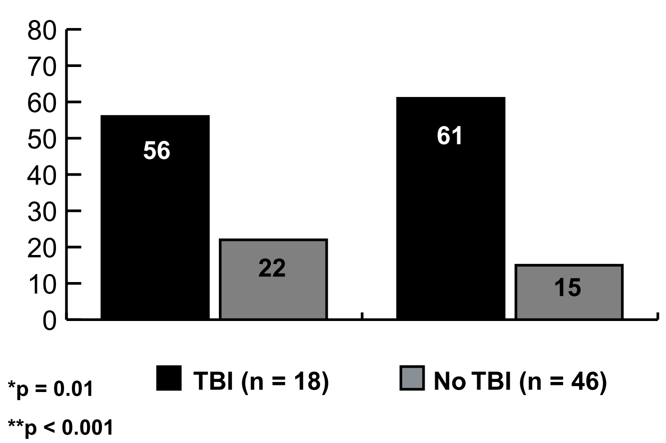


Figure 3. TBI vs. No TBI Cognitive Problems



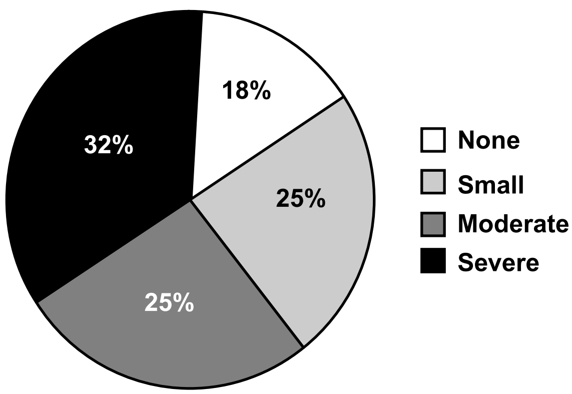
Costs

Although most of the patients had insurance to cover their medical costs, (64% private/HMO and 22% medicare/ medicaid), 32% of these patients felt the financial impact of their injury was severe and caused hardships for themselves and their families. Another 25% stated that the financial impact was moderate due to less income and large deductibles and co-pays. As illustrated in Table 6, total median costs (hospital, professional and rehabilitation) for those patients who were admitted to an in-patient rehab facility following their acute care was over $10,000 higher than costs for patients discharged to home. Moreover, these costs do not include re-hospitalization or further rehabilitative care. Thirty-four percent of patients were re-hospitalized in the first 6 months and 20% of the patients were re-hospitalized between 6 and 12 months post-trauma (data not shown).

Table 6. Median Costs and Financial Impact (N = 65)

Median Costs	
Hospital & Professional	$44,068
Inpatient Rehabilitation	$16,238
Outpatient Rehabilitation	$3,500

Financial Impact



It is apparent that lower extremity injuries have a major impact on individuals which manifests itself in several ways, including physical mobility, a patient's ability to return to work and pre-injury functional status, and the need for extensive surgical procedures and rehabilitative efforts. Those with ankle/foot injuries have the most difficult challenge, in that complete recovery may never be attained, since disruption of the complex ankle articular surfaces may never be restored. Associated mild brain injury also can impede a return to pre-injury status. In addition, lower extremity injuries add a considerable burden to the health care system

Discussion

Since the majority of cases collected so far, as part of CIREN, include occupants with modern restraint systems (usually both belts and bags), it is not possible to address questions regarding the effectiveness of these systems with regard to prevention of lower extremity injuries. However, many of the cases presented had no major injuries except for those to the lower extremities. Not long ago, individuals involved in high-speed crashes would have suffered serious multiple trauma to the head, chest, and abdomen as well as their lower extremities [14,15]. Thus, these are "success stories", since most of the patients survived. However, even with the protection afforded by seatbelts and airbags, it is apparent that patients admitted to trauma centers have still sustained serious lower extremity injury, necessitating treatment in a trauma center [12,16].

The CIREN consortium represents an opportunity to study the causes and outcomes of these injuries in greater detail. However, it is necessary to take a step beyond descriptive analyses, such as those presented here, and address more in-depth questions, such as the actual mechanism of injury, especially for the most disabling and costly of all lower extremity injuries—ankle and foot fractures. Previous findings from this research conducted at the University of Maryland in conjunction with the University of Virginia revealed that (1) not all foot and ankle injuries are associated with vehicular intrusion [17], (2) axial load (often with associated inversion or eversion forces) plays a significant role in the causation of these injuries [18,19], and (3) driver anthropometry [20] and foot placement [21] are important factors. With the evolution of CIREN, it will be possible to address such questions at multiple centers, allowing for the collection of much larger numbers of cases.

Based on the real-world findings noted among patients admitted to trauma centers, CIREN engineering/biomechanics experts can try to replicate these injuries, using tools such as computer simulation or dummy crash test experiments. Moreover, engineers from the automotive industry can provide important insights into the dynamics of a crash from the perspective of vehicle standards and performance. Many lower extremity injuries are sustained in crashes with little or no intrusion. However, accident investigations, crash test data, and simulation results suggest that factors such as a vehicle's change in velocity and rate and timing of intrusion must be considered when examining mechanisms of injury to the lower extremities. Based on engineering input, CIREN data collection protocols may be tailored to obtain more detailed measurements, for example, of toepan intrusion. Primary prevention of these common, costly, and disabling injuries should be a major goal of the automotive and medical communities encompassed by CIREN.

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