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LOWER EXTREMITY INJURIES IN AUTOMOBILE CRASHES†

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Abstract—The new United States National Crash Severity Study (NCSS) data on tow-away automobile crashes was reviewed to determine the details of the more severe injuries of the lower extremity. This review includes the frequency of injury by limb segments (pelvis, thigh, knee, leg and ankle/foot), the vehicle structure contacted to produce these injuries, and the injuries/contact differences among car occupants. Some of the finds are: of the various body regions having the more severe injuries, the lower extremity ranks second only to the thorax; lap–shoulder belted occupants hardly ever sustain the more severe lower extremity injuries; and severe lower extremity injuries occur primarily in frontal crashes. Extrapolation of the NCSS data for national estimates indicates that the more serious lower extremity injuries in car crash survivors approximately equals the total number of passenger car occupants who are killed annually (27,000).

INTRODUCTION

The existing literature is not very satisfying in establishing the relative frequency of occurrence of the more severe lower extremity injuries, nor of the severity and distribution of these injuries within the lower limb. Some reports indicate that lower extremity injuries in car crashes are quite infrequent, whereas others find lower extremity injuries in 50% of the injured occupants. Up to the present time, reliable statistics on the frequency of lower extremity injuries, necessary for vehicle design and regulation, have not been available with respect to the U.S. population.

Only recently has there been a data bank established from the National Crash Severity Study (NCSS) that provides a sample of accidents and injury data concerning passenger cars and their occupants. This file now permits a number of explorations not previously possible. In this report the lower extremity injuries sustained in passenger car crashes are examined in order to place them in perspective relative to other crash injuries elsewhere in the body, the specific location of these injuries within the lower extremity, and the contact areas related to these injuries.

LITERATURE REVIEW

Although there are many case descriptions of extremity injuries in the medical literature, they are too numerous to list, and collectively would add little to the present review. A selected review of some of the more prominent statistical publications on this subject follows.

A study by the German Motor Insurers [Anonymous, 1975] on 28,936 drivers and 14,954 front seat passengers in accidents involving an injury insurance claim indicates that the more severe (AIS–3) lower extremity injuries are infrequent (thigh, 0.5%; knee; 0.4%; leg, 0.3% and foot, 0.1–0.2%). In a review of 5597 car injured persons, Kihlberg [1970] found that the lower limb was involved in 50% of the injured occupants; the severity of the lower limb injury was

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not indicated. Nash (Australia), [1969] reported that 47% of the car occupants admitted to the hospital had some leg injury; the severity of these injuries was not reported.

Nahum *et al.* [1968], reviewed the data of 190 crashes wherein at least one occupant sustained an injury of moderate (non-dangerous) or dangerous (non-fatal) degree (239 occupants, 496 significant injuries). Of these injuries, 13% were in the lower limb, with 60% of these caused by contact with the instrument panel, floor or toe pan area. Most of these injuries occurred at impact speeds above 30 mph. Ryan (Australia) [1967], and Nagel *et al.* [1977(b)], found that the instrument panel most frequently was the impact site for lower extremity injuries. A crash injury study by Nagel and States [1977(a)], indicated that most of the knee injuries resulted from impact with the dashboard. The authors concluded that degenerative arthritis will develop in the more seriously injured knees. Leroy [1972], relates many foot fractures to the foot controls or folding of the floor due to crash forces.

Melvin *et al.* [1975], reviewed multi-disciplinary accident investigation reports of passenger cars in frontal crashes with unrestrained passengers 12 yr of age or older. They found a relatively low occurrence of lower extremity injuries.

Goegler [1962], in an extensive study of road casualties admitted to the Heidelberg Clinic (Germany, 1952–1958), reported that car drivers had injuries to the pelvis or lower extremities in 28% of the cases. However, the severity of these injuries was not indicated. Using trauma registry data (Denmark) Jorgensen *et al.* [1979], reported that the more severe lower extremity injuries were 14% in the pelvis and 10% in the lower limb. Fatal extremity injuries rarely occur in car crashes [Anonymous, 1975; Danner, 1977; Giraldo, 1973; Hight *et al.* 1972; Huelke *et al.* 1977; Huelke and Melvin, 1980; Nagel *et al.* 1973; Nahum *et al.* 1968; Perry and McClellan, 1964 and Rubinstein, 1973].

In lateral impact crashes States and States [1968], found that the majority of the lower extremity injuries were due to impacts to the front door or armrest.

Many of the above studies used a variety of injury scales, were from different accident population or injury groups and thus it is difficult to make direct comparisons with the data presented here. The German Insurance data used the AIS scale and is probably the most comparable, but it is based on injury claim accidents vs our towaway population of crashes in the U.S.

Lap-shoulder belts have been reported to be effective in reducing lower extremity injuries. Huelke *et al.* [1977], reported on frontal and rollover crashes; they found an 81% reduction in the more severe lower extremity injuries in frontal collisions and a 75% reduction in rollover crashes, reductions associated with the use of lap-shoulder belts. Others have also noted the infrequent occurrence of lower extremity injury in occupants wearing restraints [Gloyns *et al.* 1979; Hight *et al.* 1972; MacKay *et al.* 1975; Marsh *et al.* 1975; Nagel and States, 1977(a) and Rattenbury *et al.* 1979].

INJURY CLASSIFICATION

The Abbreviated Injury Scale (AIS) is used in the NCSS file to categorize the severity of injury. The Abbreviated Injury Scale is used extensively in research on automobile injuries and has been extended to other areas as well. [Petrucelli *et al.* 1980]. The AIS is a scale that categorizes injury by severity: minor (AIS–1), moderate (AIS–2), severe (AIS–3), serious (AIS–4), critical-to-life (AIS–5) and fatal (AIS–6).

The following is a list of diagnoses of more than minor injuries to the lower extremity.

AIS–2

Fractures of the pelvis or its individual parts, of the coccyx or sacrum; femoral fracture without sciatic nerve involvement, closed fractures of the patella, tibia or fibula; malleolar or tarsal fractures, dislocation of the metatarsus, knee sprain.

AIS–3

Hip dislocation, sacro-iliac fracture and/or dislocation, pubic symphysis separation; displaced, compound or comminuted femoral, patellar, tibial, fibular or tarsal fracture; laceration into knee or ankle joint, rupture of the knee or ankle ligaments; rupture of major tendons, laceration of major nerves and/or vessel involvement.

AIS–4

Amputation above or below the knee; lower extremity crush; fractures of multiple long bones in the same extremity.

SOURCES OF INFORMATION

The National Crash Severity Study (NCSS) is a major accident data collection program of the National Center for Statistics and Analysis of the National Highway Traffic Safety Administration. This data bank includes detailed crash configuration information, descriptions of injuries and their sources (contacts), and a quantitative description of vehicle damage. Crashes for the NCSS study were selected on a strict stratified sampling plan, and have some potential for making projections to a national population.

In the NCSS program, the detailed accident injury data were collected from investigations conducted by professional teams operating in eight regions of the United States. During the period from January 1977 to March 1978, 6628 accidents were investigated and computerized. In these accidents there were 8616 tow-away passenger cars containing 14,491 occupants.

For 10,151 of the 14,491 occupants, detailed injury information was available from qualified medical sources. Most of the discussion in this report is based on those occupants for which such complete injury information was available.

Figure 1 shows the distribution of AIS–3 and AIS–4 injuries in the NCSS sample. The most frequent body region injured at this level is the chest, with about 32% of all such injuries. Second in prominence is the lower extremity, with 23%.

Figure 2 displays in three-dimensional form the relationship between the body region and the contact area within or outside the car. Again, the lower extremity is prominent, particularly in interaction with the instrument panel and the floor.

CONTACT AREAS AND LOWER EXTREMITY SUBDIVISIONS

The various contact areas for the lower extremity include the instrument panel, floor, the steering assembly, the side interior, the front seat back, objects exterior to the car, "miscellaneous areas" and the "unknown" contact regions. These areas include:

Instrument panel

The instrument panel itself, including the glove compartment, radio and hardware items such as knobs and control devices, heater outlets, air conditioning duct work, vents, parking brake and parcel tray.

Floor

Includes the floor, toe board, floor-mounted transmission lever, foot controls and console.

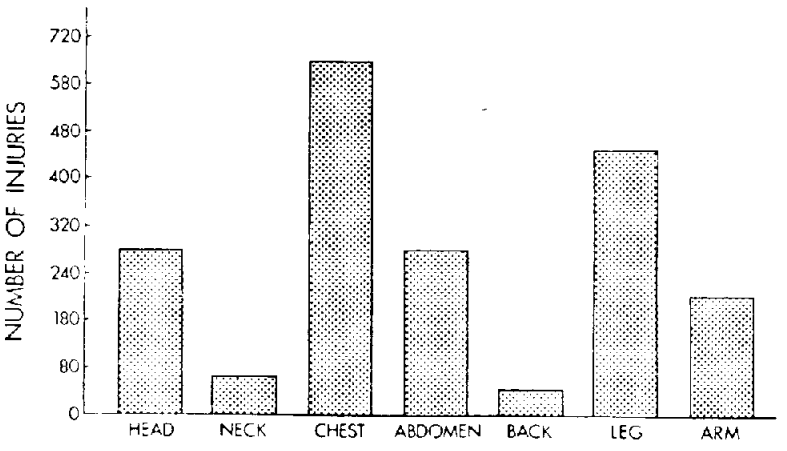

Fig. 1. Body region distribution of the more severe injuries (AIS–3 or 4) in the NCSS sample.

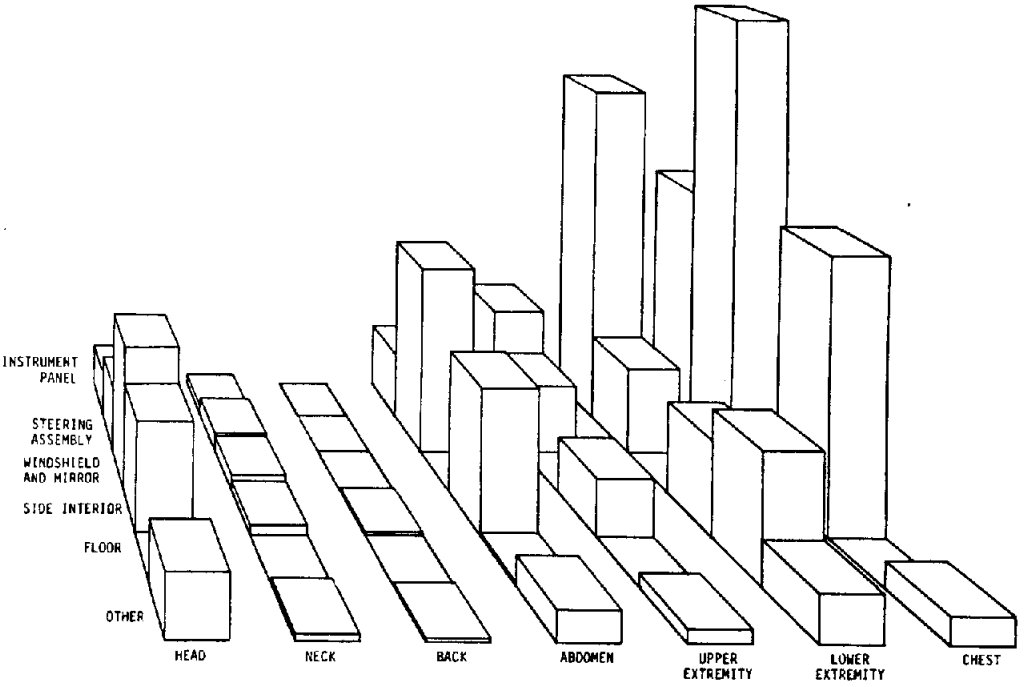

Fig. 2. AIS-3 and AIS-4 injuries by body region and contact.

Steering assembly

The steering wheel, the steering column, the column mounted transmission lever and the turn signal lever.

Side interior

The door or side interior and associated hardware such as door handles and window controls, armrests, side glass and frame, roof side rail and coat hooks.

Exterior

Any objects exterior to the vehicle, such as the ground, trees, poles and pillars, etc; another vehicle and intruding hood.

Front seat back

The back of the front seat. Exclusively a rear-seat occupant contact area.

Miscellaneous

Add-on items such as CB radios, courtesy lights, A-pillars and "other" items.

Unknown

Contact areas that are not specified in the data.

The lower extremity has been divided into five anatomical regions—the pelvis, thigh, knee, leg and the ankle/foot.

Pelvis

The pelvis includes the bony pelvis and hip joint; it does not include the pelvic organs or the external genitalia.

Thigh

The thigh is the region between the hip articulation and the knee. It includes the femur and the overlying muscles and associated neurovascular structures but not the hip or knee joint components.

Knee

The knee consists of the lower articular surfaces of the femur and associated articular area of the tibia, the patella, knee ligaments and surrounding tissue.

Leg

The leg extends from the knee region to the ankle but does not include the bony or ligamentous structures of the ankle joint.

Ankle/foot

For this report the ankle and foot are considered to be one general region. The ankle region includes the lower articular ends of the tibia and fibula, the ankle joint and associated ligaments, and enclosing soft tissue. The foot includes all of the bones of the foot and toes, their joints and soft tissues.

DATA ANALYSIS

In the NCSS File there were 14,491 occupants of cars in tow-away crashes. Medical data were available on 10,151. Of these, 1353 occupants had injuries at the severe or greater level (AIS–3+) with 371 occupants having 419 lower extremity injuries of the more severe nature (AIS–3 or 4).

Of the 371 occupants with the more severe lower extremity injuries, 222 (60%) had the lower extremity as the more severely injured body area. Of the 371, 51 died, but the fatal lesion was never in the lower extremity. Thus, the lower extremity has a significant frequency of the more serious car crash injuries, is not an infrequent body area involved, and often is the most severely injured body region.

Frontal crashes account for 71% of the more severe lower extremity injuries (Table 1), whereas for occupants with any sort of an AIS–3 or greater injury, frontal crash involvement accounts for only 57%.

CONTACT AREAS AND SEAT POSITIONS

Contact areas

Interior car components immediately in front of the occupants predominate as a lower extremity contact area. Approximately three quarters of the more serious lower extremity injuries are due to contacts with the instrument panel, floor and steering assembly. Of all the more serious lower extremity injuries of unrestrained car occupants, 44% of the known contacts are to the instrument panel (Table 2). The floor and the side interior are next in importance, but together they account for 31% of these injuries. The steering assembly is fourth in the frequency of lower extremity injury contact and is exclusively a driver contact area. Lower extremity injuries related to other structures occur noticeably less often.

Seated positions

Drivers. Unrestrained car drivers have a lower frequency of the more serious lower limb injuries than the average of all occupants. Of the 419 more severe lower extremity injuries, 58%

Table 1. Crash experience involving unrestrained occupants, not ejected

Type of Crash	All	Occupants with AIS-3 or 4 Lower Extremity Injuries	Occupants with Any AIS-3 or 4 Injuries
Frontal	51%	71%	57%
Side	18%	11%	22%
Rear	4%	—	1%
Rollover	5%	5%	6%
Other	9%	5%	6%
Unknown	13%	8%	8%
Total	100%	100%	100%

Table 2. The number of the severe and serious lower extremity injuries (AIS–3 or 4) all unrestrained car occupants

Contact Areas	Drivers	Front Right	Other Front	Rear	Unknown	Total
Instrument Panel	94	57	11	--	--	162
Floor	39	21	3	--	--	63
Side Interior	28	17	--	7	--	52
Steering Assembly	44	--	--	--	--	44
Front Seat Back	--	--	--	18	--	18
Exterior	6	2	--	1	--	9
Miscellaneous	12	3	1	3	--	19
Unknown	19	15	4	13	1	52
Total	242	115	19	42	1	419

were sustained by drivers, although drivers constitute 63% of car occupants in this file. The instrument panel predominates as the main contact area of these driver injuries (42%). Less often the steering assembly and floor are involved.

Right front and other front seat occupants. Right front passengers have the more serious lower extremity injuries more often than the average occupant, for 27% of such injuries are sustained by front right passengers who constitute but 21% of all car occupants. Structures forward of these passengers (instrument panel and floor) are high in occurrence of lower extremity contacts (78%). The same is true for the "other" front seat occupants (mostly front center) who have their lower extremity injuries occurring most often from instrument panel impacts (73%).

Rear occupants. Rear seat occupants account for 10% of the serious lower extremity injuries, and constitute about 10% of all occupants. The most frequent cause of the more serious lower extremity injuries to rear occupants is the back of the front seat (62%). About 24% of these occupants contacted the side interior, indicative of a side impact collision.

Considering all occupant seated locations, those in the right front seat are proportionately the most likely to sustain severe lower extremity injuries, followed by rear seat occupants. The driver is the least likely to sustain such injuries.

LOWER EXTREMITY AREAS: INJURIES AND CONTACTS

The pelvis/hip, the thigh, or the leg each have a frequency of 20–25% of the more severe (AIS–3 or 4) injuries. Less often the knee (12%) or ankle/foot areas (17%) are involved (Table 3).

About 4% of the more severe lower extremity injuries in the NCSS file did not have the exact injury location recorded, but the contact areas were known—thus a general category of "non-specified area" is also presented.

The numbers shown in Table 3 in parentheses are the injuries to ejected occupants; these injuries are also included in the larger adjacent numbers. However, the pelvic fractures of the more severe type are found proportionately more often in ejectees than in those who are contained. Of the 56 ejectee lower extremity injuries, 18 (or 32%) were in the pelvic area, whereas for those contained in the vehicle, who were unrestrained, only 19% were to the pelvis. The specific contacts of pelvic injuries to ejectees are often reported as "unknown" suggesting that there is no significant association between pelvic injuries and the ejection event.

Pelvic injuries

Pelvic injuries are the only injuries of the lower extremity with a substantial proportion occurring by contact with the side interior (28%) (Table 4). The injuries to all other lower limb areas most frequently involve contacts in front of the occupants. Pelvic injuries are less often

Table 3. Contact areas for severe and serious lower extremity injuries to unrestrained occupants (AIS-3 or 4)*

Contact Area	Pelvis	Thigh	Knee	Leg	Ankle/ Foot	Non Specified Area**	Total
Instrument Panel	23	45(2)	35(4)	50	1	8(1)	162(7)
Floor	1	3(1)	--	6	51	2	63(1)
Side Interior	29(4)	10	2	7(1)	3	1	52(5)
Steering Assembly	24(2)	14(2)	4	1	--	1	44(4)
Front Seat Back	3	6(1)	--	7	2	--	18(1)
Exterior	--	2(2)	--	4(4)	2(2)	1(1)	9(9)
Miscellaneous	5(2)	3(2)	1	6(1)	3(2)	1	19(7)
Unknown	17	11(4)	5	9(5)	6(3)	4	52(12)
Total	102(8)	94(14)	47(4)	90(11)	68(7)	18(2)	419(46)

*All injuries presented here are of the AIS-3 or 4 (severe, serious). No critical-to-life or fatal lower extremity injuries were found in the file. Injuries of the ejected occupants are shown in parentheses.

**Specific location of the injury not specified in the data.

Table 4. Pelvic and thigh injuries (AIS-3 or 4)

Contact Area	Drivers		Front Right		Other Front		Rear		Total	
	Pelvis	Thigh	Pelvis	Thigh	Pelvis	Thigh	Pelvis	Thigh	Pelvis	Thigh
Instrument Panel	8	20	12	19	3	6	--	--	23	45
Floor	--	2	1	1	--	--	--	--	1	3
Steering Assembly	24	14	--	--	--	--	--	--	24	14
Side Interior	16	4	10	4	--	--	3	2	29	10
Front Seat Back	--	--	--	--	--	--	3	6	3	6
Exterior	--	1	--	--	--	1	--	1	0	3
Miscellaneous	3	2	1	--	--	--	1	--	5	2
Unknown	9	1	3	4	--	3	4	3	16	11
Total	60	44	27	28	3	10	11	12	101*	94

*The seating position and contact of one occupant with a pelvic injury is unknown and is not included in this table.

sustained by contact with the steering assembly (24%) or the instrument panel (23%). Other contacts were less often related to pelvic injuries. However, there is a greater number of drivers sustaining these pelvic injuries on the steering assembly, than from any other cause. Front right occupants' pelvic injuries are sustained with equal frequency by contact with either the instrument panel and/or the side interior. All other contacts occur much less frequently. The rear occupants, on the other hand, sustain pelvic injuries on the front seat back as often as from the side interior.

Thigh injuries

Thigh injuries constitute one out of five of the more severe lower extremity injuries (Table 4). Approximately half of these thigh injuries are sustained by drivers, with the majority

resulting from contact with the instrument panel (54%) or steering assembly (17%). About 12% of the thigh injuries result from impacts to the side interior. Front right occupants sustained more of their more severe thigh injuries from contact with the instrument panel.

Knee or leg injuries

Injuries to the knee area, including the patella, distal femur or proximal articular surface of the tibia, deep lacerations extending into the knee joint, or knee ligament disruptions are less frequent in occurrence (12% of the more severe lower extremity injuries). A majority of these injuries were sustained by drivers, with the instrument panel predominating as a prime contact area (Table 5).

Of the more serious injuries to the leg, 62% are due to instrument panel impacts. All other contact areas occur individually with much lower frequency.

Ankle/foot injuries

About 80% of the injuries to the ankle and foot are caused by contact to the floor and foot controls (Table 6); ankle/foot injuries are mainly seen in drivers and front right occupants.

Non-specified lower extremity injuries

Of the 419 more severe lower extremity injuries there were only 18 injuries not anatomically located in the limb (Table 6). Of these the instrument panel or floor is reported most often as the injury-producing contact.

Comment

The more severe lower extremity injuries are relatively infrequent. Pelvic injuries occurred in 1% of the 10,151 occupants, slightly more often than the more serious thigh or leg injuries (0.9% each). Ankle/foot injuries occur in only 0.5%. Only 0.2% of the known injuries were to the non specified areas of the lower extremity. However of the more severe injuries, the lower extremity ranks second only to thoracic injuries.

CONSEQUENCES OF LOWER EXTREMITY INJURIES

Lower extremity injuries are seldom fatal, but treatment and temporary total disability are longer than those associated with the more serious injuries in other body areas; permanent disability is common. Table 7 reveals that the average hospital stay for the more severe lower extremity injuries is markedly higher than for the same AIS level injuries in other body regions. Hospital days for severe and serious lower extremity injuries are twice that of similar injury

Table 5. Knee and leg injuries (AIS-3 or 4)

Contact Area	Drivers		Front Right		Other Front		Rear		Total	
	Knee	Leg	Knee	Leg	Knee	Leg	Knee	Leg	Knee	Leg
Instrument Panel	30	32	5	16	--	2	--	--	35	50
Floor	--	4	--	2	--	--	--	--	0	6
Under Panel	--	--	--	--	--	--	--	--	0	0
Steering Assembly	4	1	--	--	--	--	--	--	4	1
Side Interior	1	4	--	2	--	--	1	1	2	7
Front Seat Back	--	--	--	--	--	--	--	7	0	7
Exterior	--	3	--	1	--	--	--	--	0	4
Miscellaneous	--	5	1	--	--	--	--	1	1	6
Unknown	3	3	2	2	--	1	--	3	5	9
Total	38	52	8	23	0	3	1	12	47	90

Table 6. Ankle/foot and "non specified" injury location (AIS-3 or 4)

Contact Area	Drivers		Front Right		Other Front		Rear		Total	
	Ankle/ Foot	Non Spec.	Ankle/ Foot	Non Spec.	Ankle/ Foot	Non Spec.	Ankle/ Foot	Non Spec.	Ankle/ Foot	Non Spec.
Instrument Panel	--	4	1	4	--	--	--	--	1	8
Floor	32	1	16	1	3	--	--	--	51	2
Under Panel	--	--	--	--	--	--	--	--	0	0
Steering Assembly	--	1	--	--	--	--	--	--	0	1
Side Interior	2	1	1	--	--	--	--	--	3	1
Front Seat Back	--	--	--	--	--	--	2	--	2	0
Exterior	1	2	1	--	--	--	--	--	2	2
Miscellaneous	2	--	1	--	--	--	--	1	3	1
Unknown	2	--	2	2	--	--	2	1	6	3
Total	39	9	22	7	3	0	4	2	68	18

Table 7. Days in hospital by severity of lower extremity injury

	Lower Extremity Injury		Worst Injury in Other Body Areas	
AIS	Number	Mean Days	Number	Mean Days
1 (Minor)	1830	1.6	3235	3.8
2 (Moderate)	357	8.8	941	6.1
3 (Severe)	263	15.3	551	8.3
4 (Serious)	30	18.3	167	9.4
5 (Critical)	---	---	98	11.3

level in other body areas. Longer periods of temporary total disability for such lower extremity injuries is also noted (Table 8). The treat of permanent disability as a consequence of the more severe lower extremity injury, especially for joint injuries, is real, with the probability of clinical complication high.

NATIONAL PROJECTIONS

The previous literature has reported a variety of findings about lower extremity injuries, but has not provided much information about the relative frequency of these injuries (compared to other kinds of injuries), nor any estimate of the national frequency of lower limb injuries of the more severe nature.

Table 8. Days of work lost by severity of lower extremity injury

	Lower Extremity Injury		Worst Injury in Other Body Areas	
AIS	Number	Mean Days	Number	Mean Days
1 (Minor	1185	5.0	2060	4.2
2 (Moderate)	208	12.9	544	8.6
3 (Severe)	245	19.3	292	15.8
4 (Serious)	16	21.1	77	15.5
5 (Critical)	---	---	32	25.2

The NCSS data have been acquired by a specific sampling procedure in seven regions of the United States which, taken together, contain about 2% of the population of the country. While the NCSS regions were selected to have a rural/urban ratio similar to that of the country as a whole, it is likely that these regions do not represent the U.S. in all dimensions important to the considerations of accident projections. Even so, it is believed that a straightforward extrapolation of NCSS counts by the population ratio of the nation to the NCSS regions is a reasonable first estimate of many accident event frequencies. There are several adjustments to such an extrapolation which are largely a matter of judgement of the effect of missing data. [Huelke *et al.* 1980]

Injury data reported in NCSS currently details only the six most severe injuries. In the original reporting only the first three injuries were given, and, when the original case material was reviewed, about 10% of the severe lower extremity injuries were reported as injuries 4, 5 or 6. Whether there are additional leg injuries which might have been reported as injuries number 7, 8, etc. is not known, but it seems likely that the additional number would be small.

Of the total of 14,491 NCSS occupants in the present file, 4340 are listed without any detailed injury information. A small number of these, but a large proportion of all the fatal occupants are persons who died without an autopsy or competent medical examination being performed. Since the fatal occupants with known medical information had a high proportion (18%) with severe leg injuries, one might expect that the nearly 200 missing fatal cases would also. However, if they sustained leg injuries at the same rate as the known fatalities, about 40 cases would be added to the 371 persons with known leg injuries. At the other end of the scale, many of the missing injury reports seem to result from minor accidents for which the involved parties were injured so slightly that they were hard to find for interviews. It seems likely, then, that the effect of the missing cases on an estimate of the total number of severe leg injuries would be to add something smaller than their actual proportion of about 40%. At most this would lead to 1.4×371 or 519 persons.

An estimate of the present NCSS data may also suffer from some missing cases—i.e. cases which were supposed to be in the sample, but failed to get there because of communications difficulties between teams and police agencies. It is known that fatal accidents are somewhat underreported (perhaps by 15 or 20%), and thus all accidents (and leg injuries) might be underreported by the same proportion. At most this would seem to lead, then, to an estimate of $1.2 \times 5/9$, or about 623 persons.

Finally, the NCSS program covered a period of 15 months, and a better annual estimate may be obtained by taking 12/15 ths of the above estimates. For the last number, this would be 498 persons with severe leg injuries.

NCSS data derive solely from occupants of towed passenger cars, of course, and there may be many other leg injuries among pedestrians, motorcyclists, or truck and bus occupants. In addition it is likely that there are some such injuries among occupants of passenger cars which were not towed, although it seems likely from the present study that the proportion in such crashes would be quite small. The NCSS data provide no information about these other accident types, and any projection from NCSS should be understood to refer only to the towed passenger car population.

With all of the above qualifications it is not statistically appropriate to try to put bounds on such a projection. For the NCSS regions for one year, the recorded number of persons with severe leg injuries is about 297. It seems likely that this number should be increased to account for missing data and perhaps for missing cases, but probably not to as much as 498. To give some idea of just what this number means, recall that the number of fatalities reported in NCSS for the same period (i.e. 1 yr) is about 400, and that fatalities are more fully reported (even though there is not complete injury data available). Since there are about 27,000 front seat passenger car occupants killed each year in the U.S., the number of persons with severe leg injuries (from tow-away crashes) is estimated to be about the same.

BIOMECHANICS OF LOWER EXTREMITY INJURIES

Many of the more severe injuries to the lower extremities are due to knee impacts. For example, impacts to the instrument panel may cause localized damage to the knee, possibly deep lacerations to the joint, patellar (knee cap) fractures, or fractures of the distal end of the

femur, or the upper articular surface of the tibia or knee ligament ruptures. Also, forces from a knee impact may be transmitted through the femur, and if sufficient can cause femoral fractures. Not infrequently the pelvic area also can be fractured by knee contact with the instrument panel. In that the hip joint and its related injuries are categorized in the pelvic region, such force transmission through the femur may cause fractures or fracture–dislocations of the hip joint. Pelvic fractures, additionally, may be sustained by direct contact with the instrument panel due to vehicle occupant rotation or for example, an individual sitting sideways in the car at the time of the head-on crash [States *et al.* 1972].

The majority of fractures to the bony pelvis, except for the hip articulation are due to side impacts were forces are applied directly to the side of the pelvis. In these cases there may be localized fracturing of the side of the pelvis, as well as induced fractures of the more medial, anterior part of the pelvis—the superior and/or inferior pubic rami. The pubic rami are the thinnest portions of the pelvis in cross section, and high stress concentrations in these areas will cause fractures. In general, most all of these pubic rami fractures are not due to direct impact, for these structures are in an area that is infrequently directly impacted in car crashes. Superior and inferior pubic rami fractures may be found on the same side as where the impact was applied, or may be on the opposite side. There is no consistency as to the location of these pubic rami fractures relative to the impact site.

Fractures of the tibia, not involving the knee or ankle joint, are due to a variety of impacts, most frequently the instrument panel. In these cases the unrestrained occupant strikes the leg anteriorly causing fractures, generally in the area of the impact, with further bending of the limb possibly inducing the fracture of the adjacent fibula.

Most of the ankle/foot injuries are related to the floor and foot controls. Fractures and fracture–dislocations of the lower shaft of the tibia or fibula, in association with ankle joint involvement, true ankle joint dislocations, or fractures of the ankle bone (the talus) may be sustained due to extreme twisting and/or shearing forces about the ankle. If the foot is squeezed in the folds of the floor or in the pedals, dislocations of the foot with metatarsal fractures may occur.

There are no biomechanical tolerance data available on the pelvis or hip, or on the ankle or foot complex that are applicable to the automotive crash environment. Biomechanical data on femoral and patellar fractures are available, with some data on the tolerances of the tibia.

CONCLUSIONS

Analysis of the NCSS data indicates that passenger car occupant injuries of the more severe nature (AIS–3 or 4) in the lower extremity are exceeded in frequency only by AIS–3 or 4 thoracic injuries. When national estimates are made, it appears that there are some 27,000 car crash survivors each year sustaining the more severe lower extremity injuries. This is approximately equal to the total number of front seat passenger car occupants who are killed annually.

Considering their exposure, front right passengers more often had the more severe lower extremity injuries than other occupants; drivers sustained a lower than average frequency of the more severe lower limb injuries.

The more severe lower extremity injuries are most often sustained by unrestrained occupants impacting objects in front of them, with the lower instrument panel being the main contact location. Fractures are the most common type of the more serious lower extremity injuries.

Increased attention to impact characteristics of the lower instrument panel may prove beneficial in reducing the occurrence of the more severe lower extremity injuries. The instrument panel is associated with injuries of the pelvis, thigh, knee and leg, whereas the ankle/foot region most always is injured by floor or foot control contacts. The back of the front seat and the side interior are the objects most often impacted in side interior contacts.

Generally speaking, the subregions of the lower extremity (pelvis, thigh, knee, leg and ankle/foot) are injured with approximately the same frequency. Pelvic injuries are found most often in drivers, whereas the front passengers had the pelvis or thigh as the two areas most often injured.

Direct impact loading to any area of the lower extremity can cause injuries in that body

region. In many cases force transmission through bone to other lower extremity areas can cause fractures and/or dislocations remote from the impact site. Compression or twisting forces, especially at the ankle area, are believed to be the main cause of the injuries.

Seat belt systems appear to reduce the more severe lower extremity injuries; however, there are too few cases available in the NCSS data to verify this finding to other authors.

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