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16. Abstract

NCSS data concerning specific details of the more severe injuries (AIS-3,4) of the lower extremity were reviewed. These included the frequency of injury occurrence by individual limb segments (pelvis, thigh, knee, leg, ankle/foot), injury/contact areas related to these injuries, injury/contact differences among car occupants, and a comparison with less severe lower-extremity injuries relative to regional limb injury frequency and contact areas. Findings are: that lap shoulder belted occupants hardly ever sustain AIS-3,4 lower-extremity injuries; that severe lower-extremity injuries occur primarily in frontal impacts; and that lower-extremity AIS-3,4 injuries constitute the second-largest group at that injury level of any body area other than the chest.

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# Lower Extremity Injuries in Automobile Crashes
(An Analysis of NCSS Data)

Report Number UM-HSRI-80-10

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# I. INTRODUCTION

The National Crash Severity Study has provided a sample of accident and injury data concerning passenger cars and their occupants which permits a number of explorations not previously possible. In this report the lower extremities are examined in order to place these in perspective relative to other injury types occurring in automotive crashes, the specific locations of these injuries in the lower extremity, and the contact areas related to the injuries.

This report is organized in 10 major sections, the first of which is this introduction. Following this is a review of past literature concerning lower-limb injuries. Next, in Sections 3 and 4, the data sources used for the present study are discussed along with a description of the anatomical areas, injury types, and contact areas. Section 5 contains the majority of the statistical material in the paper, reporting on the number, type of injuries observed, and specific areas involved, the effects of restraints on lower-extremity injury frequency, and a review of the restraint effectiveness literature. Section 6 presents our national projections from the NCSS data discussed in Section 5. Section 7 describes the mechanisms of the various types of injuries in a biomechanical sense. Section 8 presents a discussion of the medical aspects of these injuries and their long-term consequences. The conclusions section contains a brief summary of the principal findings.

## II. LITERATURE REVIEW

In general there have been no accurate data on the number, frequency, or extent of extremity injuries related to motor vehicle crashes. 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.

An extensive study by the German Motor Insurers (1) on 28,936 drivers and 14,954 front seat passengers indicates that lower-extremity injuries are infrequent (thigh: 0.5%; knee:0.4%; leg:0.3%; foot:0.1% to 0.2%).

In a review of 5,597 injured persons, Kihlberg (2) found that the lower limb was involved in 50% of the injured occupants; the severity of the lower limb injury was not indicated.

In 1968 Nahum et al. (3) reviewed the data of 190 crashes. Each of these accidents involved at least one occupant who sustained an injury of moderate (non-dangerous) or dangerous (non-fatal) degree (239 car occupants, 496 significant injuries). Of these injuries, 13% were in the lower limb, with 60% caused by contact with the instrument panel, floor, or toe pan area. Most of these serious injuries were at impact speeds above 30 mph.

Ryan (Australia) (4) also found that the instrument panel was the cause of lower-extremity injuries in more than half of the cases he reviewed. Nash (Australia) (5) found that 47% of 114 car occupants admitted to the hospital had some leg injury; the severity of these injuries was not reported.

Melvin et al. (6) presented lower-extremity injury information by a review of multidisciplinary accident investigations involving passenger cars in frontal crashes, with unrestrained passengers 12 years of age or older. They found a relatively low occurrence of lower-extremity injuries in their study.

In a study of 74 accidents, Nagel and States (7) found 57 of the 153 people injured had 80 knee injuries, with 69 of these injuries resulting from impact with the dashboard. Of these, 51 had "mild injuries," 10 had moderate injuries (laceration or simple patellar fracture), and 8 had severe injuries (laceration or fracture into the joint or tearing of the knee ligaments). The authors concluded that degenerative arthritis will develop in the more seriously injured knees.

Goegler (8), in an extensive study of road casualties treated at the Heidelberg Clinic (Germany, 1952-1958), found 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.

Fatal extremity injuries rarely occur. Crash injury data hardly ever indicate deaths directly attributed to the extremities. Nagel et al. (9) did not find any lower-extremity fatalities in their series of crashes, nor did the German Motor Traffic Insurers study of 28,936 crashes, nor Danner (10) or Rubinstein (11). Huelke et al. (12) did not find any lower limb fatalities in their extensive review of frontal and rollover crashes. Nahum at al. (3) found only two lower-extremity fatalities in their review of 290 crashes. Perry and McClennen (13) found two lower-extremity fatalities in their autopsy series. Hight et al. (14) found only two limb fatalities in 225 rollover occupants. Even when pedestrians are included, the relative infrequency of lower extremity fatalities was noted by Giraldo (Columbia, South America) (15). In this study of 135 fatalities he listed only one fatality due to fat embolism following multiple lower-extremity fractures.

States and States (16) reviewed 78 occupants who were injured in lateral impact accidents. In these cases there were 27 injuries to the pelvis and lower extremities; it is not indicated whether some of these individuals had more than one injury. The 11 pelvic injuries were ascribed to the front door or arm rest, with the majority of the lower extremity injuries from the same part of the car. The injury severity level was not indicated.

The existing literature is not very satisfying in establishing the relative frequency of occurrence of the more severe lower-extremity injuries, nor in the severity and distribution of these injuries within the lower limb. The German Motorists Insurance report suggests that lower-extremity injuries are quite infrequent, but Kihlberg, on the other hand, found lower limb injuries in 50% of the injured occupants. Up to the present time reliable statistics on the frequency of this injury type necessary for design and regulation have not been available.

## III. SOURCES OF INFORMATION

The detailed accident and injury data collected in the NCSS program has resulted from investigations conducted by professional teams operating in eight regions of the United States. During the period January 1, 1977 through March 31, 1978, 6,628 accidents were investigated and computerized. In these accidents there were 8,616 towed 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. The injury distributions for those persons not fully reported are probably not the same as for the known data. In part this arises because injury detail was not available for approximately 40% of the fatalities (no autopsy or medical examiner report). At the other end of the scale, injury information was frequently missing for persons with very minor injuries, because they could not be contacted or because no medical source was available. Consequently, we might expect the 4,340 persons without medical data to be somewhat less likely to have moderate and severe injuries, and more likely to have serious/fatal injuries or minor/none. The possible effects of such bias will be discussed later in addressing a national projection of lower limb injuries.

Accidents investigated in the NCSS program were sampled at various rates depending on an injury severity measure. Crashes in which some car occupant was hospitalized at least overnight were sampled at 100%; crashes in which the most severely injured car occupant was taken to a hospital but released that day were sampled at 25%; and the remainder of the crashes were sampled at 10%. In some applications of the NCSS data, estimates of the true frequency of some event in the accident population are made by weighting the observed data by the inverse of the sampling fraction. In limiting this study to lower-extremity injuries of the more severe type (AIS-3, 4) the population studied lies almost completely within the 100% sample, and thus weighting to estimate the total frequency of such injuries is unnecessary among the 371 persons with AIS-3+ lower-extremity injuries. There are five exceptions to this rule--two persons with fractured ankles, two with fractured legs, and one with a fractured knee evidently were in the "treated and released" category.

Keeping in mind that the more severe injuries are nearly all in the 100% sample, it is appropriate to compare the relative frequency of the observed injuries across the major body regions. Figure 1 shows that the most frequent body region injured at this level is the chest, with about 32% of all such injuries. Second in prominance is the lower extremity, with 23% of the injuries at the AIS 3 or 4 level.

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.

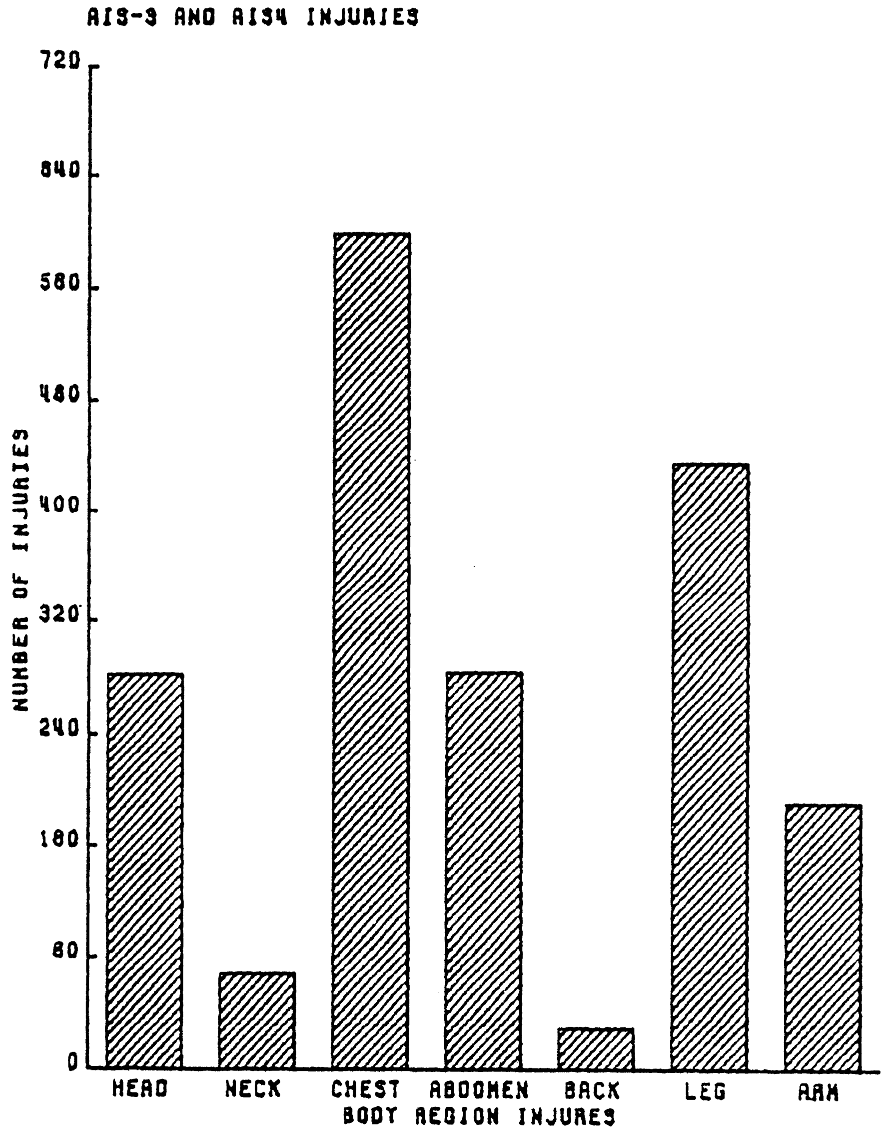


FIGURE 1

Distribution of AIS-3 and -4 Injuries by Major Body Region

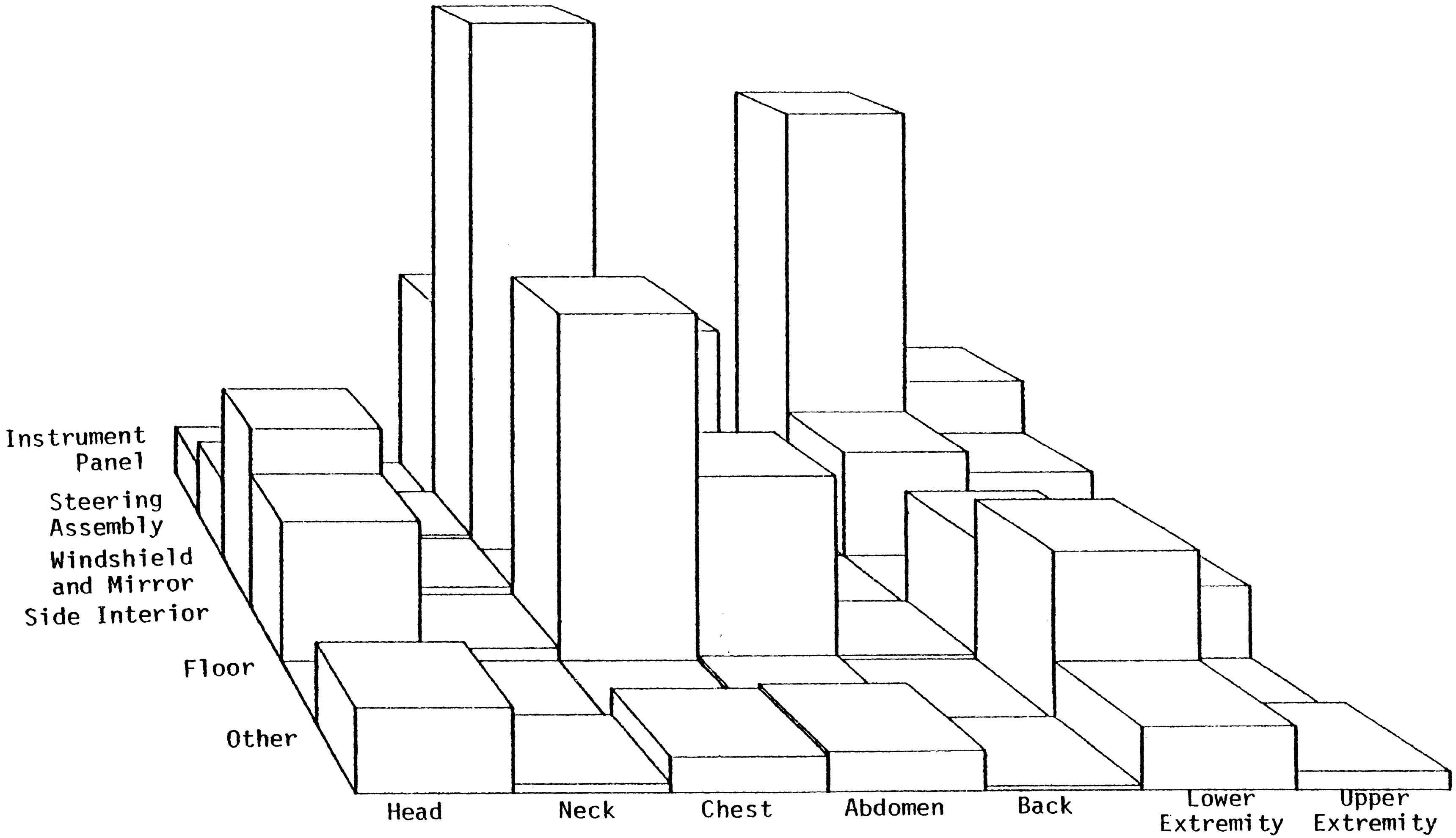


FIGURE 2

AIS-3 and -4 Injuries by Body Region and Contact

# IV. INJURY TYPES, LIMB AREAS AND CONTACTS

## A. POTENTIAL CONTACT AREAS

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. In the tables following, only these major groups will be displayed, although individual contacts 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 level, foot controls, and console.

Steering Assembly--The steering wheel, the steering column, and a column mounted transmission lever.

Side Interior--The door or side interior, 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 ground, trees, poles and pillars, etc., another vehicle, and hood.

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

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

Unknown--Contact areas that are not specified in the data.

## B. LOWER LIMB ANATOMICAL SUBDIVISIONS

The lower-extremity has been divided into five anatomical regions--the pelvis, thigh, knee, leg, and the ankle/foot (Figures 3 and 4).

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, including the femur and the overlying muscles and associated neurovascular structures.

Knee--The knee consists of the lower articular surfaces of the femur and associated articular area of the tibia, the patella, and overlying tissue.

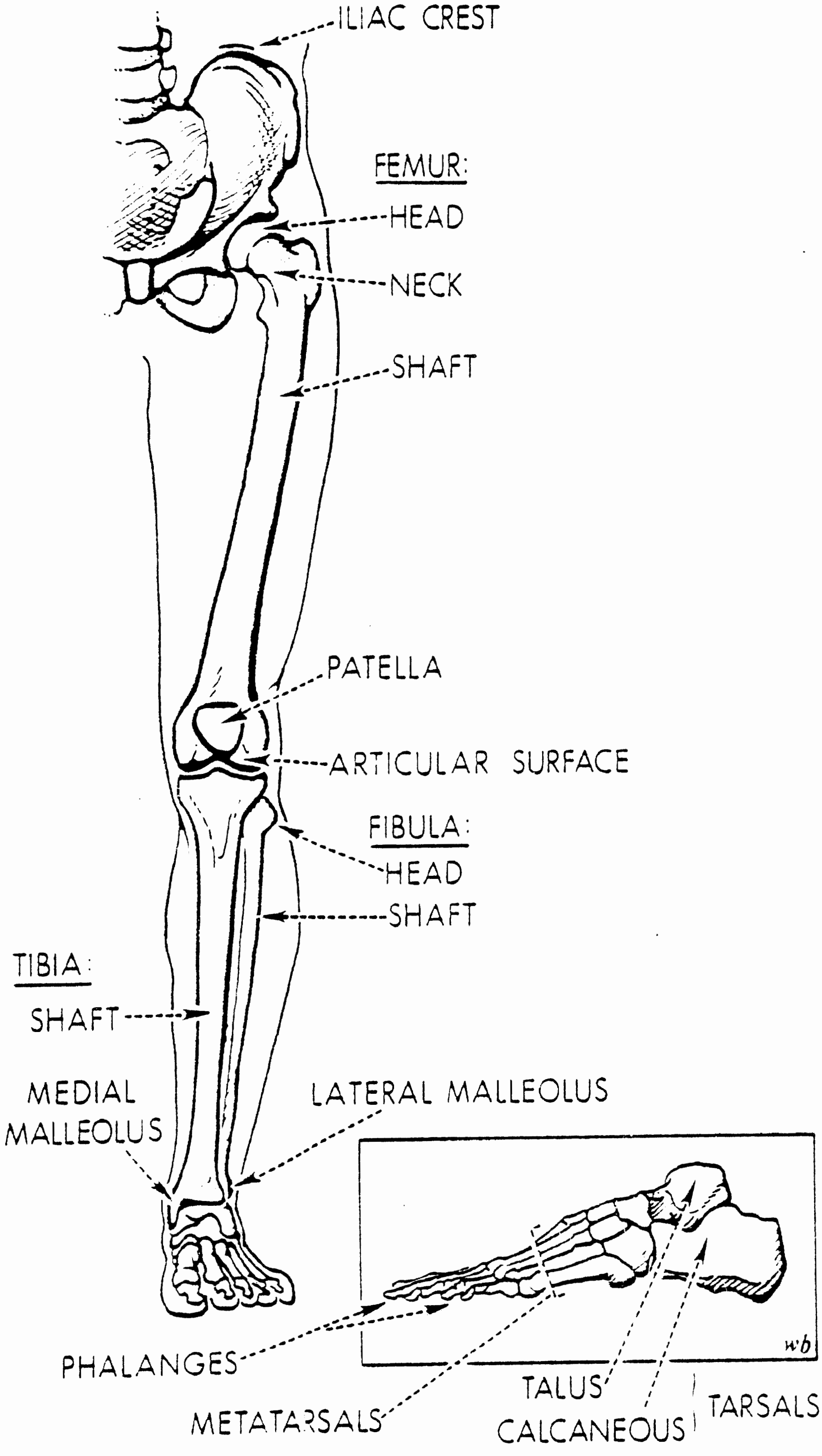


FIGURE 3

Skeletal Anatomy of the Lower Extremity

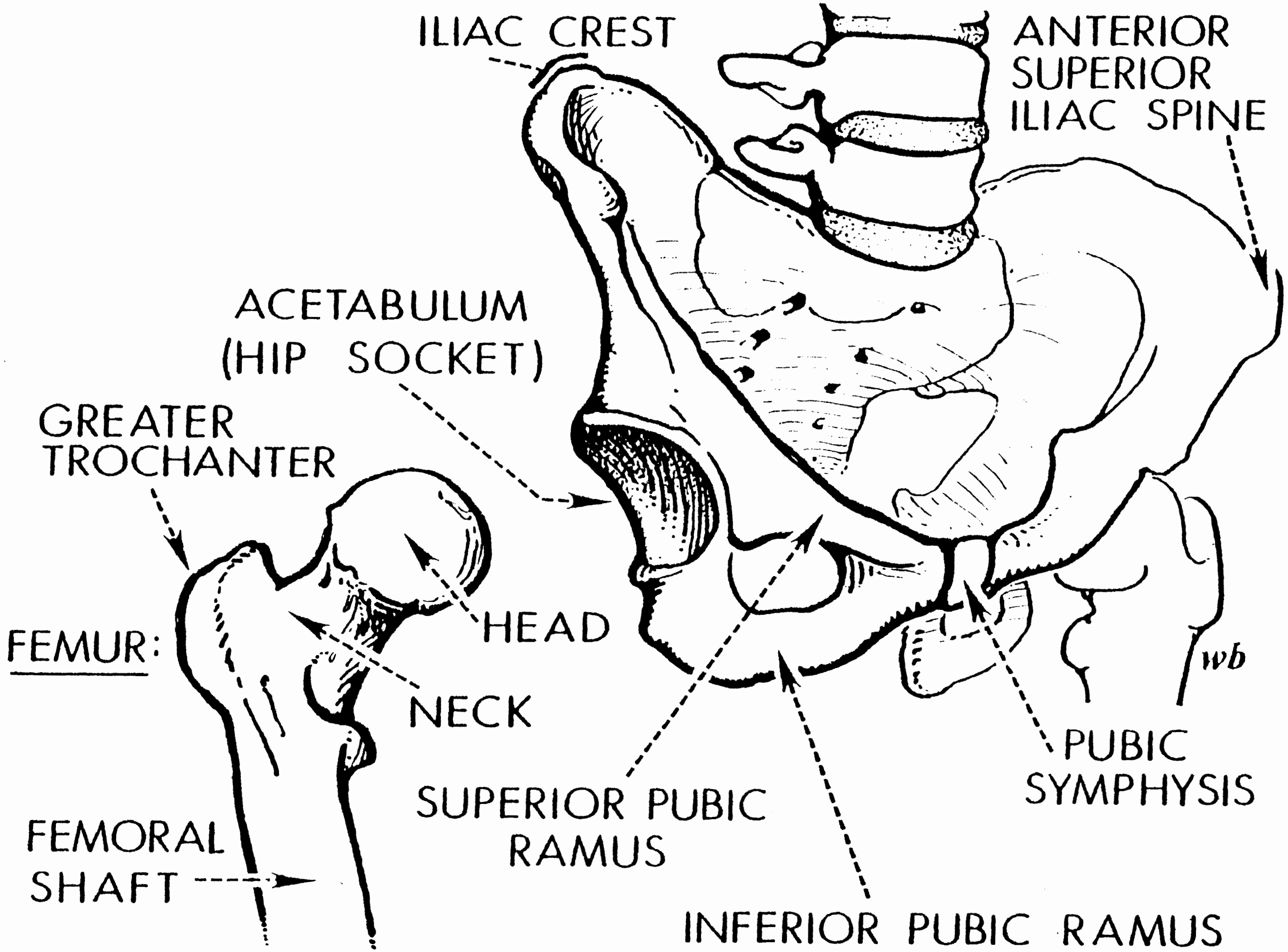


FIGURE 4

Details of Pelvic-Hip Anatomy

Leg--The leg extends from the knee region to the ankle but does not include the ankle joint. In the leg are the two bones, the tibia and fibula, the associated muscles, blood vessels, and nerves.

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

C. INJURY CLASSIFICATIONS

The Abbreviated Injury Scale (AIS) is used in the NCSS file to appropriately categorize the severity of injury.[1]

The following is a list of diagnoses of the more severe (AIS-3,4) lower-extremity injuries:

Pelvis--Dislocation and fracture - dislocation of the hip; displaced or multiple fractures of the pelvis (Pubic rami, acetabulum, iliac wings and crest, sacrum, coccyx); symphysis pubis separation.

Thigh--Fractures of the femur (surgical neck, greater and lesser trochanters, intertrochanteric fractures, shaft, supracondlar fractures).

Knee--Dislocation of the knee, dislocation of the patella; patellar fractures with separation, fractures of the femoral condyles, or of the tibial plateau.

Leg--Fractures of the tibia or fibula shaft (compound, comminuted or or displaced).

Ankle/Foot--Fractures of the ankle with displacement (medial or lateral milleolus, posterior lip of the tibia); dislocations, fracture-dislocations; displaced fractures of the tarsals and metarsals, with or without dislocations.

General--Arterial injuries of the femoral, popleteal, and tibial arteries; peripheral nerve injuries (sciatic nerve, tibial and peroneal nerves with muscle paralysis and/or sensory loss); ligamentous tears of the knee joint (medial or lateral collateral ligaments, anterior or posterior cruciate ligaments, menisci).

The moderate level (AIS-2) lower-extremity fractures are similar to the above injuries. Other moderate injuries include sprains of major joints, extensive soft tissue lacerations, and unilateral fractures of

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[1]The Abbreviated Injury Scale: 0=No Injury, 1=Minor, 2=Moderate, 3=Severe, 4=Serious, 5=Critical to Life, 6=Currently Unsurvivable.

the pelvis. This paper addresses primarily the most severe injuries. A brief discussion of the moderate lower-extremity injuries is found in Section V-E.

# V. DATA ANALYSIS

## A. OVERVIEW

In the NCSS File there were 14,491 occupants of cars in towaway crashes. Medical data were available on 10,151. Of these, 1,353 occupants had injuries at the moderate or greater level (AIS-3+) with 371 having lower-extremity injuries of the more severe nature (AIS-3,4).

The distribution of these more serious lower-extremity injuries are broken down into those who were contained (not ejected) and unrestrained, those who were contained and were wearing restraint systems, the ejected group, and those for whom it was not determined whether they were ejected and/or whether they were wearing restraint systems (Figure 5). The eight occupants who were wearing some sort of restraint system are discussed individually in Section V-F.

Of the 371 occupants with the more severe lower-extremity injuries, 222 (60%) had the lower-extremity as the most severely injured body area. Of the 371, 51 died. There were 411 individuals with moderate (AIS-2) level lower-extremity injuries and 50% of these occupants had the lower-extremity as the most severely injured body region. Additionally, 19% had the moderate lower-extremity injuries at least equal in severity to those injuries in other body regions. Thus, the lower-extremity does have a significant frequency of the more serious injuries, is not an infrequent body area involved, and often is the most severely injured body region.

Most of the more severe lower-extremity injuries occur in frontal type crashes (Table 1). Frontal crashes account for 71% of the more severe lower-extremity injuries, whereas for AIS 3+ injuries to all occupants, frontal crash involvement is only 57%.

The following tables and discussions concern the injuries and contact areas of only the unrestrained car occupants.

## B. CONTACT AREAS AND SEAT POSITIONS

### Contact Areas

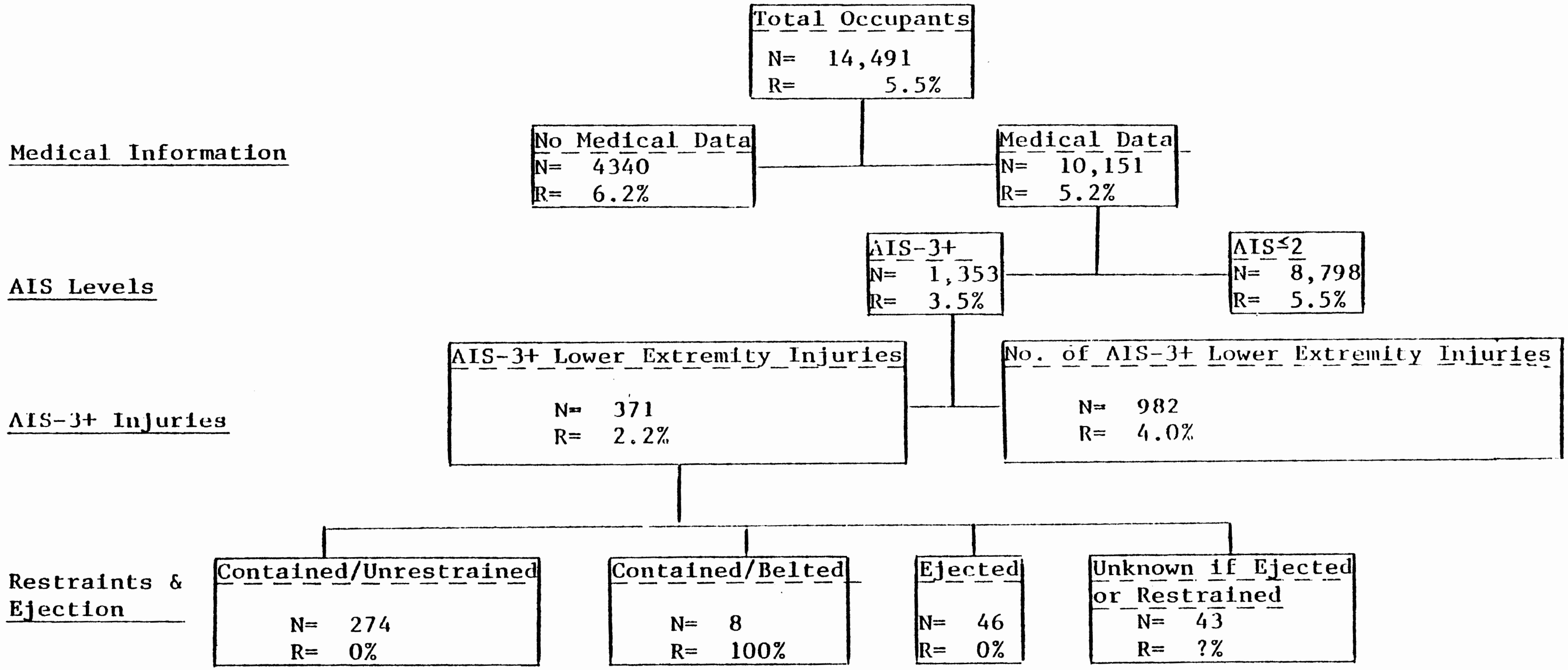


FIGURE 5

Subsets of the NCSS Occupants for Analysis

TABLE 1
CRASH EXPERIENCE INVOLVING UNRESTRAINED, CONTAINED OCCUPANTS

| Type of Crash | All (%) | Those with the More Severe Injuries (%) | Those with the More Severe Lower Extremity Injuries (%) |
|---|---|---|---|
| Frontal | 51 | 57 | 71 |
| Side | 18 | 22 | 11 |
| Rear | 4 | 1 | -- |
| Rollover | 5 | 6 | 5 |
| Other | 9 | 6 | 5 |
| Unknown | 13 | 8 | 8 |
| Total | 100% | 100% | 100% |

Even with the detailed medical descriptions in the NCSS file, 12% of the more serious lower extremity injuries did not have a specific component listed as the contact related to these injuries.

Of all the more serious lower extremity injuries of unrestrained car occupants, 44% of the known contacts are related 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.

Interior car components immediately in front of the occupants predominate as a lower extremity contact area. Approximately 3/4ths of the more serious lower extremity injuries are due to contacts with the instrument panel, floor, and steering assembly.

Seated Positions

Drivers. Unrestrained car drivers have a lower frequency of the more serious lower limb injuries than the average of all occupants. Of

TABLE 2
NUMBER OF LOWER EXTREMITY INJURIES AT THE AIS 3,4 LEVELS
ALL UNRESTRAINED CAR OCCUPANTS
(by Seat Location and Impact Areas)

| Contact Areas | Drivers | Front Right Occupants | Other Front Occupants | Rear Occupants | Unknown | Total |
|---|---|---|---|---|---|---|
| Instrument panel | 94 | 57 | 11 | - | - | 162 |
| Floor | 39 | 21 | 3 | - | - | 63 |
| Steering Assembly | 44 | - | - | - | - | 44 |
| Side Interior | 28 | 17 | - | 7 | - | 52 |
| Front Seat Back | - | - | - | 18 | - | 18 |
| Exterior | 8 | 3 | - | 1 | - | 12 |
| Miscellaneous | 12 | 3 | 1 | 3 | - | 19 |
| Unknown | 17 | 14 | 4 | 13 | 1 | 49 |
| Total | 242 | 115 | 19 | 42 | 1 | 419 |

the 419 more severe lower-extremity injuries, 58% were sustained by car 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 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 from instrument panel impacts most often (73%).

Rear Occupants. Rear seat occupants account for 10% of the serious lower-extremity injuries, and are 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.

C. LOWER EXTREMITY AREAS INJURED AND CONTACTS

1. All Unrestrained Occupants

The distribution of the more severe injuries in the lower-extremity subregions is shown in Figure 6. About 20-25% of the AIS-3,4 lower extremity injuries are in the pelvis/hip, thigh, or leg regions. Less often the knee (12%) or ankle/foot areas (17%) are involved.

About 4% of the more severe lower-extremity injuries in the NCSS file were non-specific as to location of the injuries, but the contact areas were known--thus the general category of "lower-extremity" is included in most of the tables. Fractures of the pelvic predominate, closely followed by the more serious injuries of the thigh and leg (Table 3).

Pelvic Injuries--The side interior was listed as the contact area more often (28%) than the instrument panel (23%) or the steering assembly (24%). Other items were less often related to pelvic injuries.

Thigh Injuries--Structures forward of the occupants (instrument panel, steering assembly) are most often related to thigh injuries, with the instrument panel predominating (54%). About 12% of thigh injuries are from impacts to the side interior of the car.

Knee Injuries--Eight of ten knee injuries are due to instrument panel contacts. All other contact areas occur with much less frequency.

Leg Injuries--Of the more serious injuries 62% are due to instrument panel impacts. All other contact areas occur with much less frequency.

Ankle/Foot Injuries--The more severe ankle/foot injuries primarily occur from contact with the floor and the foot controls (75%). Other contacts are very less frequent in occurrence.

The numbers shown in Table 3 in parentheses are the injuries to ejected occupants; these injuries are also included in the larger adjacent numbers. In general, ejected occupants proportionately contact the same areas for the thigh, knee, leg, and ankle/foot. 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 ejected lower-extremity injuries, 18 (or 32%) were in the pelvic area, whereas for those contained in the vehicle who were unrestrained, only 19% sustained pelvic injuries. The specific contacts of these ejected pelvic injuries are often reported as "unknown."

2. Drivers

Drivers sustain the more serious injuries to the pelvis more frequently than to any other region of the lower-extremity (Table 4). These injuries are to the hip joint, side of the pelvis (iliac wing area), or the pubic rami. Most often these injuries are due to the steering assembly or to side interior impacts.

The thigh and knee are also involved frequently in instrument panel impacts due to direct force application to the knee. Likewise the

TABLE 3
LOWER EXTREMITY INJURIES - AIS 3,4*
ALL UNRESTRAINED OCCUPANTS (Anatomical Regions and Impact Areas)

| Contact Area | Pelvis | Thigh | Knee | Leg | Ankle Foot | Lower Ext.** | 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(22) |
| Total | 102(8) | 94(14) | 47(4) | 90(11) | 68(7) | 18(2) | 419(56) |

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.
**Injuries of AIS-3 or 4, not specified as to which subregion(s) of the limb was involved.

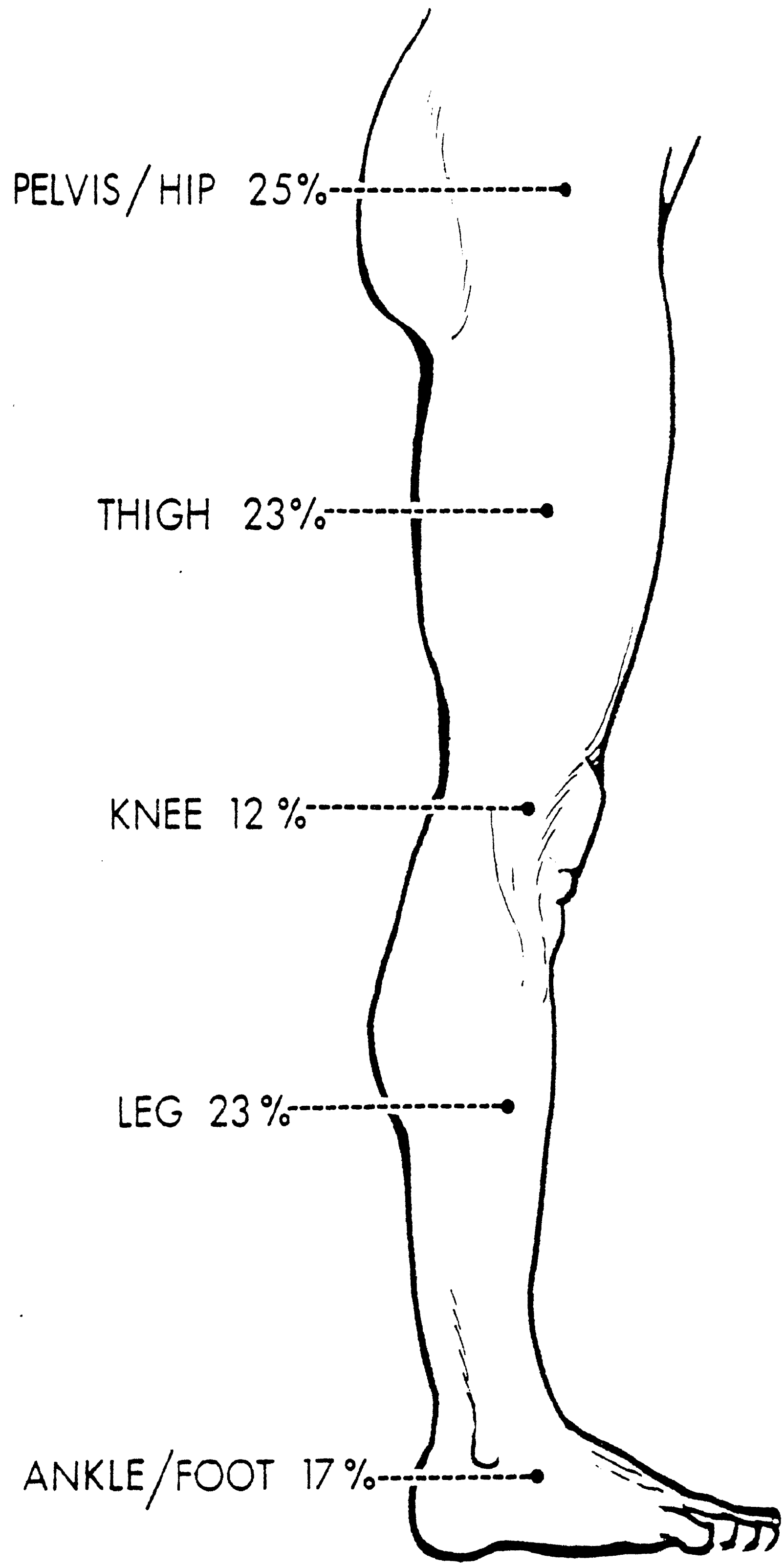


FIGURE 6

Distribution of AIS-3 and -4 Injuries Within the Lower Extremity

TABLE 4
LOWER EXTREMITY INJURIES - AIS 3,4*
UNRESTRAINED DRIVERS

| Contact Area | Pelvis | Thigh | Knee | Leg | Ankle/ Foot | Lower Ext. | Total |
|---|---|---|---|---|---|---|---|
| Instrument Panel | 8 | 20 | 30 | 32 | - | 4 | 94 |
| Floor | 0 | 2 | - | 4 | 32 | 1 | 39 |
| Steering Assembly | 24 | 14 | 4 | 1 | - | 1 | 44 |
| Side Interior | 16 | 4 | 1 | 4 | 2 | 1 | 28 |
| Front Seat Back | - | - | - | - | - | - | - |
| Exterior | - | 1 | - | 3 | 1 | 1 | 6 |
| Miscellaneous | 3 | 2 | - | 5 | 2 | - | 12 |
| Unknown | 9 | 1 | 3 | 3 | 2 | 1 | 19 |
| Total | 60 | 44 | 38 | 52 | 39 | 9 | 242 |

*See footnotes Table 1

steering assembly, primarily the steering column, can be the cause of thigh or knee injuries of the more severe nature.

As noted in Table 4, instrument panel impacts predominate among leg fractures. Again, direct force transmission of the unrestrained occupant on the instrument panel is the primary cause. Almost always the floor (including the foot controls, floorpan, etc.) is the cause of ankle/foot fractures.

3. Front Right Occupants

The front right occupants sustain pelvic injuries most often from the instrument panel or from the side interior (Table 5). Thigh injuries most often are sustained from instrument panel contacts. Surprisingly, few knee injuries are sustained by right front occupants. When knee injuries do occur, they more often are due to contacts with the instrument panel. The leg area injuries not involving the knee more often occurs due to direct leg contacts with the instrument panel. Ankle/foot injuries are more often due to contact with the floor.

4. "Other" Front Seat Occupants

There were relatively few occupants who were in the front seat position other than the driver or the right front passenger (Table 6). As previously stated, these occupants are usually seated in the front center position, but occasionally on the lap of the front passenger, or lying down. Because of the low numbers of the "other" front seat occupants no comments are offered on their injuries or injury contacts.

5. Rear Seat Occupants

Pelvic, thigh, and leg injuries occur with equal frequency to occupants of the rear seat (Table 7). Two-thirds of the known thigh and leg injuries are sustained from contacts on the front seat back. The side interior is also a contact noted for rear occupants, more often related to pelvic and thigh injuries. For the rear seat occupants, the front seat back is a similar position as is the instrument panel for the front seat occupants. It is not surprising that the front seat back is a significant contact area for the unrestrained rear seat occupant. Knee injuries for rear seat occupants are almost non-existent.

TABLE 5
LOWER EXTREMITY INJURIES - AIS 3,4*
UNRESTRAINED FRONT RIGHT OCCUPANTS

| Contact Area | Pelvis | Thigh | Knee | Leg | Ankle Foot | Lower Ext. | Total |
|---|---|---|---|---|---|---|---|
| Instrument Panel | 12 | 19 | 5 | 16 | 1 | 4 | 57 |
| Floor | 1 | 1 | - | 2 | 16 | 1 | 21 |
| Steering Assembly | - | - | - | - | - | - | 0 |
| Side Interior | 10 | 4 | - | 2 | 1 | - | 17 |
| Front Seat Back | - | - | - | - | - | - | 0 |
| Exterior | - | - | - | 1 | 1 | - | 2 |
| Miscellaneous | 1 | - | 1 | - | 1 | - | 3 |
| Unknown | 3 | 4 | 2 | 2 | 2 | 2 | 15 |
| Total | 27 | 28 | 8 | 23 | 22 | 7 | 115 |

*See footnotes, Table 1

TABLE 6
LOWER EXTREMITY INJURIES - AIS 3,4*
UNRESTRAINED OTHER FRONT SEAT OCCUPANTS**

| Contact Area | Pelvis | Thigh | Knee | Leg | Ankle Foot | Lower Ext. | Total |
|---|---|---|---|---|---|---|---|
| Instrument Panel | 3 | 6 | - | 2 | - | - | 11 |
| Floor | - | - | - | - | 3 | - | 3 |
| Steering Assembly | - | - | - | - | - | - | 0 |
| Side Interior | - | - | - | - | - | - | 0 |
| Front Seat Back | - | - | - | - | - | - | 0 |
| Exterior | - | - | - | - | - | - | 0 |
| Miscellaneous | - | 1 | - | - | - | - | 1 |
| Unknown | - | 3 | - | 1 | - | - | 4 |
| Total | 3 | 10 | 0 | 3 | 3 | 0 | 19 |

*See footnotes, Table 1
**Occupants in the front seat, NOT in the front outboard positions (front center, on lap, lying down, etc.).

TABLE 7
LOWER EXTREMITY INJURIES - AIS 3,4*
UNRESTRAINED REAR SEAT OCCUPANTS**

| Contact Area | Pelvis | Thigh | Knee | Leg | Ankle Foot | Lower Ext. | Total |
|---|---|---|---|---|---|---|---|
| Instrument Panel | - | - | - | - | - | - | 0 |
| Floor | - | - | - | - | - | - | 0 |
| Steering Assembly | - | - | - | - | - | - | 0 |
| Side Interior | 3 | 2 | 1 | 1 | - | - | 7 |
| Front Seat Back | 3 | 6 | - | 7 | 2 | - | 18 |
| Exterior | - | 1 | - | - | - | - | 1 |
| Miscellaneous | 1 | - | - | 1 | - | 1 | 3 |
| Unknown | 4 | 3 | - | 3 | 2 | 1 | 13 |
| Total | 11 | 12 | 1 | 12 | 4 | 2 | 42 |

*See footnotes, Table 1
**All rear seating locations, any occupant position

## D. LOWER EXTREMITY INJURED AREAS, CONTACT AREAS AND SEAT POSITION

### 1. Pelvic Injuries

Pelvic injuries for all occupants are more often sustained by contact with the side interior (Table 8). Pelvic injuries are the only injuries with a substantial proportion occurring by contact with the side interior. The injuries to all other limb areas most frequently involve contacts in front of the occupants. Less often the steering assembly and instrument panel are also contacts for pelvic injuries. Of drivers, however, there is a greater number 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 from the front seat back as often as from the side interior.

### 2. Thigh Injuries

Thigh injuries constitute one out of five of the more severe lower extremity injuries (Table 9). Approximately half of these thigh injuries are to drivers, with the majority of them resulting from contact with the instrument panel or the steering assembly.

Front right occupants sustained most of their more severe thigh injuries from contact with the instrument panel.

### 3. Knee Injuries

Injuries to the knee area , including the patella, distal femur, or proximal articular surface of the tibia, with deep lacerations extending into the knee joint or knee ligament disruptions are less frequent in occurrence (12% of all severe and greater lower-extremity injuries). The majority of these injuries are sustained by drivers, with the instrument panel predominating as the primary contact area (Table 10).

### 4. Leg Injuries

Approximately half of the injuries to the leg occur from instrument panel contact (Table 11). No other contact area comes close in frequency of occurrence in relation to the more severe injuries.

TABLE 8
PELVIC INJURIES - AIS 3,4

| Contact Area | Drivers | Front Right Occupants | Other Front Occupants | Rear Occupants | Unknown | Total |
|---|---|---|---|---|---|---|
| Instrument Panel | 8 | 12 | 3 | - | - | 23 |
| Floor | - | 1 | - | - | - | 1 |
| Steering Assembly | 24 | - | - | - | - | 24 |
| Side Interior | 16 | 10 | - | 3 | - | 29 |
| Front Seat Back | - | - | - | 3 | - | 3 |
| Exterior | - | - | - | - | - | 0 |
| Miscellaneous | 3 | 1 | - | 1 | - | 5 |
| Unknown | 9 | 3 | - | 4 | 1 | 17 |
| Total | 60 | 27 | 3 | 11 | 1 | 102 |

TABLE 9
THIGH INJURIES - AIS 3,4

| Contact Area | Drivers | Front Right Occupants | Other Front Occupants | Rear Occupants | Total |
|---|---|---|---|---|---|
| Instrument Panel | 20 | 19 | 6 | - | 45 |
| Floor | 2 | 1 | - | - | 3 |
| Steering Assembly | 14 | - | - | - | 14 |
| Side Interior | 4 | 4 | - | 2 | 10 |
| Front Seat Back | - | - | - | 6 | 6 |
| Exterior | 1 | - | 1 | 1 | 2 |
| Miscellaneous | 2 | - | - | - | 3 |
| Unknown | 1 | 4 | 3 | 3 | 11 |
| Total | 44 | 28 | 10 | 12 | 94 |

TABLE 10
KNEE INJURIES - AIS 3,4

| Contact Area | Drivers | Front Right Occupants | Other Front Occupants | Rear Occupants | Total |
|---|---|---|---|---|---|
| Instrument Panel | 30 | 5 | - | - | 35 |
| Floor | - | - | - | - | 0 |
| Under Panel | - | - | - | - | 0 |
| Steering Assembly | 4 | - | - | - | 4 |
| Side Interior | 1 | - | - | 1 | 2 |
| Front Seat Back | - | - | - | - | 0 |
| Exterior | - | - | - | - | 0 |
| Miscellaneous | - | 1 | - | - | 1 |
| Unknown | 3 | 2 | - | - | 5 |
| Total | 38 | 8 | 0 | 1 | 47 |

TABLE 11
LEG INJURIES - AIS 3,4

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

5. Ankle/Foot Injuries

About 80% of the injuries to the ankle and foot are caused by the floor and associated items (Table 12). This is primarily a problem for drivers and the front right occupants.

The more severe lower extremity injuries of the 10,151 occupants with medical data is relatively infrequent. Pelvic injuries occurred in 1%, slightly more often than the more serious thigh or leg injuries (0.9% each). Ankle/foot injuries (0.7%) are about as infrequent as the more serious knee injuries (0.5%). Only 0.2% of the known injuries were to the "non-specified areas of the lower extremities. The distribution of these injuries probably follows a similar pattern as for the known areas of lower extremity injuries.

6. "Non-Specified" Lower Extremity Injuries

There were only 18 non-specified lower extremity injuries of the more severe nature (of the total of 419) (Table 13). Of these, the instrument panel or floor predominates in terms of occupant contact as related to the lower extremity injury.

E. MODERATE LEVEL (AIS 2) INJURIES

This paper has addressed the more severe lower extremity injuries--those coded at AIS levels 3 and 4, and thus those most likely to lead to long term disability or permanent impairment.

Although not reported in detail here, there is in the NCSS population a number of moderate (AIS 2) level lower extremity injuries. The anatomical distribution of these moderate injuries and the associated contact areas are shown in Table 14, the count being of actual injuries.

The frequency distribution of contacts with the various potential areas related to the moderate lower extremity injuries is similar to that in the more severe group (compare Table 14 with Table 3).

The instrument panel is by far, the leading cause of these moderate level injuries followed by the floor contacts and the side interior. The steering assembly ranks fourth but is less frequently contacted than

TABLE 12
ANKLE/FOOT INJURIES - AIS 3,4

| Contact Area | Drivers | Front Right Occupants | Other Front Occupants | Rear Occupants | Total |
|---|---|---|---|---|---|
| Instrument Panel | - | 1 | - | - | 1 |
| Floor | 32 | 16 | 3 | - | 51 |
| Under Panel | - | - | - | - | 0 |
| Steering Assembly | - | - | - | - | 0 |
| Side Interior | 2 | 1 | - | - | 3 |
| Front Seat Back | - | - | - | 2 | 2 |
| Exterior | 1 | 1 | - | - | 2 |
| Miscellaneous | 2 | 1 | - | - | 3 |
| Unknown | 2 | 2 | - | 2 | 6 |
| Total | 39 | 22 | 3 | 4 | 68 |

TABLE 13
"NON SPECIFIED" LOWER EXTREMITY INJURIES - AIS 3,4

| Contact Area | Drivers | Front Right Occupants | Other Front Occupants | Rear Occupants | Total |
|---|---|---|---|---|---|
| Instrument Panel | 4 | 4 | - | - | 8 |
| Floor | 1 | 1 | - | - | 2 |
| Steering Assembly | 1 | - | - | - | 1 |
| Side Interior | 1 | - | - | - | 1 |
| Front Seat Back | - | - | - | - | 0 |
| Exterior | 2 | - | - | - | 2 |
| Miscellaneous | - | - | - | 1 | 1 |
| Unknown | - | 2 | - | 1 | 3 |
| Total | 9 | 7 | 0 | 2 | 18 |

TABLE 14
LOWER EXTREMITY INJURIES - AIS 2*

| Contacts | Pelvis | Thigh | Knee | Leg | Ankle/ Foot | Total |
|---|---|---|---|---|---|---|
| Instrument Panel | 6 | 26 | 44 | 22 | 6 | 104 |
| Floor | 1 | 3 | - | 6 | 75 | 85 |
| Side Interior | 25 | 10 | 3 | 8 | 2 | 48 |
| Steering Assembly | 12 | 4 | 7 | - | 1 | 24 |
| Front Seat Back | - | 4 | - | 3 | 3 | 10 |
| Miscellaneous | 2 | - | 1 | 2 | 2 | 7 |
| Exterior Object | 1 | - | 1 | 3 | - | 5 |
| Unknown | 31 | 14 | 6 | 21 | 30 | 102 |
| Total | 78 | 61 | 62 | 65 | 119 | 385 |

*The data in this table are from the period July 1977 through March 1978.

Fractures are the most frequent injury type; less frequently about one sixth as often, are sprains or lacerations. The ankle/foot area is more often involved with moderate- level injuries, with two-thirds of these injuries being fractures (Table 15). The pelvic area is next in occurrence, with fractures predominating.

## F. RESTRAINT SYSTEM USAGE AND EFFECTIVENESS

### 1. Overview

Severe lower-extremity injuries to belted individuals are relatively rare. But in the NCSS sample, reported belt usage by any occupant is also infrequent. Only eight persons who sustained a lower extremity injury of AIS-3 or AIS-4 were reported to be belted (2.2% of 371 persons). For all other persons with at least an AIS-3 injury, belts were worn by 41 of 1163 persons, or 3.7%. While this is at least an indication that belts have been useful in minimizing lower-extremity injuries, the number of belted persons is so low that this finding is not very significant statistically. In addition, there are other differences between the compared groups which may interact with such a finding, but the data are really too sparse to do further testing of these.

The eight cases of severe and greater lower-extremity injuries when restraints were worn are detailed in this section. Seven of the eight are over forty years of age. But a true measure of the effectiveness of belts in preventing leg injuries will have to await a larger sample, or a sample with substantially higher belt-usage rates, so that such interactions can be studied.

### 2. Lap and/or Shoulder Belted AIS-3,4 Lower Extremity Cases

The following is a description of the eight cases of occupants wearing lap-shoulder belts who sustained the more serious lower extremity injuries:

Case No. 1. A 1977 intermediate-size Chevrolet was struck by a full-sized car in the right front area (2 o'clock). The lap-shoulder belted front right female passenger (51 years old) sustained critical abdominal injuries (side armrest), severe pelvic fracture (side interior), severe

TABLE 15
LOWER EXTREMITY INJURIES - AIS 2*

| Injuries | Pelvis | Thigh | Knee | Leg | Ankle/ Foot | Total |
|---|---|---|---|---|---|---|
| Fracture | 109 | 72 | 37 | 66 | 96 | 380 |
| Sprain | 2 | - | 13 | - | 53 | 68 |
| Laceration | 2 | 9 | 37 | 13 | 4 | 65 |
| Contusion | - | 2 | 3 | 5 | 1 | 11 |
| Avulsion | 1 | - | 3 | 4 | - | 8 |
| Abrasion | 1 | - | - | 1 | 1 | 3 |
| Dislocation | - | - | - | - | 3 | 3 |
| Other | - | - | 1 | - | 1 | 2 |
| Unknown | - | 1 | - | - | - | 1 |
| Total | 115 | 84 | 94 | 89 | 159 | 541 |

*More than one type of moderate injury occurred in the lower-extremity of some occupants (541 injuries/385 occupants).

chest injuries (instrument panel), and moderate arm lacerations (A-pillar). [Delta V = 12 mph; CDC = 02RFEW03]

Case No. 2. A 1977 Chevrolet compact car driven by a lap-belted 45-year old male, was struck by a truck in the front (12 o'clock). He sustained a severe right leg fracture (instrument panel) and minor facial lacerations (windshield).[Delta V = 21 mph; CDC =12FZEW3]

Case No. 3. A 1977 Oldsmobile intermediate size car was struck on the front left side (10 o'clock). The 43-year old female lap-shoulder belted driver sustained severe pelvic fractures (side interior), minor facial and neck lacerations (window glass), and a minor left elbow contusion (side interior).[Delta V = 17 mph; CDC = 10LYEW4]

Case No. 4. A 1971 Chevrolet subcompact was struck in the front left by a subcompact car (11 o'clock). The lap-belted 68-year old male driver sustained a severe right ankle/foot fracture (floor), a severe left arm fracture and a moderate fracture of the face (windshield).[Delta V = 39 mph; CDC = 11FYAW9]

Case No. 5. A 1972 full-sized Chevrolet was struck in the front left area by a tractor-trailer (11 o'clock). Damage extent was extreme. The lap-shoulder belted 63 year old female had severe fractures of the leg (A-pillar) The cause of death was not reported.[Delta V = Unknown; CDC = 11FLAE9]

Case No. 6. A 1973 Chevrolet subcompact was struck in the front (12 o'clock) by a full-sized car. The lap-belted 16 year old male driver had a severe right knee fracture (instrument panel), and minor facial lacerations and pain in the right shoulder (steering assembly).[Delta V = 16 mph; CDC = 12FDEW3]

Case No. 7. A 1972 full-sized Ford was struck by a compact car in the front (01 o'clock). The lap-belted 48 year old male driver sustained a severe pelvic fracture and minor abdominal abrasions (Steering Assembly).[Delta V = 24 mph; CDC = 01FZEW3]

Case No. 8. A 1976 Datsun was struck in the left side (7 o'clock) by an intermediate-sized car. The 72 year old lap-shoulder belted male driver had a severe pelvic fracture, a minor left wrist/hand laceration (window glass), and minor back pain.[Delta V = Unknown; CDC = 07LPEW4]

## 3. Literature Review

Lap-shoulder belts have been reported to be effective in reducing lower-extremity injuries. In a study of 108 lap-shoulder belted car occupants with injuries in various crash types, MacKay et al. (England) (17) found 21 pelvic injuries (7 at the AIS-3 level), 66 lower-extremity injuries (7 at the AIS-3 and 1 at AIS-4). No pelvic injuries were due to the belt systems in this study.

In their rollover study of 225 occupants, Hight et al. (14) found only 18 with lower-extremity injuries of AIS-3 or greater.

Huelke et al. (12) reported on frontal and rollover crashes and found an 81% reduction in the more severe lower-extremity injuries in frontal collisions, and a 74% reduction in rollover crashes associated with the use of lap-shoulder belts.

In a study of 1973 and 1974 passenger cars, Marsh et al. (18) presented data indicating lap and/or lap-shoulder belted occupants have a lower frequency of lower-extremity injuries than do unbelted occupants.

Huelke and Lawson (19) presented data on injuries associated with automobile seat belts. Using multidisplinary accident investigation data they found that the pelvic area was injured in 5% of unrestrained occupants and in 9% of those wearing lap belts. Their data base included 3,845 unrestrained front seat occupants and 945 wearing lap belts. However, when the more serious injuries of AIS-3 or greater were reviewed, it was noted that 28% of those unrestrained front seat occupants had more severe pelvic injuries as compared to 9% of those wearing a lap belt. A review of the hard copy of the actual cases indicate to the authors that in at least 7 of the belted individuals with pelvic injuries, the injuries could have been caused by objects such as the steering wheel, door or instrument panel, transmission lever, etc., either solely or in combination with the lap belt. Of those occupants with pelvic fractures, most all were in crashes in the higher speed ranges. They also concluded that the outboard seat belt angle had no relation to pelvic or lower torso injuries.

Nagel and States (7) reported only one serious knee injury among 15 seat-belted occupants. Hight et al. (14) found only one severe pelvic fracture in 39 restrained occupants involved in rollovers. Rattenbury et al. (20) had a low frequency (6-10%) of the more severe lower extremity injuries in lap-shoulder belted occupants. They found that these injuries are as frequent in the leg and ankle/foot area as in the pelvis and thigh. They indicated that most of the pelvic fractures were due to intrusion into the vehicle.

Gloynes et al. (21) in a study of 101 lower limb injuries of AIS-2 or greater found knee loading to be the most frequent cause of injuries to the knee/femur/pelvis complex. They found a lower incidence of lower limb injuries of the more severe nature in lap-shoulder belted occupants, belts reducing driver knee-pelvic fractures by 50%.

## 4. Conclusion

The infrequency of restraint usage in the NCSS sample precludes any strong conclusion regarding the effectiveness of restraints in preventing severe lower-extremity injuries. Previous literature results almost uniformly conclude that belts have been effective in reducing such injuries. If the trend presently observed in the NCSS data continues, there may be enough information at the end of the study to draw a firmer conclusion on the effectiveness of belts on lower extremity injury prevention.

## VI. 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 severe lower limb injuries.

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 other sources of error, however, which deserve mention.

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, if 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, 4,340 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 x 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 x 519, or about 623 persons.

Finally, the NCSS program covered a period of fifteen months, and a better annual estimate may be obtained by taking 12/15ths 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, and the warning that it is not statistically appropriate to try to put bounds on such a projection, we will make an estimate anyway. 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., one year) is about 400, and that fatalities are more fully reported (even though there is not complete injury data available). A reasoned guess, then, would be that there are about as many persons with severe leg injuries (from crashes for which their cars were towed) as there are persons killed in the same kind of crashes. Since there are about 27,000 passenger car occupants killed each year in the U.S., the number of persons with severe leg injuries is estimated to be about the same.

## VII. 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 injured 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 case at the time of the head-on crash (States, et al. [22]).

The majority of fractures to the bony pelvis, except for the hip articulation are due to side impacts where 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 located deep into the pubic hair region, 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 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 [23]. 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 (LeRoy, 24).

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 patallar fractures are available, with some data on the tolerances of the tibia. For a complete discussion on the available biomechanical data of the lower limb, the reader is directed to the publication entitled, "NCSS Analysis Project Literature Review (Anatomy, Injury Frequency, Biomechanics and Human Tolerances)" as SAE Publication No. 800098 (25).

# VIII. MEDICAL CONSEQUENCES OF LOWER EXTREMITY INJURIES

## A. OVERVIEW

Lower-extremity injuries are seldom fatal, but treatment and temporary total disability are longer than those associated with more serious injuries (AIS-3,4) in other body areas and permanent disability is common. Table 16 reveals that the average hospital stay for the more severe lower-extremity injuries is 20% higher than for those in other regions. Similar percentages reveal longer periods of temporary total disability for such lower-extremity injuries (Table 17). The extent and frequency of permanent disability resulting from such injuries cannot be determined from the available literature and data samples. Clinical experience reveals that permanent disability is common and often requires restructuring of a patient's lifetime occupation and goals.

TABLE 16
DAYS IN HOSPITAL BY SEVERITY OF LOWER EXTREMITY INJURY

| AIS | Lower Extremity Injury | | Worst Injury in Other Body Areas | |
|---|---|---|---|---|
| | N | Mean | N | Mean Days |
| No Injury (0) | 7167 | 1.196 | 4358 | 2.303 |
| Minor (1) | 1830 | 1.548 | 3235 | 3.769 |
| Moderate (2) | 357 | 8.810 | 941 | 6.141 |
| Severe (3) | 263 | 15.274 | 551 | 8.305 |
| Serious (4) | 30 | 18.308 | 167 | 9.364 |
| Critical (5) | - | - | 98 | 11.264 |

## B. TREATMENT

Most adults and a significant fraction children with the more severe lower-extremity injuries require hospitalization. All such

TABLE 17
DAYS OF WORK LOST BY SEVERITY OF LOWER EXTREMITY INJURY

| AIS | Lower Extremity Injury | | Worst Injury in Other Body Areas | |
|---|---|---|---|---|
| | N | Mean Days | N | Mean Days |
| No Injury (0) | 5697 | 1.774 | 4081 | 0.145 |
| Minor (1) | 1185 | 4.974 | 2060 | 4.167 |
| Moderate (2) | 208 | 12.870 | 544 | 8.649 |
| Severe (3) | 245 | 19.345 | 292 | 15.825 |
| Serious (4) | 16 | 21.063 | 77 | 15.481 |
| Critical (5) | - | - | 32 | 25.250 |

injuries are best treated in a hospital emergency department, and all musculoskeletal injuries require x-ray for accurate diagnosis.

Fractures and dislocations require reduction and stabilization in the reduced position. Manipulative reduction by the surgeon (closed reduction) and immobilization in a plaster cast is the most common form of treatment.

Immobilization of the injured structures is essential for healing and requires a minimum of a month and more, commonly longer periods--sometimes as much as six months or even a year. Fractures of the shaft of the tibia are the slowest and most uncertain fractures with respect to healing. Immobilization may go on for extended periods of time. The minimum immobilization period for a tibial shaft fracture in an adult is three months.

Traction is an alternative means of immobilization, particularly for fractures of the femoral shaft and the supercondlar region. Some joint motion occurs with traction and is desirable because it reduces joint stiffness as bone healing is taking place.

Reduction through surgical incision (open reduction), and internal fixation with screws, plates, nails, and/or bolts, is necessary and/or desirable for some fractures. However, open surgical treatment introduces the risk of infection, particularly bone infection, which is catastrophic. Healing time in spite of optimal reduction may be prolonged because of surgical intervention. Circulation and nerve supply may also be impaired because of surgical intervention.

In spite of the added risks of open reduction and internal fixation, its use is amply justified in fractures which cannot be treated satisfactorily with closed manipulation and casts, or with traction. Traction requires that a patient remain in bed. Debilitated and elderly patients do not tolerate bedrest because of the risk of pulmonary and renal infection and of thromboembolism (blood clots flowing into lungs or brain). Open reduction permits earlier mobilization, sometimes without casts. Earlier joint mobilization is usually possible, reducing the risk of permanent stiffness and of traumatic arthritis.

## C. COMPLICATIONS OF AIS 3+ LOWER EXTREMITY INJURIES

A wide variety of complications, many life-threatening and/or permanently disabling, may occur because of the more severe lower extremity injury. Thrombophlebitis is the most common complication occurring among hospitalized patients and is life-threatening because of the risk of pulmonary embolism, where clots lodge in the lung and interfere with the body's ability to acquire oxygen. Prophylaxis includes early walking, use of blood thinning agents, including aspirin, heparin, coumadin. In spite of vigorous prophylaxis fatal embolization still occurs. The risk of thrombophlebitis increases with the patient's age but is practically unknown in children.

Fat embolization is a less frequent but equally life-threatening complication. Small globules of fat, presumably originating from the bone marrow, may enter the circulation and lodge in the lungs, brain, or any other organs interfering with their functions. Steriods (cortisone, etc.) and blood-thinning agents identical to those used in the treatment of thrombophlebitis are helpful in reducing the effects of fat embolization. When fatal embolism occurs very suddenly it is untreatable because of its rapid onset.

Infection may occur in any fracture or dislocation open to the exterior because of a laceration in the overlying skin and soft tissue, or because of a surgical incision. Compound (open) fractures may have dirt ground into them by impacting surfaces, particularly pavement, floor mats, or other dirt-covered vehicle or roadside surfaces. Dirt represents gross contamination because it always contains pathogenic bacteria. Staphlococcus and tetanus are the most common bacteria, but a wide variety of destructive bacteria are constantly present in our environment.

Antibiotics are life-saving in their ability to kill or arrest bacterial growth in the human body. They are widely used in the treatment of open fractures, but are not always successful. Visible foreign material must be surgically removed from an open injury. Antibiotics penetrate only to the extent that the blood and body fluids circulate. Foreign materials provide a protected nidus for the growth of bacteria even in the presence of antibiotics. Bone and soft tissue injured because of trauma lose their circulation and may provide similar protected havens for bacterial growth. Such tissue needs must be surgically removed to adequately combat infection.

The long-term risks of infection are chronic bone infection (osteomyelytis) and destruction, joint and soft tissue adhesion and arthritis. Bone infection, once it is established, cannot be eradicated, but only suppressed. Treatment, including antibiotics for long periods of time, and extensive surgical drainage and removal of infected tissue never completely eliminates infection. Infected bone characteristically flares up recurrently throughout a patient's lifetime. Acute recurrences are managed with antibiotics and surgical drainage. Bone may be weakened, causing it to fracture because of the chronic infection. Joints may be damaged and become stiff, painful, and weak. Replacement of infected joints with total prosthetic joints is seldom successful in the long term because of recurrent infection. In summary, bone infection and osteomyelytis is a catastrophic complication.

Initial injury may tear out sections of skin, subcutaneous tissue, and occasionally underlying muscle and fascia Such tissue may also die in the course of treatment because of loss of circulation, swelling, or infection. Replacement of skin and soft tissue may occur naturally if the defect is not too large, the underlying fracture can be stabilized, circulation is satisfactory, and infection is not present. Frequently not all of these conditions can be met, and skin grafting is necessary. Circulation must be provided for the grafted skin, and techniques to do this are complex and require prolonged healing periods, often several months. However, in many instances, skin coverage of a fracture site has to be provided before bone healing can begin. Skin grafts for areas of several square inches, particularly over the lower leg are not unusual. Fractures will not heal unless covered with skin and soft tissue. The fracture callus (bone repair tissue) can grow onto bone only when it is covered with skin.

Delayed or nonunion of the fracture site may occur because of inadequate immobilization, insufficient circulation, lack of skin coverage, and infection. Occasionally union is slow or it does not occur for reasons unknown. The shaft of the tibia is the area most unlikely to encounter delayed or nonunion, but this complication can occur in any fracture site.

Delayed union is defined as failure to heal in less than a year. Any fracture which is not healed after a year is defined as a nonunion. The area at the fracture site is filled with scar tissue but not bone. Stress on the fracture site results in bending because of the presence of scar tissue rather than bone at the fracture site.

More rigid immobilization and bone graft, using bone commonly from the pelvis, are the techniques usually used for delayed and nonunion. The skin coverage, through skin grafting if necessary, must also be provided. Infection must be controlled and adequate circulation provided as well. Delayed union may add months or even years to the healing time of the fracture. Untreated, a nonunion will loosen up, angulate, and eventually result in loss of use of the extremity. Gross deformity will occur, and will preclude walking and weight-bearing with the extremity.

More adequate fixation in the treatment of delayed and nonunions consists of bone grafting to the fracture site, or on internal fixation device such as a plate or nail. Rigid immobilization is essential for healing. Whenever possible, weight-bearing is encouraged because circulation is stimulated. Muscles can function inside a case and will maintain at least part of their tone better than with complete rest. Muscle activity aids circulation and fracture healing, provided motion at the fracture site does not occur.

Circulation changes may occur in the first few days after the occurrence of a fracture or after a surgical procedure, causing loss of blood supply to the muscles and nerves. Muscles deprived of circulation initially swell but then atrophy and are replaced with scar tissue which contrasts causing loss of motion, strength, and function. If nerves are damaged further paralysis and loss of sensation will occur beyond the site of injury. This condition is called Volkman's ischemic contracture and more commonly occurs in the forearm and hand but is a complication of lower-extremity fractures and dislocations as well.

Dislocations of the hip, knee, or ankle can block arterial circulation. The results of the blockage are related to the local anatomy. The femoral head may die as a result of dislocation because the small arteries supplying it run on the surface of the femoral neck, just below the head, and may be directly crushed by the dislocation. This is not recognizable until the bone has softened sufficiently to cause pain or actually collapse, resulting in mechanical incongruity of the hip joint. The process takes a minimum of six months and sometimes five to ten years to become apparent. Replacement of the joint is the only satisfactory means of treatment.

Knee dislocation may close the popliteal artery because of mechanical obstruction. It is the only artery of any significance passing the knee area. This is an acute emergency because clotting of the artery may occur, making restoration of adequate blood impossible. Immediate reduction in the knee is demanded, and is easily accomplished without anesthesia, simply by manipulation. However, arteriography is essential to be certain that circulation has been restored and that clotting within the arteries has not occurred. If clotted, the arteries must be opened and clots removed or the arteries surgically replaced to restore circulation. Amputation is a result of delayed treatment of knee dislocations when the arterial supply is involved.

Ankle and foot dislocation may result less commonly in acute loss of arterial circulation in the foot or a more prolonged slowing of circulation resulting in bone death and collapse. Surgical treatment is far less satisfactory because the vessels are very small. Satisfactory prosthetic replacements, except possibly for the ankle, do not exist for the foot.

D. PERMANENT DISABILITY

Some degree of permanent disability follows most of the more severe injuries of the lower-extremity. The extent and nature of the disability depends on the nature and location of the original injury, the response to treatment, the occurrence of complications, and the age and ability of the patient to rehabilitate himself. It is assumed that medical care of contemporary quality is available to the patient.

Certain injuries, because of their nature, result in permanent disability. Fractures extending into joints heal but change the geometric configuration of the joint that leads to articular cartilage breakdown and traumatic arthritis. An identical fracture that does not extend into a joint will heal with no long-term consequences and without permanent disability.

The knee joint is unique in that ligamentous injury may result in traumatic arthritis. Torn knee ligaments are repaired by direct suture or by replacement or reinforcement with other ligaments or tendons. In spite of this some looseness may result and it has proved impossible to completely replace or satisfactorily repair knee ligaments without altering the complex biomechanics of the joint. Such alteration results in abnormal pressures on the articular cartilage leading to traumatic arthritis. Knee ligament injuries are common in football and other sports but also occur in traffic accidents.

The joints of the lower-extremity are particularly at risk because of their weight-bearing function. Joint irregularities in articular cartilage injuries cause the articular cartilage to break down with weight bearing and to become arthritic. The same injury in the upper extremity will not cause significant disability because the upper extremity does not bear weight.

The knee and ankle joint commonly develop traumatic arthritis because of fractures extending into the joint. Accurate reduction, usually with screws or bolts, and early activity may bring about healing of the joint surface (articular cartilage) and prevent traumatic arthritis. The joints beneath the ankle (subtalar joint) which allow sideways motion of the foot to accommodate rough ground may similarly develop traumatic arthritis because of fractures extending through the talus or calcaneous (heel bone). The ball and socket of the hip joint may also develop traumatic arthritis because of the fractures that extended into the joint.

Total joint replacement is currently the most satisfactory means of treating traumatic arthritis of the hip and knee. Total joints are available which have one surface of stainless steel or a similar implantable metal and the other surface, a socket of high density polyvinyl chloride or a carbon fiber variation of high density PVC. Identical joints are used for treating degenerative and rheumatoid arthritis. They work well in older patients, but may loosen or even wear out in younger patients who have a higher activity level and a stronger musculature.

Total joint replacement is available for the ankle, but it is not as successful and is much less frequently used. Fusion of the ankle is an equally satisfactory procedure when weighed against the risks of total joint failure. The subtalar joints are best treated by fusion because there is little motion to start with and its loss causes only minimal additional disability.

Traumatic arthritis causes pain, stiffness, weakness, grinding and snapping, and giving way of an affected joint. It is identical to degenerative arthritis caused by what presumably is normal wear and tear of aging. Microscopically the smooth glistening slippery joint surface (articular cartilage) becomes thinner and eventually disappears completely. The underlying bone is exposed and comes in contact with the opposite joint surface. Collapse due to microfractures in this bone may occur early in the arthritic process. Collapse takes away normal support of the articular cartilage. The onset of pain may be related to the beginning of a collapse of the underlying bone.

Permanent disability in the form of restricted joint motion may occur because of adhesions of muscles, tendons, and ligaments to the underlying bone, most commonly at the fracture site. Early mobilization and vigorous exercise may prevent this. Adhesions may occur in spite of the best therapeutic efforts because of initial soft tissue damage due to the original injury and resulting in scar tissue formation.

Shortening of a lower-extremity may occur because of overriding in the fracture site or loss of bone substance. Occasionally fragments of bone are expelled at the time of injury or have to be removed later during treatment. Shortening of two centimeters or less is usually not noticeable even to the patient. More than two centimeters shortening produces tilt of the pelvis because one hip is lower than the other and may disturb the lumbo-sacral spine. Backache and intervertebral disc disease may occur at a result of this tilt.

Peripheral nerve damage caused by the initial lower-extremity injury or as a complication is difficult to repair. Occasionally the injured segment of nerve can be removed and the ends sewed together with regeneration occurring. This requires optimal circumstances. Nerve grafting is rarely successful. Permanent paralysis is more often the result of peripheral nerve injury.

E. SUMMARY

The more severe lower-extremity injuries are most commonly displaced fractures or dislocated joints. Such injuries are seldom life-threatening but treatment frequently requires prolonged immobilization, either with casts or traction. Open reduction and the use of screws, plates, bolts, and nails for internal fixation may be necessary. The risk of infection is present in open fractures or when surgery is performed. Bone infection results in chronic osteomyelitis which will cause bone weakening, recurrent acute infection, and lifelong threat of disability.

Fractures not entering joints usually heal completely and usually do not cause permanent disability. Fractures extending into joints or injuries dislocating the joint, injuring the ligaments about the knee joint or damaging the surface of the joint may cause traumatic arthritis and permanent disability. Weight-bearing joints, particularly the hip and knee, are prone to this complication. Total joint replacement is the most satisfactory means of treatment, but may loosen or wear out in younger, active patients. Total joint replacement cannot be performed in the presence of infection.

# IX. CONCLUSIONS

Analysis of the NCSS data indicates that injuries of the more severe nature (AIS 3,4) in the lower-extremity are exceeded in occurrance only by severe thoracic injuries. No other body region, other than the chest, comes close in terms of the number of the more severe injuries sustained in car crashes. 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 passenger car occupants who are killed annually.

The medical consequences of lower-extremity injuries of the more severe nature may be extreme, including prolonged immobilization, long recovery periods, and the potential for the development of traumatic arthritis. Bone infection is a hazard that can cause bone weakening, recurrent infection, and life long threat of disability. Not infrequently many of the individuals with these AIS 3,4 lower-extremity injuries will have some degree of permanent impairment.

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.

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.

Of all of the sub-regions of the lower-extremity, the pelvic injuries are found most in drivers, whereas the front passengers had pelvis or thigh as the two areas most often injured.

Direct impact loading to any areas of the lower-extremity can cause injuries in that body region. In many cases force transmission through bone to other lower-extremity area 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 to the ankle and foot.

Seat belt systems appear to reduce the more severe lower-extremity injuries; however, there are too few cases available in the NCSS data to make a definitive statement.

Increased attention to impact characteristics of the lower instrument panel may prove beneficial in reducing the occurrence of the more severe lower-extremity injuries.

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