ANALYSIS OF THE INTER-RELATIONSHIP OF PEDESTRIAN LEG AND PELVIS INJURIES

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ABSTRACT

In 1997 pedestrian accidents accounted for 27% of all road user fatalities and just over 23% of road user serious injuries in the UK. Across Europe the absolute number of pedestrian fatalities currently exceeds 6000 per annum.

In order to address the problem of pedestrian fatalities and injuries, sub-system tests for vehicle front-end structures have been proposed. However, there is concern that designing a vehicle to comply with each of these impactor tests may, in some cases, result in changes to the injury distribution and not an absolute reduction in injury levels.

A database of severely injured pedestrians was obtained from the Major Trauma Outcome Study (MTOS) conducted by a UK hospital. This database contains 316 injured pedestrians who received over 1200 injuries. Though biased towards severely injured pedestrians (99% received a Maximum Abbreviated Injury Score (MAIS) of 2 or more injuries) a comparison has been made to the UK Stats19 distributions to assess the representativeness of the database. Injuries were coded using AIS 90 and an aspect was assigned to each injury where possible.

Statistical analysis of the database has been performed to identify the inter-relationships between injuries in light of the injury criteria specified for the proposed impactor tests. Probabilities of sustaining certain injuries have been calculated depending on the incidence of injuries caused earlier in the impact event. Further, the types of injuries have been closely examined in order to understand the likely injury mechanisms. Conclusions are presented regarding the potential benefits and concerns of complying with the proposed impactor injury criteria through vehicle related pedestrian protection measures.

THE MAJOR TRAUMA OUTCOME STUDY (MTOS) was set up in the UK by a number of hospitals in order to gather data on the types of treatment being given to patients and the outcomes of those treatments. The data considered was collected between April 1994 and February 1998 from a participating hospital in the city of Nottingham. The database includes information on the injury, pre-hospital intervention and action, accident and emergency work carried out, details of x-rays, treatments, and operations. Though not directed solely to pedestrian accidents, there are a significant number of injured pedestrians contained in the database. For a trauma patient to be included in the MTOS database they must fulfil several criteria, alongside which there are several exemptions applied.

All trauma patients were included, irrespective of age, where the following criteria were met:

- Length of stay is 72 hours or longer
- Admitted to an Intensive Care or High Dependency area
- All deaths of injured patients in hospital

The following were patients who incurred the following injuries and are not included in the study:

- Those with fractures of the femoral neck or single pubic rami fractures aged 65 years or more
- Isolated closed, undisplaced, not comminuted limb injuries
- Soft tissue spinal strains
- Closed, undisplaced facial injuries
- Simple penetrating injuries not involving deeper structures or less than 20% blood loss

Due to the nature of the study it does have some limitations when performing an analysis of pedestrian injuries. The database has no record of the vehicle involved, the speed of impact or the orientation of the pedestrian. Front-end designs of cars have evolved over the last 20 years for various reasons, such as styling and fuel efficiency to reduce drag. Also bumper materials have changed from chromed steel to plastics with recent vehicles having a stiff armature behind the plastic bumper cover. These changes have affected the type and severity of injury sustained a pedestrian and will also influence the kinematics of the pedestrian. The vehicles involved in this study will represent both old and new styles of cars, as well as other types of vehicles. Though the database does not permit assessment of lower leg injury as a function of vehicle age or impact speed, it does permit analysis of the inter-relationship between certain lower leg injuries.

No distinction can be made between injuries which were caused by contact with the vehicle and those which may have been caused by contact with the ground or other street furniture. The database contains information on pedestrian age, but has no information on the height or weight of the pedestrian. Despite these shortcomings, it is believed that there is useful information in the database that would assist in developing an understanding of the inter-relationship of certain injuries. The true extent of pedestrian injuries within the MTOS database, though, is an underestimate due to the above case types being excluded. There are also no ligament injuries mentioned related to the knee joint.

Having obtained the data for the patients who suffered a pedestrian accident from the whole MTOS database, some adjustments were made to separate injuries that had been grouped by the clinician entering the data. Once all injuries were isolated they were assigned an aspect identifier, where possible, and were coded using AIS 90. The Maximum Abbreviated Injury Score (MAIS) and Injury Severity Score (ISS) for each patient were also calculated.

In order to check how representative this database was of the national scenario a comparison was made with the UK National Stats19 published data. As the MTOS database contains 99% MAIS 2 or more injuries, a comparison was made with the seriously injured and fatally injured pedestrians found in Stats19 (Figure 1) which indicates that the MTOS study tended to be biased towards fatalities.

The distribution of patient age in the MTOS study compared to the age distribution of fatalities and seriously injured pedestrians in the Stats19 database is illustrated in Figure 2. It can be seen that both the older and the younger population groups are under-represented in the MTOS database compared to the UK national data. The MTOS database contains 32% of patients in the 0-15 year old age group compared to 36% in the same age group in Stats19. Conversely the MTOS database contains 18% in the 16 to 24 age category compared to 14% in the same category in the national data. The over representation in this age category may be due to the fact that Nottingham is a University City and will have a higher percentage of population in this age band. Overall, the age distribution within the database does not give rise to concern over its representivity.

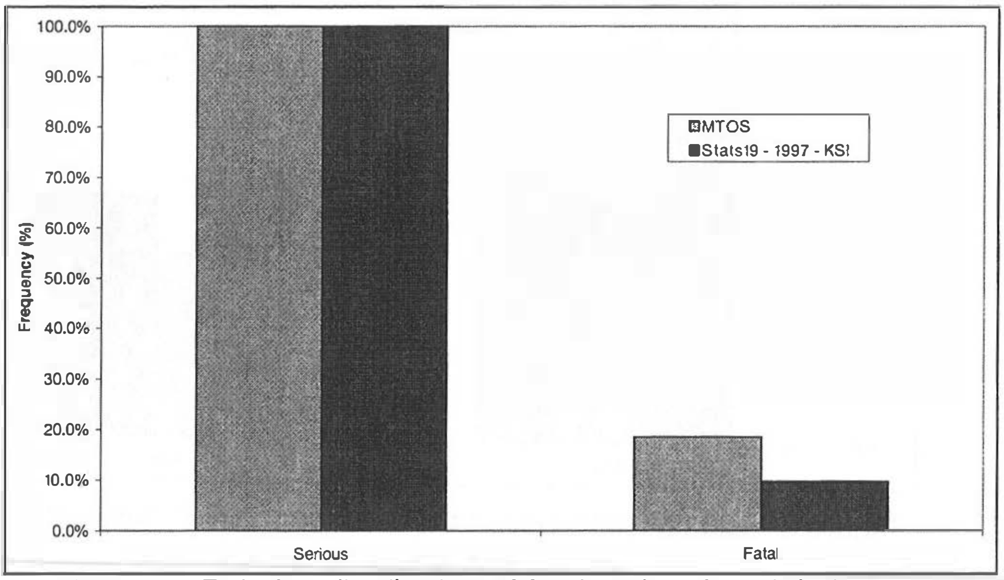

Figure 1 - Relative distribution of fatal and serious injuries between the MTOS database and the Stats19 database

The gender distribution is illustrated in Figure 3 showing a 9.5% shift towards males in the MTOS database. This means that the database is biased towards males, with a ratio of 2.43:1 as opposed to 1.59:1 for the national data. This bias in the database towards males is across all age bands with the exception of the 5-11 year olds and pedestrians in the over 80 year old category.

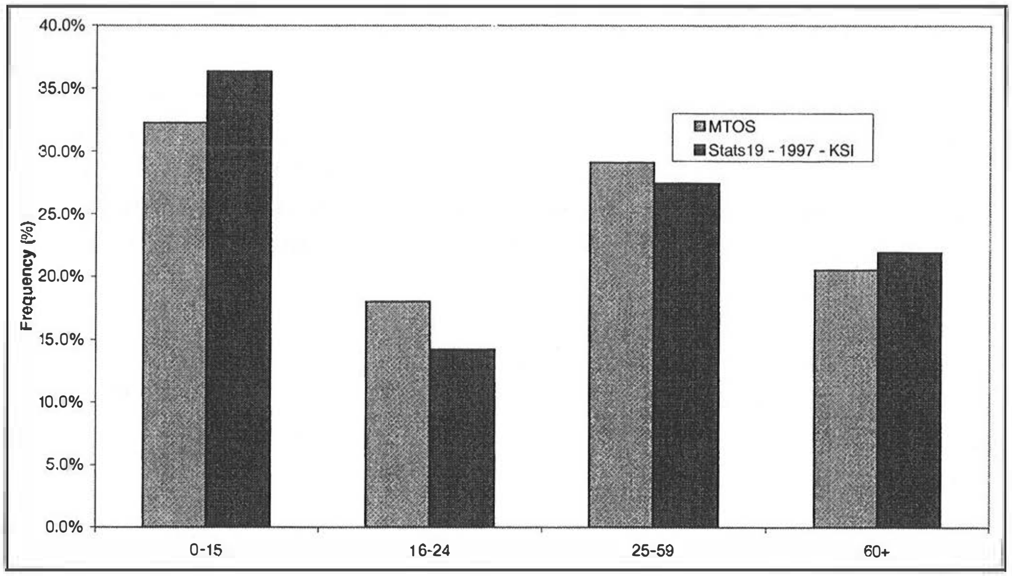

Figure 2 - Relative distribution of pedestrians within the MTOS and Stats19 databases by age

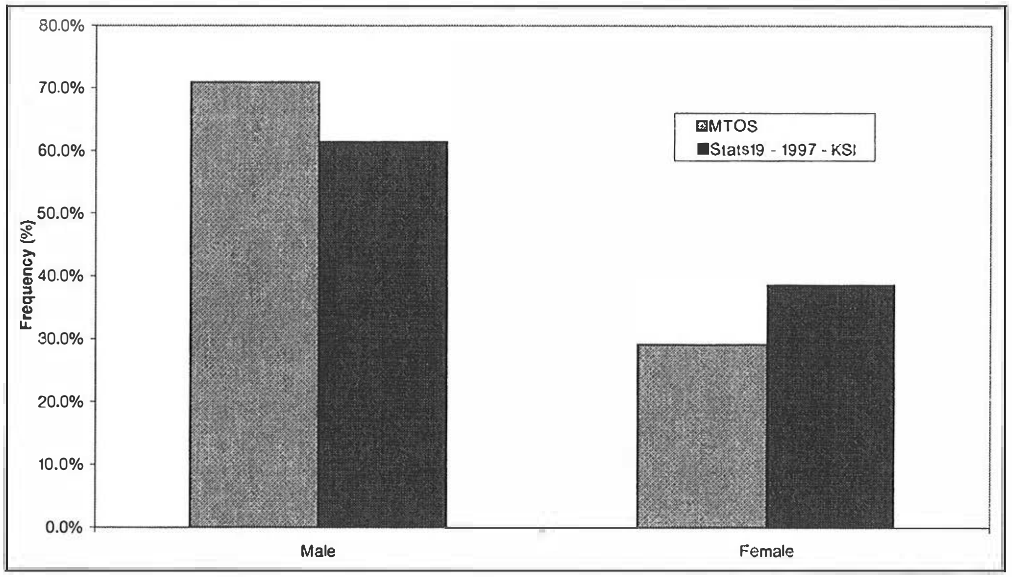

Figure 3 - Relative distribution of pedestrians within the MTOS and Stats19 databases by gender

FREQUENCY OF INJURIES

The study group comprises 316 pedestrian accident victims with an average injury severity score (ISS) of 10.

The fatality rate within the study was 15.5% (n=49), but this is explained by the severity of the database and categories of pedestrians chosen for the study. The fatality rate for the 0-15 year old and 25-59 year old groups was 10.8% and 10.9% respectively. In the 16-24 year old category the fatality risk increased to 21.1% implying that other factors, such as social behaviour increasing risk taking, are involved. The highest fatality risk was for the 60+ age group where the risk was 24.6%. This higher risk is indicative of the increased susceptibility of the elderly population.

The distribution of all types of injuries within the database was studied to gain a perspective of the general pedestrian injury incidences. The most frequently sustained injuries were to the lower limb with 206 pedestrians (65.2%) receiving fractures and soft tissue injuries, of which 197 pedestrians received 352 fractures - an average of 1.8 per person. Head/Face injuries were the second most frequently sustained injury at 57.9% (n=183) of the pedestrians. Upper limb injuries were next in frequency with 27.8% (n=88), and abdominal injuries 5.4% (n=17). Spinal injuries included cervical, thoracic and lumbar injuries, of which there were 6.3% (n=20).

The incidence and distribution of lower leg fractures, is shown in Figure 4. The most common fracture sites were the Tibia (29.7%), Fibula (25.3%), Pelvis (20.6%), and Femur (13.6%).

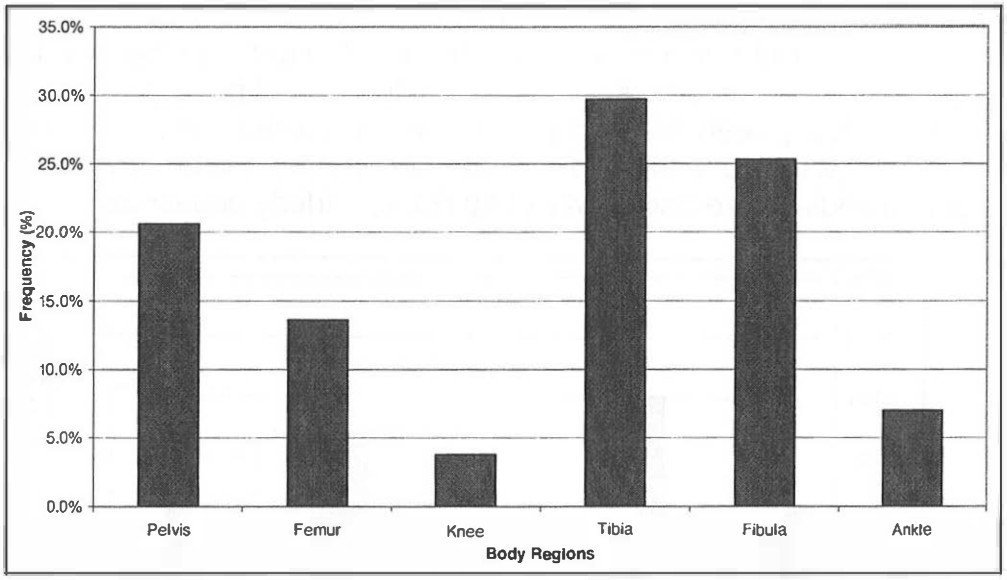

Figure 4 - Distribution of lower leg fracture

On closer inspection of the database comparing the frequency of injuries to lower limb regions with the overall MAIS (Figure 5), it can be seen that the MAIS 3 group incurs the highest risk of tibia/ fibula fractures. However, it is in the MAIS 2 group that the highest risk of pelvis and tibia injuries is found. The knee and ankle regions have the lowest injury risk, which could be due to the database not containing ligamentous injuries. If the overall MAIS can be taken as a surrogate for the impact severity, then the injury risk for the tibia and fibula implies that there is a significant change in the kinematics of the accident at higher impact severities.

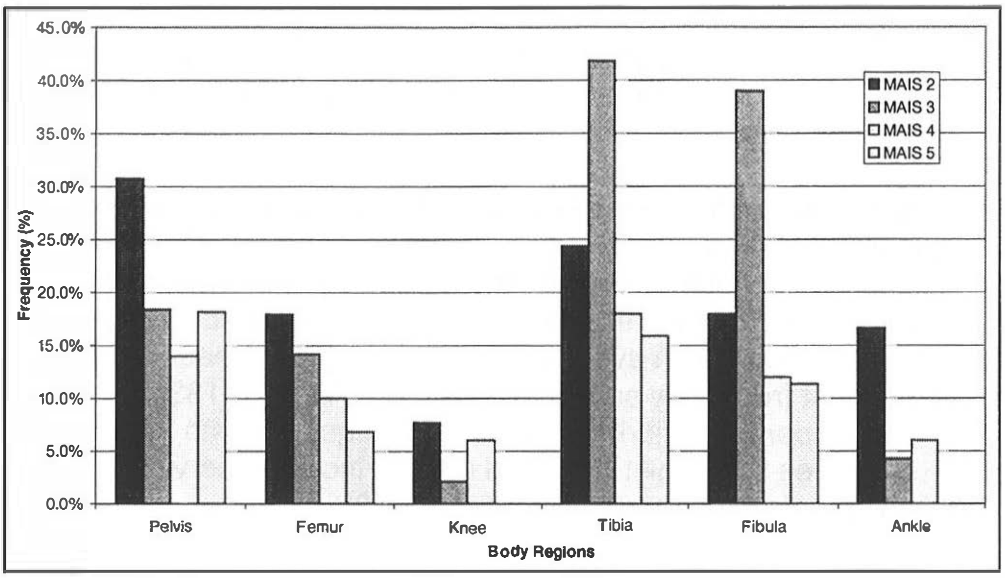

Figure 5 – Distribution of MAIS per pedestrian associated with a lower limb injury

The following graph (Figure 6) shows the effect of age on the distribution and risk of the lower limb injuries within the MTOS study, on a general age banding format. These differences can be a function of pedestrian height and this can be clearly seen by the high risk of femur fractures in the 0-15 year age group. The age trends within the data are not pronounced but there is a slight increase in fibula, knee and pelvis injury risk for elderly pedestrians.

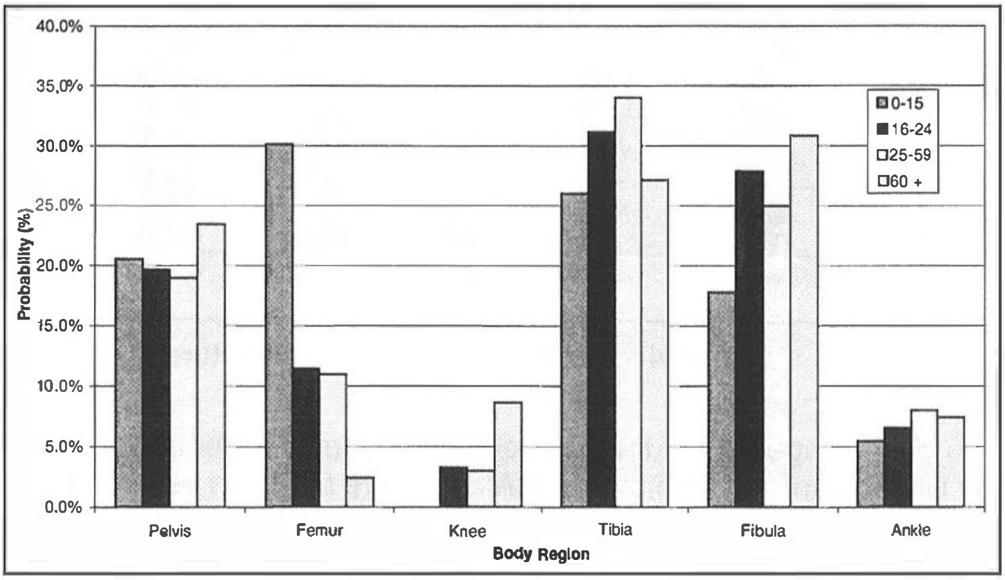

Figure 6 – Lower leg injury risk, by age group

TYPES OF INJURIES

People vary widely due to the human body being so complex. One assumption used is that when the body is optimised in such a way that when one component fails the next is close to failure (MacAuley 1992). Fractures are predictable, and specific loading, whether direct and indirect, causes specific injuries. A fracture may be caused by a direct blow to soft tissues overlying the bone or indirectly from forces transmitted via the other structures proximal or distal to the one involved (Levine1993).

All fractures are either open or closed. A displaced fracture (ie. If bone ends have shifted either totally or partially relative to one another) can give a hint of the forces involved, e.g. displaced fractures result from higher forces. Also comminution (bone broken into more than two pieces) correlates to energy input: the higher the energy the greater the comminution. The rate of loading also affects the fracture patterns and Kress (1995) noticed that fracture patterns of low speed impacts are very similar to those of high speed, with the exception that high comminution was not observed in fractures produced at low speeds. Energy and loading rates are not the only factor to consider as bone strength has a large influence especially on weaker bones that can comminute more easily (Goldstein 1993).

When the pelvis is loaded from the front it is usually by an antero-posterior load. Concentrated loads are most frequently transmitted via the femur than from direct loading to the pelvis itself. The pelvis seems to be more susceptible to damage by direct contact when it is loaded laterally, causing fracture of the iliac crest or the hip joint socket. An acetabular fracture results from loading of the acetabulum through the femoral head following an intense blow to the femur at the greater trochanter, and when forces are distributed it often results in a pubic rami fracture. Within the MTOS database this theory is supported in that, of all pelvic injuries, 61.5% were pubic rami fractures of which 17.5% were with an acetabular fracture.

Studies by Eastridge & Burgess (1997) recognised that pelvic fractures were a substantial factor in pedestrian morbidity and mortality. Although most of the morbidity and mortality is not caused by the inherent nature of the pelvic fracture itself, the severity of these injuries is associated with the degree of the destructive energy transmitted to the body as a whole, as manifested by the number and severity of associated injuries. Within the MTOS study 15.4% of the pedestrians with a pelvic fracture were fatally injured yet 27.7% received multiple/bilateral fractures and survived. The remaining 56.9% received single fractures of the pelvis. Five of the 10 fatal cases received highly unstable fractures and severe disruption of the internal organs, which makes it highly probable this was one of the main reasons for their outcome. The other five fatally injured received head and chest conditions that would have been the likely cause of their outcome.

Knee injuries have been suggested to occur at high speeds (Ashton 1981), and Aldman et al (1979) stated that injuries to the knee ligaments were to be found at impact speeds as low as 17 km/h. Knee injuries within the MTOS study appeared to be the most minimal injury to the lower limb (3.8%). This may be due to the fact that no ligament injuries were found within the database. The most common damage mechanism is due to a combination of shearing and bending deformation of the knee, resulting in joint fractures and ligament damage (Kajzer et al 1997).

Within the MTOS database, the ankle injuries sustained were fractures of the lateral and medial malleoli, and bi-malleoli fractures. The ankle joint maintains stability if the talus bone and ligaments remain in one piece, With pedestrian injuries there may be direct impact on the ankle joint either from a secondary impact with the vehicle or with roadside structures. The most likely cause of injuries is from indirect loading sustained when force is applied laterally or medially from the tibia or fibula causing the joint to be severely adducted or abducted within the joint. This can wrench the ligaments and avulse bone sections they are attached to, which could be the lateral malleolus of the fibula, or the medial malleolus of the tibia. Within the MTOS study the majority of injuries were to the medial malleoli suggesting that the majority of impacts were from the lateral aspect of the tibia/fibula, implying that this was the struck leg. The loading caused abduction of the ankle, stretching of the ligaments and avulsion of the malleolus. Within this process there is also a tendency to fracture the lateral malleolus of the fibula as the talus bone impacts it, but this depends on the extent of abduction.

AGE AND SEX INFERENCES - Age influences pedestrian injuries in several ways. For children, height and weight are related to age, and therefore children will experience different impact conditions to each other and to adults. The length of long bones will also influence the likelihood of sustaining a fracture for the same applied load due to changing the applied moment. Injury tolerance is a function of age, and the bones of children less than 10 years old are more flexible than the bones of adults (Crawford Adams 1972). The elderly tend to be more sensitive to injury than the other age groups due to their decreased bone strength, density, and reduced muscle mass, and once injured, are more likely to die from the injuries of a given severity. The differences between gender have an implication generally in that women tend to have less bone mass than men do, especially after the menopause. Also, certain muscles of the male are larger than the female, with the points of attachment – tuberosities, lines, and ridges – being more prominent in the male. There tends to be a higher number of fractures in older females which is consistent with post-menopausal reduction and a more rapid reduction in bone mass resulting in a decreased injury tolerance.

SEQUENCE OF EVENTS – PEDESTRIAN KINEMATICS

Before a study of the inter-relationships within the MTOS data are described it would be useful to review the sequence of events in a pedestrian impact. This can be done using a mathematical simulation of a 50^{th} percentile male dummy struck by a typical car at 40 kph (25mph) with no pre-impact braking and 0.5g post-impact braking (see Figure 7). This kinematic is the 'textbook' scenario, but real-world accidents are extremely variable.

The first point of contact is between the bumper and the tibia, which is accelerated away breaking frictional resistance between the shoe and the ground. A turning moment about the centre of gravity of the body starts to be created by the tibia impact causing the upper body to arc downwards. The next point of contact may be between the upper leg and bonnet-leading edge depending on the shape of the vehicle and the speed of impact. The severity of this contact depends on the relationship between vehicle front-end geometry and the stature of the pedestrian. The third point of contact is usually between the bonnet top surface and the head, shoulder and chest.

While these impacts are occurring, the pedestrian is accelerated close to the impact speed and as the vehicle slows down, is often projected forward onto the ground where further injuries may be received by the impact and subsequent sliding and rolling motions along the ground surface.

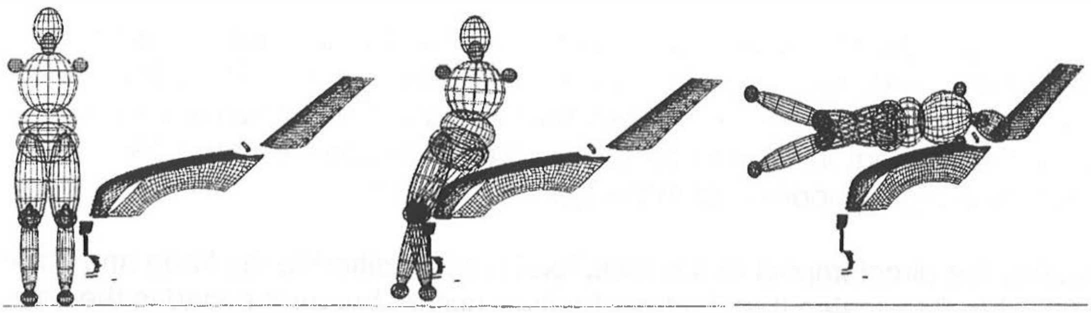

Figure 7 - Sequence of pedestrian kinematics from simulation

INTER-RELATIONSHIPS OF PEDESTRIAN LOWER LIMB INJURIES

Usually lower limb injuries do not exceed AIS 3 as they are rarely life threatening, although lower extremity trauma can be life-threatening when it produces severe blood loss. The AIS scale does not account for long term impairment injuries. The influence of tibia and fibula fractures on the injury frequency of the other lower leg regions has been investigated to see if the incidence of fracture affords protection from more impairing injuries.

Table 1 shows the incidence of fibula fracture with tibia fractures. In more than three out of four cases (77.7%) in which there was a tibia fracture, a fibula fracture was also sustained. This relationship is essentially true for all ages of pedestrian, though fibula fractures are more pronounced for the elderly both when a tibia fracture occurs and in the absence of a tibia fracture.

Table 1 - Inter-relationships between tibia and fibula

	Age Group	With Tibia Shaft Fracture	Without Tibia Shaft Fracture	TOTAL
Fibula Fracture	0-15	13 (68.4%)	0 (0.0%)	
	16-24	16 (84.2%)	1 (2.6%)	
	25-59	25 (73.5%)	0 (0.0%)	
	60 plus	19 (86.4%)	6 (14.0%)	
	All	73 (77.7%)	7 (3.2%)	80 (25.3%)
No Fibula Fracture	0-15	6 (31.6%)	83 (100.0%)	
	16-24	3 (15.8%)	37 (97.4%)	
	25-59	9 (26.5%)	58 (100.0%)	
	60 plus	3 (13.6%)	37 (86.0%)	
	All	21 (22.3%)	215 (96.8%)	236 (74.7%)
TOTAL		94 (100%)	222 (100%)	316 (100%)

The majority of the tibia/fibula fractures were open/displaced/comminuted (65%), which compares with other researchers (Brainard et al 1992; Kress 1995) and 9.6% of these were bilateral tibia fracture. Consideration has to be given to the fact that this database is biased towards more serious cases, and will include a high proportion of these types of injuries.

Following the direct impact to the tibia, load is transmitted to the knee and ankle joints. Table 2 indicates that if a tibia fracture occurs before the load in the knee and ankle joint is sufficient to cause injury, then the risk of injury to these joints is reduced. The risk of an ankle or knee fracture is 9% and 5% respectively when there is no fracture and reduces to 2.1% and 1.1% if a fracture occurs. This implies that the incidence of tibia fracture has a protective influence on the knee and ankle joints. Where a tibia fracture occurs, the elderly are more susceptible to ankle and/or knee joint injuries. There are no recorded instances of knee or ankle injury to children or young adults. In the absence of tibia fractures children are least likely to sustain an ankle fracture, whilst the elderly are most likely to sustain a knee fracture.

Though the contact with the tibia will transfer a load to the knee joint, it will not tend to apply any significant loading to the femur or pelvis. However, the incidence of a tibia fracture can change the kinematics of the pedestrian resulting in a different severity of direct loading from the vehicle to the femur and pelvis. The results tabulated in Table 3 show a clear reduction in the frequency of femur fractures when a tibia shaft fracture occurs. In those cases where a bilateral tibia fracture was reported there was no association with either pelvis or femur injuries. The probability of femur fracture reduces from 17.1% to 5.3%, approximately one third of the risk. However for the pelvis, although there is a reduction in the injury risk, the effect is less pronounced reducing from 21.6% to 18.1%. Again, this data would suggest that the incidence of tibia fractures have an injury reducing influence on other lower leg regions.

Table 2 - Inter-relationships between tibia, ankle and knee

	Age Group	With Tibia Shaft Fracture	Without Tibia Shaft Fracture	TOTAL
Ankle Fracture	0-15	0 (0.0%)	4 (4.9%)	
	16-24	0 (0.0%)	4 (10.5%)	
	25-59	1 (2.9%)	7 (12.1%)	
	60 plus	1 (4.5%)	5 (11.4%)	
	All	2 (2.1%)	20 (9.0%)	22 (7.0%)
Knee Fracture	0-15	0 (0.0%)	0 (0.0%)	
	16-24	0 (0.0%)	2 (5.3%)	
	25-59	0 (0.0%)	3 (5.2%)	
	60 plus	1 (4.5%)	6 (13.6%)	
	All	1 (1.1%)	11 (5.0%)	12 (3.8%)
Ankle and/or Knee Fracture	0-15	0 (0.0%)	4 (4.9%)	
	16-24	0 (0.0%)	6 (15.8%)	
	25-59	1 (2.9%)	10 (17.2%)	
	60 plus	2 (9.1%)	11 (25.0%)	
	All	3 (3.2%)	31 (14.0%)	34 (10.8%)
No Ankle or Knee Fracture	0-15	19 (100.0%)	78 (95.1%)	
	16-24	19 (100.0%)	32 (84.2%)	
	25-59	33 (97.1%)	48 (82.8%)	
	60 plus	20 (90.9%)	33 (75.0%)	
	All	91 (96.8%)	191 (86.0%)	282 (89.2%)
TOTAL		94 (100%)	222 (100%)	316 (100%)

Children experience the highest risk of sustaining a femur fracture, whilst the elderly are least likely to receive a fracture to the femur. However, for all age groups the incidence of a tibia fracture has a significant injury mitigating effect for the femur. Young adults between 16 and 24 years have twice the risk of sustaining a pelvis fracture as other pedestrians when the tibia is first fractured. However, in the absence of a tibia fracture the risk for the 16 to 24 year group is reduced. The elderly are most likely to sustain a pelvis fracture without first sustaining a tibia fracture. The overall mitigating affect of a tibia fracture is not seen for the 16 to 24 year group where the risk is twice as high following a tibia fracture.

Table 3 - Inter-relationships between Tibia, Pelvis and Femur

	Age Group	With Tibia Shaft Fracture	Without Tibia Shaft Fracture	TOTAL
Femur Fracture	0-15	2 (10.0%)	20 (25.6%)	
	16-24	1 (5.3%)	6 (15.8%)	
	25-59	2 (6.1%)	9 (14.5%)	
	60 plus	0 (0.0%)	3 (6.8%)	
	All	5 (5.3%)	38 (17.1%)	43 (13.6%)
Pelvis Fracture	0-15	3 (15.0%)	12 (15.4%)	
	16-24	6 (31.6%)	6 (15.8%)	
	25-59	5 (15.2%)	14 (22.6%)	
	60 plus	3 (13.6%)	16 (36.4%)	
	All	17 (18.1%)	48 (21.6%)	65 (20.6%)
Pelvis and/or Femur Fracture	0-15	5 (25.0%)	32 (41.0%)	
	16-24	7 (36.8%)	12 (31.6%)	
	25-59	7 (21.2%)	23 (37.1%)	
	60 plus	3 (13.6%)	19 (43.2%)	
	All	22 (23.4%)	86 (38.7%)	108 (34.2%)
No Pelvis or Femur Fracture	0-15	15 (75.0%)	46 (59.0%)	
	16-24	12 (63.2%)	26 (68.4%)	
	25-59	26 (78.8%)	39 (62.9%)	
	60 plus	19 (86.4%)	25 (56.8%)	
	All	72 (76.6%)	136 (61.3%)	208 (65.8%)
TOTAL		94 (100%)	222 (100%)	316 (100%)

It was reported earlier that in 77.7% of tibia fracture cases, the fibula was also fractured. Table 4 shows the results where only those cases with both tibia and fibula fracture are compared to femur and pelvis fractures. In this case there is a further reduction in the risk of femur fractures, with the risk where there is both tibia and fibula fracture now being only a quarter of that where both the tibia and fibula are not fractured. A greater difference is seen for the pelvis where the risk with tibia and fibula fracture is 13.7% compared to 22.6% for the no tibia and fibula fractures case. This would suggest that whereas the fracture of the tibia significantly reduces the injury risk only to the femur, fracture of both the tibia and fibula significantly reduces the risk to both the femur and the pelvis. Considering the age distributions of the pedestrians, the patterns noted in Table 3 are seen in this data too.

Table 4 - Inter-relationships between Tibia and Fibula, Pelvis and Femur

	Age Group	With Tibia and Fibula Shaft Fracture	Without Tibia and Fibula Shaft Fracture	TOTAL
Femur Fracture	0-15	1 (7.7%)	22 (24.4%)	
	16-24	1 (6.3%)	6 (14.0%)	
	25-59	1 (4.0%)	9 (13.0%)	
	60 plus	0 (0.0%)	3 (7.3%)	
	All	3 (4.1%)	40 (16.5%)	43 (13.6%)
Pelvis Fracture	0-15	1 (7.7%)	15 (16.7%)	
	16-24	5 (31.3%)	8 (18.6%)	
	25-59	2 (8.0%)	14 (20.3%)	
	60 plus	2 (10.5%)	18 (43.9%)	
	All	10 (13.7%)	55 (22.6%)	65 (20.6%)
Pelvis and/or Femur Fracture	0-15	2 (15.4%)	33 (36.7%)	
	16-24	6 (37.5%)	18 (41.9%)	
	25-59	3 (12.0%)	24 (34.8%)	
	60 plus	2 (10.5%)	20 (48.8%)	
	All	13 (17.8%)	95 (39.1%)	108 (34.2%)
No Pelvis or Femur Fracture	0-15	11 (84.6%)	57 (63.3%)	
	16-24	10 (62.5%)	25 (58.1%)	
	25-59	22 (88.0%)	45 (65.2%)	
	60 plus	17 (89.5%)	21 (51.2%)	
	All	60 (82.2%)	148 (60.9%)	208 (65.8%)
TOTAL		73 (100%)	243 (100%)	316 (100%)

In summary, the results presented in this study support the hypothesis that the occurrence of tibia fractures, co-incident with fibula fractures in many cases, has an injury mitigating affect on the risk of injury to the ankle, knee, femur and pelvis. Some differences are noted when considering the age distribution of pedestrians, which result from variations in pedestrian stature and physiological tolerances.

CONCLUSIONS

The MTOS database has been used to investigate the inter-relationship between lower leg injuries according to the sequence of events in a typical pedestrian accident. The database contains details of pedestrians that have received serious injuries in an accident involving hospitalisation and those that were fatalities. A comparison with the UK Stats19 data indicates that the database forms a reasonable representation of the killed and seriously injured national scene. Small variations in the distributions are due to local reasons.

The analysis performed on this database leads to the following conclusions:

- Lower leg injuries are the most frequent injury in serious pedestrian accidents, being sustained by 65.2% of the pedestrians in the sample.
- The most common location of skeletal injury occurring to lower legs are to the tibia (29.7%), fibula (25.3%), pelvis (20.6%), and femur (13.6%).
- Fibula fractures occur in 77.7% of the cases where a tibia fracture is sustained.
- When tibia fractures occur, the risk of injuries to the ankle and knee is reduced significantly for all ages. This implies that the occurrence of a tibia fracture has a protective effect on the knee and ankle joints by reducing the bend and shear forces being transmitted along the tibia.
- The risk of femur and pelvis injuries is affected by the occurrence of a tibia fracture, especially when in combination with a fibula fracture. Children have the highest risk of sustaining a femur fracture, irrespective of tibia fracture. Pelvis fractures are most common in 16 to 24 year olds with a tibia fracture, and in the over 60's without a tibia fracture. It is believed that these trends are due to changing the kinematics of the pedestrian and so lessening the severity of direct impact from the vehicle structure.

These conclusions have an implication for the legform sub-system test being proposed by EEVC WG17 for pedestrian protection. It can be expected that at sufficiently low impact severities a vehicle with good pedestrian design should cause no, or only minor, injuries. However, this will not be true for all impact severities. In higher impact severity accidents, some degree of injury to the lower leg is inevitable, as it is the first point of contact between a moving vehicle and the pedestrian.

The legform impactor has a rigid tibia and will therefore continue to transmit force to the knee joint irrespective of whether a tibia fracture load has been reached or not. Because of this affect, the impactor can not truly replicate the real world kinematics and will overestimate the actual knee loads.

In order to be able to design a vehicle that will provide protection for pedestrians across a broad range of impact severities it is important to have an appropriate test tool. It is well established that tibia shaft injuries are easier to treat and have reduced long term impairment consequences than knee injuries, be they skeletal or ligamentous. The analysis included in this paper indicates that at higher impact severities a potential tibia shaft fracture will lead to a reduction in the forces transmitted to the knee, and thereby protect the knee from an impairing injury. Such a strategy would require that the legform impactor was able to replicate the fracture of the tibia shaft. Some form of frangible tibia that would respond to the primary contact location and permit the legform kinematics to replicate the pedestrian leg kinematics is necessary.

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