CONSEQUENCES AND COSTS OF LOWER EXTREMITY INJURIES

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ABSTRACT

Lower extremity injuries resulting from motor vehicle crashes are common and have become relatively more important as more drivers with newer occupant restraints survive high-energy crashes. CIREN data provide a greater level of clinical detail based on coding guidelines from the Orthopedic Trauma Association. These detailed data, in conjunction with long-term follow-up data obtained from patient interviews, reveal that the most costly and disabling injuries are those involving articular (joint) surfaces, especially those of the ankle/foot. Patients with such injuries exhibit residual physical and psychosocial problems, even at one year post-trauma.

During the last 10 years there have been great improvements in vehicular occupant safety, but during this time there has also been a relative increase in the significance of lower extremity injury (LEI). That is, more occupants survive high-energy crashes, due to the lower incidence of head, thoracic, and abdominal injuries, but many still sustain disabling LEIs which, in the past, were often overlooked in light of the more life-threatening injuries [1].

Data from the National Highway Traffic Safety Administration's (NHTSA) National Accident Sampling System (NASS) reveal that LEIs (at or below the pelvis) account for 32% of all injuries [2] with an Abbreviated Injury Scale (AIS) [3] score of 2 or higher for belted occupants (24% for unbelted). Injuries to the ankle/foot complex account for 33% of the AIS$\geq$2 injuries to the lower extremities for belted occupants (24% for unbelted) and are the most prevalent LEI [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 [4]. Surveys also 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 [5–7]. In a study of the one-year treatment charges for persons hospitalized in Maryland with motor vehicle-related injuries, LEIs accounted for 40% of the treatment charges [8].

In a recent analysis of real-world crash data from NASS, Kuppa et al. [9] showed that the lower extremities are the most frequent AIS 2+ injured body region for front outboard occupants in airbag-equipped vehicles. Among LEIs occurring annually in the U.S. to front outboard occupants in airbag-equipped vehicles, 33% were due to the foot and ankle, and these injuries accounted for 41% of the life years lost to injury. The authors conclude that, though foot and ankle injuries are not life-threatening, "both the combination of the absolute number of annual injuries and their associated high level of disability, impairment, and functional loss makes injury prevention efforts in the area have the potential for high benefits."

Lower extremity injuries from car crashes tend to be high-energy injuries, which have a poorer prognosis than comparable low-energy injuries caused by slips and falls [10]. Because they involve weight-bearing surfaces and major articulating joints, hip, 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 foot and often result in long-term impairment and disability. Unfortunately, the disabling nature of these injuries has not been reflected by their low scores on injury severity scales, such as the AIS; that is because the AIS is primarily designed to indicate threat to life, and not to characterize disabilities associated with non-fatal outcomes.

While the devastating impact of LEIs is not new to orthopedic surgeons, the disabling nature of specific types of LEIs, especially articular injuries of the ankle and foot, is generally not well recognized. There are several reasons for this lack of recognition. First, the most commonly used injury scoring systems are ICD-9 (International Classification of Diseases, 9^{th} revision) [11] and AIS. ICD-9 is an international categorization of disease and injury, whereas AIS was developed specifically for motor vehicle related injuries and ranks those injuries by severity. However, they do not provide appropriate detail with respect to the most disabling injuries; that is, those that involve an articular surface, such as tibial plateau or ankle fractures. While ICD-9 and AIS codes do indicate the presence of a tibial fracture, no indication is given that the articular surface, where two bones meet to form a joint, has been disrupted. Such a description requires more definitive clinical input such as the coding system developed by the Orthopaedic Trauma Association (OTA) [12]. This information is usually not available from large population-based datasets such as the NASS data or data derived from hospital discharge records. Finally, the true impact of these injuries, including the physical, psychosocial, and financial burden, cannot be determined at the time of hospital discharge, when outcome determinations are often made. Many LEIs require multiple surgeries as well as rehabilitation, frequently depleting family finances and resulting in a myriad of psychosocial problems that impede return to pre-injury functioning. Many patients still exhibit problems related to their LEIs at one year post-injury [13–15].

Based on CIREN data, it is possible to categorize patients with LEI based on detailed orthopedic coding systems, and to determine outcomes from these injuries one year post-crash.

METHODS

The CIREN project focuses research on persons who have sustained serious injury despite the availability of modern occupant restraint systems. The mission of CIREN is to improve the understanding of injury causation, thereby identifying specific ways to modify vehicles or to improve the treatment and rehabilitation of persons injured in car crashes.

Through crash reconstruction studies and intensive case reviews, investigators obtain detailed data on the causes and outcomes of crash-related injuries. The crash reconstruction team (Dynamic Science, Inc.) locates the vehicle and goes to the scene to obtain photographs and detailed measurements of the forces, contact points, and intrusions associated with the documented injuries. Meanwhile, detailed information is obtained on the nature and extent of patients' injuries, including photographs, x-rays, computed tomography (CT) scans, and documentation of clinical procedures.

In the CIREN project, LEI is defined as skeletal injuries involving joints or bones at and below the pelvis. These injuries correspond to AIS codes with the first two digits equal to '85' and a severity of 2 or higher. Each AIS code is counted as one injury; two injuries are counted for those cases with two codes that are exactly the same.

At the Maryland CIREN Center, patients are interviewed in the hospital to obtain pre-injury history and again after discharge to document the long-term consequences of their injuries in terms of physical limitations, as well as financial and psychosocial costs. Interviews include several components: a) a pre-injury health survey and trauma history; b) two questions that measure depression [16]); c) items meeting the diagnostic criteria for PTSD [17]; and d) a numeric pain intensity scale [18]. The 36-item Short Form Health Survey (SF-36), a standardized generic questionnaire designed to show general health status, is also administered at each patient contact. It includes questions that address eight different domains of health, including physical and emotional scales [19].

Financial information regarding CIREN patients (acute hospital, professional, and clinic costs) are obtained directly from the physician billing group associated with the trauma center. Rehabilitation costs are obtained through the University of Maryland Medical Systems Patient Financial Services. The majority of Shock Trauma patients who are rehabilitation candidates are discharged to a University of Maryland facility. Room charges and those for physical, occupational, and cognitive therapy are therefore used to estimate services received at outside facilities.

RESULTS

As of August 2003, there were 1,750 cases in CIREN. Of these, 987 (56.4%) involved at least one LEI. The CIREN cases are stratified according to LEI group in Table 1. Less than half (43.6%) sustained no LEI, while 5.0% incurred only a single LEI, 7.7% had multiple LEIs, and 43.7% had an LEI and at least one other significant injury in a separate body region. Among those with LEI, 9.0% suffered a single LEI, 13.7% had multiple LEIs, and 77.3% had a LEI and an injury to at least one other body region.

Table 1 - Motor Vehicle Drivers and Passengers With At Least One Injury Diagnosis Code
All CIREN Centers (N=1,750)

Lower Extremity Injury Group	Frequency	Percent	% Total LEI
None	763	43.6	
Single	88	5.0	9.0
Multiple	134	7.7	13.7
LEI & Other injuries	765	43.7	77.3
Total	1,750	100.0	

As mentioned previously, OTA codes allow for more specific classification of fracture patterns, including disruption of articular surfaces, which often result in long-term disability. Table 2 details in-hospital charges for CIREN patients with a single LEI according to the corresponding OTA code. This allows for greater distinction between fracture types within a given bone and for fractures with differing degrees of articular involvement. Even though there are small numbers of OTA codes for individual LEIs, fractures that include the articular surface, both partial and complete involvement, prove to have the higher in-hospital charges. Case 44B, with total charges of $103,382, had a two-week hospital stay due to complications from a severe wound infection. Discrimination between fractures that do or do not involve the articular surface is not possible using ICD-9 or AIS coding schemes.

Table 2 - In-Hospital Median Charges for Single Lower Extremity Injuries by OTA code
All CIREN Centers (N=62)

Body Region	OTA Code	N	AIS Score	Median	Articular*
Thigh	31B Femur Neck Fracture	1	3	48,910	No
	32A Femur Simple Fracture	17	3	20,695	No
	32B Femur Wedge Fracture	18	3	25,639	No

Table 2 (continued) - In-Hospital Median Charges for Single Lower Extremity Injuries by OTA code
All CIREN Centers (N=62)

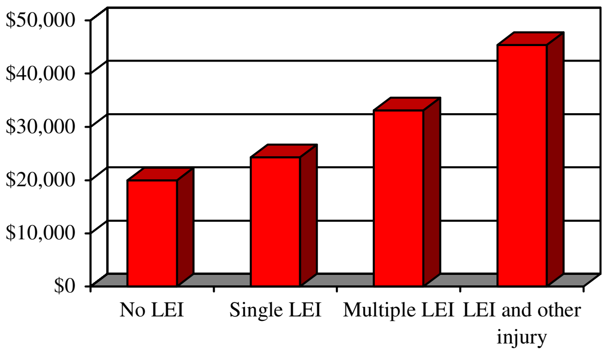
Body Region	OTA Code	N	AIS Score	Median	Articular*
Thigh	32C Femur Complex Fracture	1	3	33,723	No
	33C Femur Distal Simple Fracture	3	3	67,134	Complete
Knee	45B Patella Fracture	1	2	17,733	Partial
Leg	41B Tibia/Fibula Proximal Fracture	3	2	17,766	Partial
	41C Tibia/Fibula Proximal Fracture	2	2	40,052	Complete
Ankle	44B Tibia/Fibula Malleolar Fracture Transsyndesmotic	1	2	103,382	Complete
	44C Tibia/Fibula Malleolar Fracture Suprasyndesmotic Lesion	1	2	16,773	Complete
Foot	73B Calcaneus Fracture	1	2	9,370	No
	72A Talus Fracture	2	2	16,910	No
	72B Talus Fracture	2	2	35,460	Partial
	72D Subtalar Dislocation	2	1	24,259	No
	81A Metatarsal Proximal Fracture	6	2	3,109	No
	81C Metatarsal Proximal Fracture	1	2	12,010	Complete

* Complete articular involvement indicates 100% of the weight-bearing articular surface is disrupted.

Partial articular involvement indicates that some part of weight-bearing articular surface is disrupted.

It is apparent that the lowest median acute care charges (i.e., in-hospital) were incurred by hospitalized drivers with no LEI (Figure 1). Among those with LEIs, those with multiple LEI had greater charges than those with a single injury, and those with LEI in addition to injuries to other body regions had the highest charges.

Figure 1 - Distribution of Median In-Hospital Charges
All CIREN Centers



Tables 3 and 4 compare charges and outcomes for patients with and without ankle/foot fractures. Among patients admitted to the Maryland trauma center, there were 103 persons with LEIs and one-year follow-up data. Most of these patients had multiple trauma, and each had at least one LEI.

Table 3 - Ankle/Foot Fracture vs. No Ankle/Foot Fracture
Long Term Outcomes – Charges and Physical Functioning
Maryland CIREN Center
(N=103)

	A/F Fracture (N=50)	No A/F Fracture (N=53)	p-value
Hosp + Prof Charges (median $)	51,869	38,602	0.06
Inpatient Rehab Charges (median $)	20,000	13,095	0.11
Outpatient Rehab Charges (median $)	8,000	6,170	0.33

Table 3 (continued) –
Ankle/Foot Fracture vs. No Ankle/Foot Fracture
Long Term Outcomes – Charges and Physical Functioning
Maryland CIREN Center
(N=103)

	A/F Fracture (N=50)		No A/F Fracture (N=53)		
	n	%	n	%	p-value
Rehospitalization					
At least once	28	56	15	28	0.004
Ambulation Problems					
6 months	38	76	30	57	0.04
1 year	34	68	21	40	0.004
Cannot return to driving					
6 months	22	44	14	27	0.07
1 year	14	28	10	19	0.27
Cannot return to work					
6 months	13	26	6	11	0.05
1 year	14	28	7	13	0.06

Of all LEIs, ankle and foot injuries have the most debilitating long-term effects. Thus, differences in long term outcomes were also analyzed among LEI patients who did and did not incur an ankle or foot fracture, as defined by AIS score, since such injuries frequently involve articular surfaces (Table 3). Patients with ankle/foot fractures were more likely than were those without such fractures to be rehospitalized at least once within the 12-month period for circumstances related to their initial injury (p=0.004). Approximately two-thirds of those patients who sustained ankle or foot fractures reported significant ambulation problems at 6 months and one year. Patients sustaining an ankle or foot fracture were also less likely to return to work or activities such as driving at 12 months post-trauma.

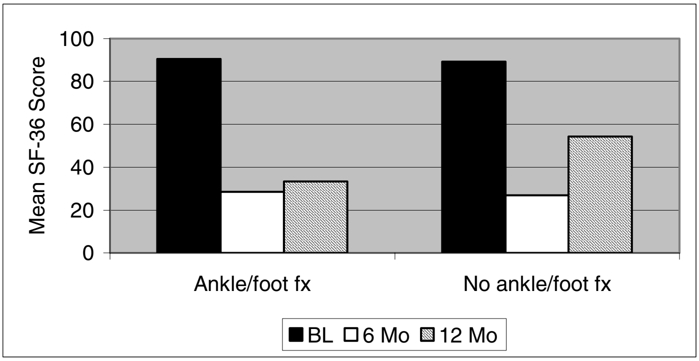
There was a high prevalence of psychosocial problems in the LEI group, although no differences were noted between those with and without ankle/foot fractures (Table 4). Psychosocial problems, such as PTSD, were evident in over 20% of all patients with LEI. Depression was a significant issue post trauma, affecting over one-third of the study group; patients with a pre-injury history of depression were twice as likely to exhibit symptoms of depression at 1 year post trauma, prolonging their return to functioning. Cognitive problems (difficulty with concentration, attention and memory) were also experienced by 30% of patients and behavioral changes, such as increased irritability or personality changes, were reported for 20% of the group. Joint pain, still experienced by over one-half of patients at 1 year post trauma, also contributes to a delay in return to work or poorer work performance.

Table 4 - Ankle/Foot Fracture vs. No Ankle/Foot Fracture
Long Term Outcomes – Psychosocial Functioning
Maryland CIREN Center
(N=103)

		A/F Fracture (N=50)		No A/F Fracture (N=53)		
		n	%	n	%	p-value
PTSD						
	6 months	11	22	15	28	0.46
	1 year	12	24	15	28	0.62
Patients with History of Depression		(n=19)		(n=21)		
Depression at 6 months		13	68	11	52	0.30
Depression at 1 year		11	58	14	67	0.57
Patients without History of Depression		(n=31)		(n=32)		
Depression at 6 months		14	45	12	38	0.54
Depression at 1 year		10	32	11	34	0.86
Behavioral Changes						
	6 months	16	32	19	36	0.68
	1 year	10	20	11	21	0.92
Cognitive Changes						
	6 months	16	32	17	32	0.99
	1 year	15	30	18	34	0.67
Pain	6 months	34	68	31	58	0.32
	1 year	28	56	23	43	0.20

Further evidence of the debilitating nature of ankle/foot injuries can be shown by results of the 36-item Short Form Health Survey (SF-36), which is administered at baseline and 6 and 12 months post-injury. The SF-36 provides a measurement of eight health concepts, or domains, related to physical and social functioning. Scores for each domain range from 0 to 100, with a higher score indicating a more positive outcome. For each domain, results indicated that patients generally declined in function from baseline to 6 months post-trauma before improving slightly at 12 months, to below baseline levels. With the exception of the domain of *role physical* (which measures physical problems in performing daily and work-related activities), this trend occurred within both the ankle/foot and no ankle/foot fracture groups. Figure 2 summarizes the interaction between fracture occurrence and *role physical* functioning over time. Patients without an ankle or foot fracture scored twice as high at 12 months than at 6 months. However, those with an ankle/foot fracture exhibited almost no improvement between 6 and 12 months.

Figure 2 - Role Physical Mean Scores According to Fracture Group Changes Over Time



For both inpatient and outpatient aspects of their treatment, those with an articular ankle/foot fracture incur higher charges, on average, than those with a non-articular ankle/foot fracture (Table 5). The most apparent difference is seen in acute hospital charges and outpatient rehabilitation, which supports the conclusion that fractures involving articular surfaces are more costly in the long-term, after the patient leaves the hospital, than those that are non-articular in nature.

Table 5 - Involvement of Articular Surface in Ankle/Foot Fractures
Maryland CIREN Center

	A/F Fracture (N=50)		
	Articular (N=42) Median ($)	Non-Articular (N=8) Median ($)	p-value
Hosp + Prof Charges	55,704	35,553	0.12
Inpatient Rehab Charges	20,500	19,388	0.51
Outpatient Rehab Charges	8,880	3,570	0.30
Hosp + Prof + Rehab	78,694	37,439	0.08

Thus, in summary, crash victims with LEIs have higher hospital charges than those without LEIs. Furthermore, within a given fracture type (especially ankle/foot), those with articular damage have higher in-hospital costs than those without. However, upon examination of more long-term costs (post hospital discharge), it is apparent that those with ankle/foot fractures (the majority of whom have an injury with an AIS=2) fare considerably worse at one year in terms of ability to return to pre-injury functioning. This is especially true for those with articular disruption such as that seen in pilon fractures.

DISCUSSION

These findings illustrate the long-term physical and psychosocial "costs" associated with LEI. With the evolution of modern occupant restraints, there has been a relative increase in the burden of these injuries due to the fact that more drivers who survive high-energy crashes (and previously did not) still sustain LEI. Total hospital charges for drivers and passengers in the state of Maryland alone in the year 2000 were estimated to be $49 million, of which approximately $21 million (43%) were attributable to LEI. By 2001, statewide charges associated with hospitalized vehicular occupants had increased to $56 million, of which approximately $25 million (45%) were attributable to LEI. It is apparent from these analyses of CIREN data that patients with articular fractures contribute disproportionately to these total costs. However, these estimates reflect merely the "tip of the iceberg," as they do not address lost productivity, property damage, litigation, and decreased functional capacity and quality of life.

Previous studies addressing the cost of LEI have concluded that costs increase with increasing AIS scores [20]. However, these analyses have usually been based on "administrative" or hospital discharge records, which do not have the advantage of the degree of clinical insight and thus, detail, documented in CIREN. In addition, many analyses related to costs address only the acute care costs associated with the initial hospitalization, thereby missing the long-term costs associated with rehabilitation, repeated surgeries, job loss, and impairment of mobility. These longer-term and indirect costs frequently dwarf those associated with acute care despite the fact that many patients who experience difficulties in returning to pre-injury functioning have injuries with low AIS scores.

The primary costs to patients with articular injuries are reflected in their inability to return, or lengthy delay in returning, to pre-injury activities such as driving, employment, household maintenance, or leisure time activities. In comparison to those without articular injuries, there was no difference in cognitive/behavioral problems, as a high incidence of such problems was noted in both groups. Increased dependence in conjunction with decreased income and continued legal issues frequently exacerbate the aftermath of a crash and can lead to symptoms of depression and post-traumatic stress.

These social "costs," although indirect, difficult to measure, and difficult to assign a dollar value, impede the recovery process. Now that more and more people survive high energy crashes due to state-of-the-art vehicles, emergency medical transport and trauma systems, it is paramount that adequate treatment be provided to address these clinical issues and reduce societal costs both in the workplace and at home. Furthermore, financial debts and altered lifestyle impact not only the patient but his/her family and other caregivers, extending burdens such as time lost from work, transportation costs, and other issues such as child-rearing to other family members. Thus, costs attributable to the crash are not limited to the injured party per se, but also to their family members, community, and society in general [8, 14, 15, 21].

Although estimates of long-term costs are not available for this population, based on the work of Zaloshnja et al. [20, 22, 23], it is possible to "impute" the magnitude of the economic burden by examining the ratio of medical to non-medical costs. For example, for a lower leg fracture of MAIS 2, average medical costs were estimated to be $14,272, while comprehensive costs attributable to this injury were $184,386; for MAIS 3 these estimates were $18,555 and $237,203, respectively. For an ankle/foot fracture of MAIS 2, medical costs were $11,568, with total costs of $148,975; for MAIS 3, these costs were estimated to be $28,836 and $218,465, respectively. Thus, it is apparent that medical costs represent only a small proportion of the comprehensive costs associated with these common injuries.

These cost estimates reflect a direct association between MAIS and costs, for each category of costs; that is, with increasing MAIS, there are increasing costs for every economic category. While intuitively logical, this association assumes that the AIS categories are specific enough to reflect long-term quality of life issues, which they were not designed to do. Based on the data presented herein, it is apparent that an injured vehicle occupant with an AIS of 2 and an articular fracture may have significantly greater medical costs and long-term physical and psychosocial sequelae than a comparable occupant with an AIS 3 fracture and no articular involvement. This greater level of medical specificity may be useful for future analyses of interventions targeting the prevention of LEI, especially ankle/foot fracture.

Injury severity scales that reflect disability need to more accurately capture the fact that fractures involving articular surfaces frequently have the greatest long-term impact on patients' return to pre-injury functioning. In fact, such an effort is already under way by the Association for the Advancement of Automotive Medicine (AAAM). As previously explained, AIS codes were originally based on mortality, not morbidity, and therefore do not adequately reflect long-term disability. However, AAAM is currently developing an updated AIS coding system that incorporates detail on articular fracture patterns. This new system will assign more specific severity codes based on threat to life as well as extent of disability.

These data highlight the uniqueness of the CIREN effort, with its ability to document detailed injury and crash information, including long-term outcomes. Without the detailed classification presented by the OTA data and post-trauma follow-up data, it would not be possible to illustrate the significantly higher burden imposed by articular fractures, and thus to conclude, mistakenly, that fractures with higher AIS scores are the more costly injuries.

These findings also strengthen the need for primary prevention, which in turn must be based on a comprehensive understanding of the biomechanics of LEI. Based on the real-world findings noted among patients admitted to trauma centers, CIREN engineering/biomechanics experts can try to replicate these injuries by 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 LEIs are sustained in crashes with little or no intrusion [24]. However, crash reconstruction 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 LEI injury mechanisms.

Meanwhile, until there is improved success in primary prevention, medical care providers, families, and crash survivors need to be more aware of the life-altering impact of these seemingly "minor" injuries.

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DISCLAIMER

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The crash investigation process is an inexact science which requires that physical evidence such as skid marks, vehicular damage measurements, and occupant contact points be coupled with the investigator's expert knowledge and experience of vehicle dynamics and occupant kinematics in order to determine the pre-crash, crash, and post-crash movements of involved vehicles and occupants.

Because each crash is a unique sequence of events, generalized conclusions cannot be made concerning the crashworthiness performance of the involved vehicle(s) or their safety systems.

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