The Mechanisms of Below Knee Injury in Frontal Collisions: An accident analysis study

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Introduction

Lower limb injury is seen to be increasing in frequency in comparison with other body regions involved in frontal collisions. Below knee injuries make up a large proportion of the total socio-economic cost of this group. These injuries vary considerably in their mechanism, severity and long term physical impairment. Current restraint systems using seat belts and airbags have not been seen to be protective for this body region. Further development of effective safety systems for the lower limb will depend on a better understanding of the mechanisms for those commonly occurring severe injuries.

Methodology

Thirty-five cases were identified in which an individual had sustained a lower limb injury (AIS $\geq$ 2) as the result of a frontal car collision. Police and local hospital sources were used to identify cases between Aug'97 and June'98. This enabled the researchers to gather information within a short time of the accident occurring.

The vehicle from each of the cases was examined by an Accident Investigator who carried out a detailed assessment of the crashed vehicle. Measurements relating to intrusion, structural damage, points of contact, pedal movement and possible entrapment were recorded. This report was in addition to the information that is routinely collected as part of the UK Co-operative Crash Injury Study (CCIS).

The injured occupant was interviewed and examined and where possible this took place while the patient was still in hospital. This provided further information about the accident and included a detailed assessment of injuries. All injuries were scored using the American Orthopaedic Foot and Ankle Society's AFIS scoring system for injury severity and impairment.

Lower limb anthropometry was also recorded to enable an assessment to be made of the position of the occupant's legs prior to impact.

Undeformed cars of the same model and type as the cars involved in the study were also examined, measured and photographed. These measurements allowed the researchers to reconstruct a profile of the footwell, seating and pedal position.

The assessment of the injured front seat occupant and crash vehicle was used to reconstruct the occupants pre and post crash leg positioning in relation to intrusion and control panel interaction. A panel that comprised of the accident investigator, 2 vehicle safety researchers and an orthopaedic surgeon then reviewed the data and determined the injury mechanism.

Results

Thirty-five cases were identified in which front seat occupants sustained a total of 50 AIS $\geq$ 2 below knee injuries (58% affecting the right leg and 42% the left leg). The group consisted of 22 males and 13 females with an average age of 33.5yrs (+/- 14.1). The majority of the group were restrained (91.4%) drivers (80%). The average delta-V, as measured using Crash 3, was 50.9km/h. The collision object was another car in 60% of cases, 23% collided with a heavy goods vehicle and 17% with a wall or lamp post.

This study looked specifically at those factors that contribute to the generation of high severity injuries as well as specific injury mechanisms.

Pilon fractures: (n=6) Six pilon fractures were recorded in 5 restrained front seat occupants. The average intrusion measurement specific to the injured foot was 10.7cm. In 5 of the 6 pilon fractures there was a good history of the legs being braced prior to impact. It was noted that all occupants had a 'straight leg' driving position with an average knee angle of 136°.

Fractured Tibia (+/- Fibula): (n=11) The mechanism responsible for these injuries was estimated to be a bending moment in association with axial load in 9 cases and direct loading in 2 cases. The average intrusion in this group was 20.5cm.

Talar neck fractures: (n=3)These fractures were seen to have occurred under very similar conditions. All three were restrained drivers in which there was good evidence of pre-impact bracing and contact with the control pedals at the time of impact. In 2 of the cases the edge of the control pedal had been bent as a result of loading by the driver. In these cases it is very suggestive of point loading being an important feature in the generation of this fracture.

Calcaneal fracture: (n=1)Only one calcaneal fracture was recorded in the study and this was not typical of the comminuted intra-articular fractures seen commonly in high-energy collisions.

Tarsal fractures: (n=7) Footwell intrusion was variable in this group with an average of only 9.7cm. In all of the cases the injury mechanism was determined to be direct loading of the mid-foot. In the 6 drivers in this group the control pedals were felt to have contributed as the result of pedal roll-off.

Metatarsal fractures: (n=10) This is a frequently occurring low severity injury and in the majority of cases was the result of forced dorsi-flexion.

Malleolar fractures: (n=8) These injuries are also associated with minimal long term impairment and were caused by excessive ankle rotation. The control pedals were believed to have been responsible in many of the low energy collisions by initiating ankle rotation.

Injury Severity and Impairment: Using the six point AFIS scoring systems the injury severity score (1-6) and impairment score (0-5) were correlated with the factors that were believed to have contributed to the below knee injuries. Injuries with the highest three severity and impairment scores were compared with injuries with the lowest three impairment scores. Collision speed, footwell intrusion and the injured occupant's anthropometry were not seen to correlate with injury severity and impairment. Pedal involvement was more frequently observed in the low severity and impairment injury groups (80%, 69% respectively) in comparison to the high severity and impairment groups (54%, 59%). A correlation was seen with pre-impact leg position. Those injuries that are associated with the highest impairment had significantly greater knee angles (128° i.e. straighter legs) than those injuries with the lowest impairment scores (112°), p=0.0069. For each injured limb the knee contacts were categorised: 1) 'No' knee contact 2) 'Heavy' knee contact, which caused structural damage

3) 'Scuffing', where a knee contact was noted but this did not prevent forward motion. The proportion of high and low severity injury groups in each category were similar, Figure 1. Comparison of the high and low impairment injury groups shows that an equivalent proportion had 'Scuffing' contacts but 'Heavy' knee contact was more frequent in the low impairment group (62%). 'No' knee contact was seen more frequently in the high severity group (29%), Figure 2.

Figure 1: AFIS-Severity: Knee Contact

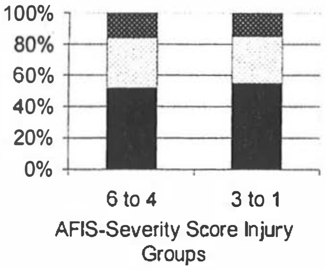
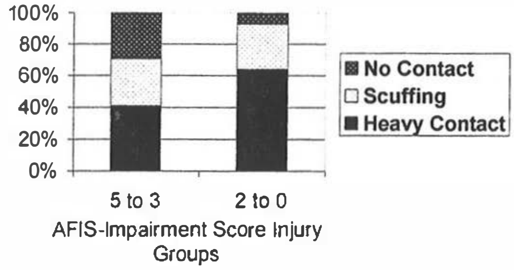


Figure 2: AFIS-Impairment: Knee Contact



Discussion

By studying standard (measurable) risk factors as well as additional features relevant to occupant leg positioning we have attempted to highlight links that are relevant to the mechanisms of specific injuries.

Pilon, tibial and talar neck fractures made up the majority of severe injuries seen in this study. It is noted that on comparison of these groups there is considerable variability of many factors such as intrusion, collision overlap, knee contact and pedal involvement. However within each of these injury groups the conditions are similar and it has been possible to hypothesise a mechanism of injury.

The factors that link the severe injury groups appear to be pre-impact bracing, pre-impact leg position and the type of knee contact. All of these factors contribute to the axial load experienced by the lower leg.

Many studies have used severity scores to characterise injuries and correlate against risk factors. In this study, knee angle and knee contacts were seen to have no significant correlation with the AFIS-Severity score but there was a correlation with the AFIS-Impairment score. Impairment scores are likely to be more predictive of the total human cost of an individual injury.

Conclusion

Factors that contribute to increasing the axial load in the limb are common in those injuries with the highest severity and impairment scores. Further development of the car footwell can reduce axial load and improve the protection of the lower limb. However, the contribution of the occupant to axial loading of the legs must also be considered.

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