crash trends in the before period. However, the after period consisted of different numbers of years. The analysis indicated crash reductions at the treatment sites in the before after analysis.

The findings are consistent with past research on the effectiveness of gateways in lowering crashes. In a study on the effectiveness of traffic calming measures in lowering crashes, Taylor and Wheeler found that gateways (without downstream traffic calming) led to a 43% reduction in fatal and serious crashes while minor crashes increased by 5%. On the other hand, fatal and serious crashes fell by 70% and minor injuries by about 30% with an overall reduction of 45% where downstream traffic calming was also implemented [6].

This study found that gateways led to a 26% reduction in all crashes and 23% reduction in fatal and serious crashes. There was a 35% reduction in all crashes at pinch point gateways with fatal and serious crashes falling by 41%. This indicates that gateways, particularly pinch point gateways, are a useful measure for addressing crash reductions at transition zones.

This evaluation was part of a larger Austroads research project on effective speed management techniques on rural roads (engineering treatments). The information in this paper provides one possible solution for managing speed at rural urban transition zones. Further information on other evaluated treatments is outlined in the project report [7].

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Human body modelling of motorcyclist impacts with guardrail posts

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Abstract

Recent research into motorcyclist collisions with roadside barriers has indicated that while they are infrequent events, they often result in severe injury outcomes. Impacts with steel guardrail (W-beam) barrier posts have been identified as significant contributors to such injuries. Thoracic injury has been revealed as the body region most frequently seriously injured (AIS 3+), amongst fatal and non-fatal collisions. One approach to help reduce such trauma is to perform numerical simulations of motorcyclist-barrier collisions, and to develop and assess barrier types and barrier modifications and their impact on injury outcomes. The aim of the present study is to validate a human FEM model of a motorcyclist impact with a guardrail post, specifically focusing on the incidence and severity of thoracic injuries. Field-observed cases of motorcyclist-barrier collisions in Australia are identified, where a collision of a motorcyclist sliding into a steel guardrail barrier was fully reconstructed. A numerical model of the THUMS human body model sliding into a steel guardrail barrier is developed using LSDYNA. The biomechanical response of the THUMS model is validated against cadaver experiments of blunt anterior-posterior and lateral impacts to the chest, and against the field-observed collisions. The validated model will be a useful tool to develop and assess barriers and barrier modifications designed to improve the safety of roadsides for motorcyclists.

Keywords

Motorcyclist, guardrail, thoracic injury, FEM, computer simulation

Introduction

Motorcyclist serious injuries and fatalities contribute significantly to road trauma in Australia and internationally. Per distance travelled, Australian motorcyclists are 30 times more likely to be killed and 37 times more likely to be seriously injured than car occupants [6]. While motorcycle collisions with barriers are rare events (5.4% of motorcyclist fatalities in Australasia), they often result in serious and fatal injuries to motorcyclists [8, 10]. The MAIDS study [14] identified 60 injuries resulting from barrier collisions, while Peldschus et al. [17] reported injury profiles from a European study of motorcyclist collisions with roadway infrastructure including roadside barriers. More recently, Bambach et al. [3] and Bambach et al. [4] described injuries resulting from single-vehicle motorcycle-barrier collisions in Australasia for fatal and non-fatal cases, respectively, while Daniello and Gabler [5] reported non-fatal cases in the United States. These studies have indicated that motorcycle collisions with roadside barriers can result in severe injuries and fatalities, and present a considerable injury risk to motorcyclists.

Of particular concern raised in these motorcycle-barrier collision studies was the incidence of serious thoracic injury (AIS severity 3 or greater, AAAM 2005). Bambach et al. [3] found that amongst motorcyclists fatally injured in single-vehicle collisions with roadside barriers, the thorax was the body region with the highest incidence of serious injury (81% of motorcyclists), and the highest incidence of maximum injury (50% of motorcyclists). This study also highlighted the substantial injury potential provided by the posts of steel W-beam barriers, as have other studies [17]. For non-fatal collisions with barriers, Bambach et al. [4] also found the torso (thorax and abdomen) had the highest incidence of serious injury (42% of motorcyclist casualties). Daniello and Gabler [5] also found that the thorax was the most frequently seriously injured body region following motorcyclist single-vehicle collisions with barriers.

The provision of a safe road environment for all road users, including motorcyclists, is an objective of all road authorities and is the basis of the Safe Systems approach recently adopted in Australia [2]. Therefore, there is a need to address the injury potential of roadside barriers to motorcyclists, and in particular, the most harmful injury mechanism of thoracic injury. There is also a need to assess barrier modifications and their efficacy in reducing the injury potential of barriers to motorcyclists. This is especially true for roadways that form popular motorcycling routes.

One approach to help reduce such trauma is to perform crash tests and/or numerical simulations of motorcyclist-barrier collisions. Currently there is no established procedure in Australia for the testing of motorcyclist collisions with roadside barriers, while there exists a European technical specification for such crash tests [19]. However, the European specification does not prescribe injury assessment methods for thoracic injury, which severely limits its applicability to Australian conditions. Additionally, there are significant cost implications associated with performing crash tests.

The present approach adopted to assess thoracic injury in such collisions was to develop a human body model of a motorcyclist impacting a barrier. A valid finite element method (FEM) numerical model of such collisions may be used to assess different barrier types (such as steel W-beam, concrete and wire-rope barriers) and barrier modifications (such as rub-rails, protectors and post paddings), and their impact on injury outcomes. The specific aim of the present study is to validate a human FEM model of a motorcyclist impact with a guardrail post, focusing on the incidence and severity of thoracic injuries.

Methods

Motorcyclist-barrier collision crash cases

In a previous study by the authors Bambach et al. [3], 78 fatal motorcyclist-barrier collisions were identified that occurred in Australia and New Zealand during the period 2001 to 2009 (inclusive). The full Coronial case files were collected from the various Coroners Courts; being the documents relating to the inquest held to formally establish the cause of death. These files typically contained a police report (including a reconstruction of the crash scene and events as determined by the on-scene investigating police), an autopsy, a toxicology report and a mechanical inspection report.

For the purposes of the present study, cases were identified that involved a motorcyclist colliding with a steel W-beam barrier (guardrail) in the sliding posture, and for which a full reconstruction of the crash scene was available, including the approach angle, sliding distance, pre-crash speed and final resting position of the motorcyclist. The injuries sustained by the motorcyclist were coded to the Abbreviated Injury Scale [1] and only serious injuries were coded (AIS 3+). The sliding posture involves the motorcyclist impacting the roadway prior to contact with the barrier, then sliding along the road surface into the barrier.

Cases were identified where the motorcyclist was likely to have collided with the post of the guardrail. These were identified as when either: a witness saw the motorcyclist impact a post; the motorcyclist was found lying in contact with a post; or the motorcyclist was found immediately adjacent to a post. Motorcyclists that were redirected along or away from the barrier and were found lying in the roadway were assumed to have impacted the W-beam of the barrier rather than a post (redirected) and were excluded from the study. The post-collision cases with serious thoracic injury were assumed to have impacted the post in the thorax-leading orientation. Two thorax-leading impact scenarios were considered, where the motorcyclist was assumed to impact the guardrail post with the thorax laterally or frontally, as shown in Figure 1a and 1b, respectively. Cases where the thoracic injuries occurred predominantly unilaterally were assumed to have resulted from impact with a post in the lateral orientation, and those occurring bilaterally were assumed in the frontal orientation.

The post impact speed was determined from the pre-crash speed and the measured distance the motorcyclist slid on the roadway. Several authors have determined drag coefficients for humans sliding on roadways, with values ranging from 0.37 to 0.75 [18, 7, 16, 21]. A mean value of 0.6 was used in the present analysis, and standard equations for velocity changes occurring from sliding distances were employed.

FEM model development

The Total Human Model for Safety (THUMS) average size male (50th percentile - AM50) FEM model was used to simulate the human body, developed by Toyota Motor Corporation [9]. The THUMS model simulates human body kinematics and injury responses in crashes. High-resolution CT scans were used to digitise the interior of the body and to generate precise geometrical data for the bones, organs, tissues, ligaments, muscles, skin etc. The FE mesh consists of around 2,000,000 elements representing the components of the human body.

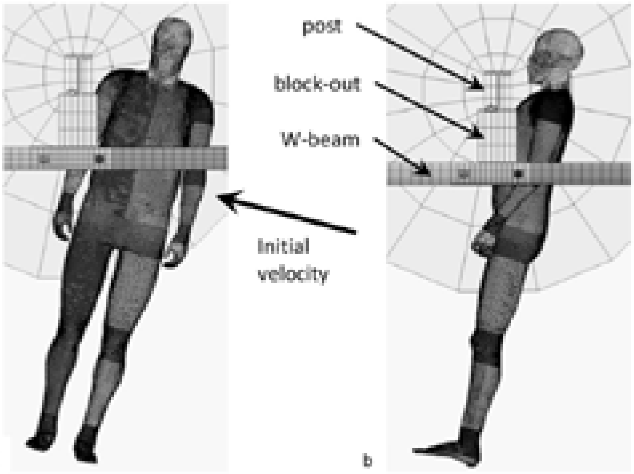

Figure 1. FEM model of THUMS impacting a guardrail post in the thorax-leading orientation; a) lateral impact, b) frontal impact

The steel W-beam barrier FEM model developed by the National Crash Analysis Centre (NCAC) at George Washington University in the United States [15] was used to simulate the barrier. The barrier model consists of steel posts set into the ground, wooden blockouts and steel W-beams (Figure 1). The FEM mesh consists of around 125,000 elements and is used extensively for vehicle-barrier collision modelling. In Australia, guardrail posts are typically 150mm deep steel C-sections. The steel post in the FEM model is a 150mm deep I-section, thus the use of this model assumes the motorcyclist impacted the open face side of a C-section post. The impact position of the thorax on the post was assumed to be the same in all cases, and was determined by sliding the THUMS model into the barrier at an angle of 15 degrees (the average angle of all 78 cases in Bambach et al. [3]), such that the head did not contact the preceding post.

Validation of the thorax of the human body model with cadaver tests

The biofidelity of the THUMS model was validated against experiments on cadavers subjected to blunt anterior-posterior and lateral impacts to the chest. The anterior-posterior thoracic impacts [12, 13] were generated with a six inch diameter unpadded impactor of varying mass (3.6 to 52 pounds) propelled at varying velocities (11 to 32 mph). The lateral thoracic impacts [20] were generated with a 150mm diameter unpadded impactor with a mass of 23.4kg propelled at varying velocities (4.5 to 9.4 m/s). The experimental setup and impact conditions were modelled with THUMS. The force-deflection response corridors of the impactors in the cadaver experiments were compared with those obtained with the THUMS model.

Validation of the motorcyclist-barrier collision model with collision crash cases

The numerical model of the motorcyclist-guardrail collision was validated against the field-observed motorcyclist-barrier collisions. For each crash case, the initial crash conditions were input into the model (impact speed, angle and frontal/lateral orientation). In the cadaver studies [12, 13, 20] the incidence and severity of thoracic injuries were found to be closely associated with the normalised thoracic compression, being the thoracic deflection divided by the thoracic diameter. The thoracic diameter is the width of the thorax measured along the direction of the applied impact load. The normalised thoracic compression was used to compare the motorcyclist-guardrail collision model results with the field-observed crashes.

Results

Motorcyclist-barrier collision crash cases

A total of nine cases were identified from the motorcyclist-barrier collision crash cases in the sliding posture, where the motorcyclist was likely to have collided with the post of the guardrail in the thorax-leading orientation. These cases are summarised in Table 1. The assumed impact orientation is tabulated in Table 1, where three cases were assumed to have occurred laterally with the remaining six frontally. The calculated post impact speeds varied between 25.9km/h and 76.2km/h, and the impact angles varied between 5 and 32 degrees. The maximum AIS severity levels of the thoracic injuries (MAIS) were generally quite severe, ranging from AIS3 to AIS6 with five cases of critical injury (AIS5+), which is to be expected considering the high impact speeds and the fact that the crashes were fatal.

Validation of the thorax of the human body model with cadaver tests

A variety of impactor mass and speed combinations were modelled for frontal and lateral thoracic impacts and the THUMS model generally performed well, with the force-deflection curves lying approximately within the response corridors. Some examples are presented in Figure 2.

Validation of the motorcyclist-barrier collision model with collision crash cases

The crash mechanics of the motorcyclist-barrier post collision numerical model is presented in Figure 3 for the thorax-leading lateral orientation. The frontal orientation results were similar, where the majority of the motorcyclist kinetic energy is expended upon impact with the rigid post, and the motorcyclist body wraps around the post.

Table 1. Motorcyclist-barrier collision crash cases with guardrail post impacts in the thorax-leading orientation

Assumed impact orientation	Thoracic injuries determined from autopsy	MAIS thorax	Post impact speed [a] (km/h)	Impact angle (degrees)	Thoracic deflection/ thoracic diameter
Frontal	L ribs #1-4 fx, R rib #2 fx, ruptured pericardial membrane, perforated R heart ventricle, L lung collapse, R lung oedema, R lung contusions, L haemothorax	6	75	21	0.562
Frontal	Multiple bilateral rib fx with flail chest, transected sternum, multiple heart lacerations with rupture, bilateral haemothorax	5	63	16	0.539
Frontal	Bilateral lung collapse, bilateral haemopneumothoraces, posterior subparietal pleural haemorrhages, transverse fx at T1-T2 with partial cord transection	4	26	19	0.423
Frontal	Tension pneumothorax, multiple bilateral rib fx	5	76	16	0.592
Lateral	L lung contusions and lacerations, L haemothorax, L ribs #3-8 fx (parasternal), R ribs #5-8 fx (lateral)	3	29	18	0.393
Frontal	Bilateral collapsed lungs, L ribs #1-12 fx (anterolateral), R ribs #1-6 fx (anterior), flail chest with sternum fx, bilateral haemothoraces, pericardium and heart lacerations, aorta transection	6	63	16	0.534
Lateral	L flail chest with ribs #5-11 fx (posterolateral), L lung contusions and lacerations, L lung collapsed, L haemopneumothorax, diaphragm lacerations	4	39	28	0.527
Lateral	L ribs #2-6 fx (parasternal)	3	30	32	0.417
Frontal	R ribs #3-5 fx, L ribs #3-5 fx, sternum fx, bilateral haemothoraces, R ventricle and L atrium ruptures, T3 fx with cord transection	6	72	5	0.566

L = left, R = right, fx = fracture

[a] calculated from the pre-crash speed estimate and measured sliding distance

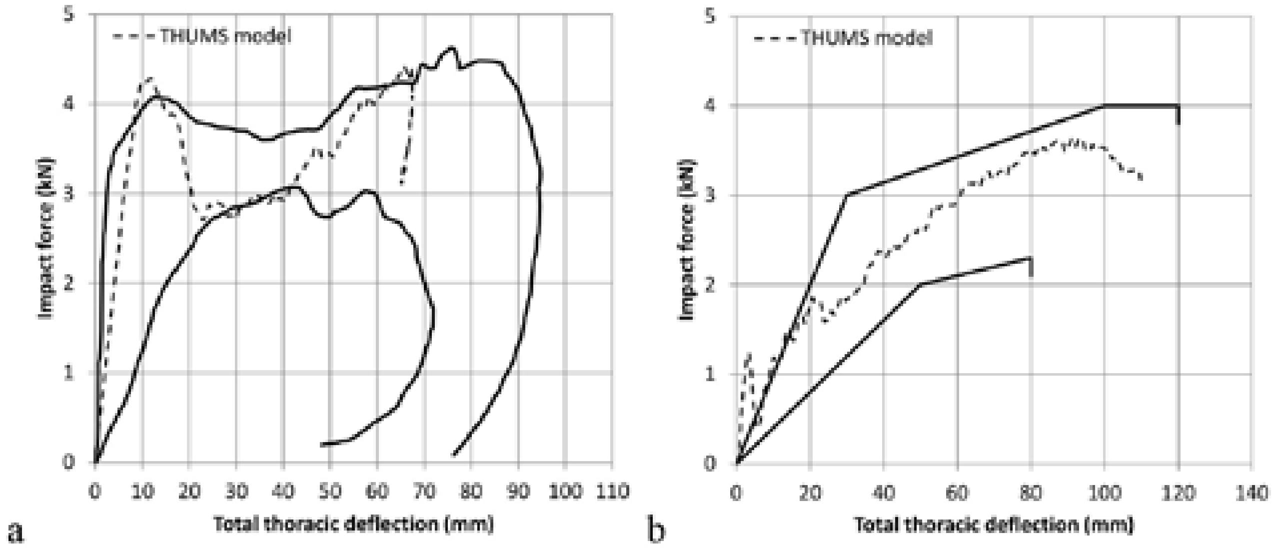

Figure 2. Force-deflection response of the THUMS model compared with the cadaver response corridors; a) frontal thoracic impact with a 23.1kg impactor at 7.2m/s (Kroell et al 1974), b) lateral thoracic impact with a 23.4kg impactor at 6.7m/s (Viano et al 1989)

The response of the thoracic bony structures and internal organs to lateral impact is presented in Figure 4. The impact is somewhat dampened by the presence of the upper arm (not shown), however significant lateral compression of the thorax results as the leading side of the thorax stops against the post and the inertia of the torso compresses the ribs and internal organs.

The biomechanical response of the THUMS model to thorax-leading impact with a guardrail post in the frontal and lateral orientations is expressed as the normalised thoracic deflection from the model. The FEM normalised thoracic deflection results are tabulated in Table 1, and plotted in Figure 5 against the MAIS of the field-observed injuries. The thoracic FEM normalised deflection and MAIS values are compared with those determined experimentally with cadavers [13, 20] in Figure 5. The full results for the variety of initial impact conditions tested in the cadaver experiments are presented.

Discussion

Notwithstanding the large variability in the cadaver experiments with respect to age, gender, physiological condition and experimental variability [12, 13, 20], the results in Figure 2 suggest that the THUMS thorax model is a biomechanically valid representation of the human thorax of an average size male. The THUMS thorax typically unloaded at a lower deflection than in the cadaver tests under frontal impact. However, in the majority of cases subjected to the impact conditions in Figure 2 (12 of 13 cadavers), the cadavers sustained multiple rib fractures. Rib fractures were not explicitly modelled with THUMS, thus the THUMS model could be expected to be stiffer than the cadavers subsequent to rib fracture.

The results of the THUMS impact with a guardrail post in the thorax-leading orientation, shown in Figures 3 and 4 for lateral impact, are generally in agreement with the field-observed collisions of direct impacts with a guardrail post, where the majority of the motorcyclist kinetic energy is dissipated during the impact and the motorcyclist resting position was against or adjacent to the post.

The biomechanical response of the THUMS thorax in response to the guardrail post impact is generally in agreement with that derived from cadaver experiments [12, 13, 20], where increasing kinetic energy results in increasing thoracic compression, which in turn results in increasing thoracic injury severity. However, the comparisons in Figure 5 indicate that the numerical predictions of thoracic compression for the motorcyclists tend to over-estimate those determined from the cadaver experiments. That is, for a motorcyclist that sustained a thoracic injury of a particular AIS severity, the numerical model of the motorcyclist impacting the guardrail post predicted thoracic compression greater than that observed in cadavers with the same AIS severity. Assuming that the THUMS model is a reasonable representation of an average size male thorax under impact (Figure 2), the over-estimation of the thoracic compression in the guardrail post impact numerical models may therefore be attributed to: the idealisation of the post impact orientation and impact surface; and/or uncertainties in establishing the initial post impact conditions; and/or physiological differences between the cadavers and the motorcyclists. These issues are discussed further below, and should be considered as limitations to the numerical modelling approach used in this study.

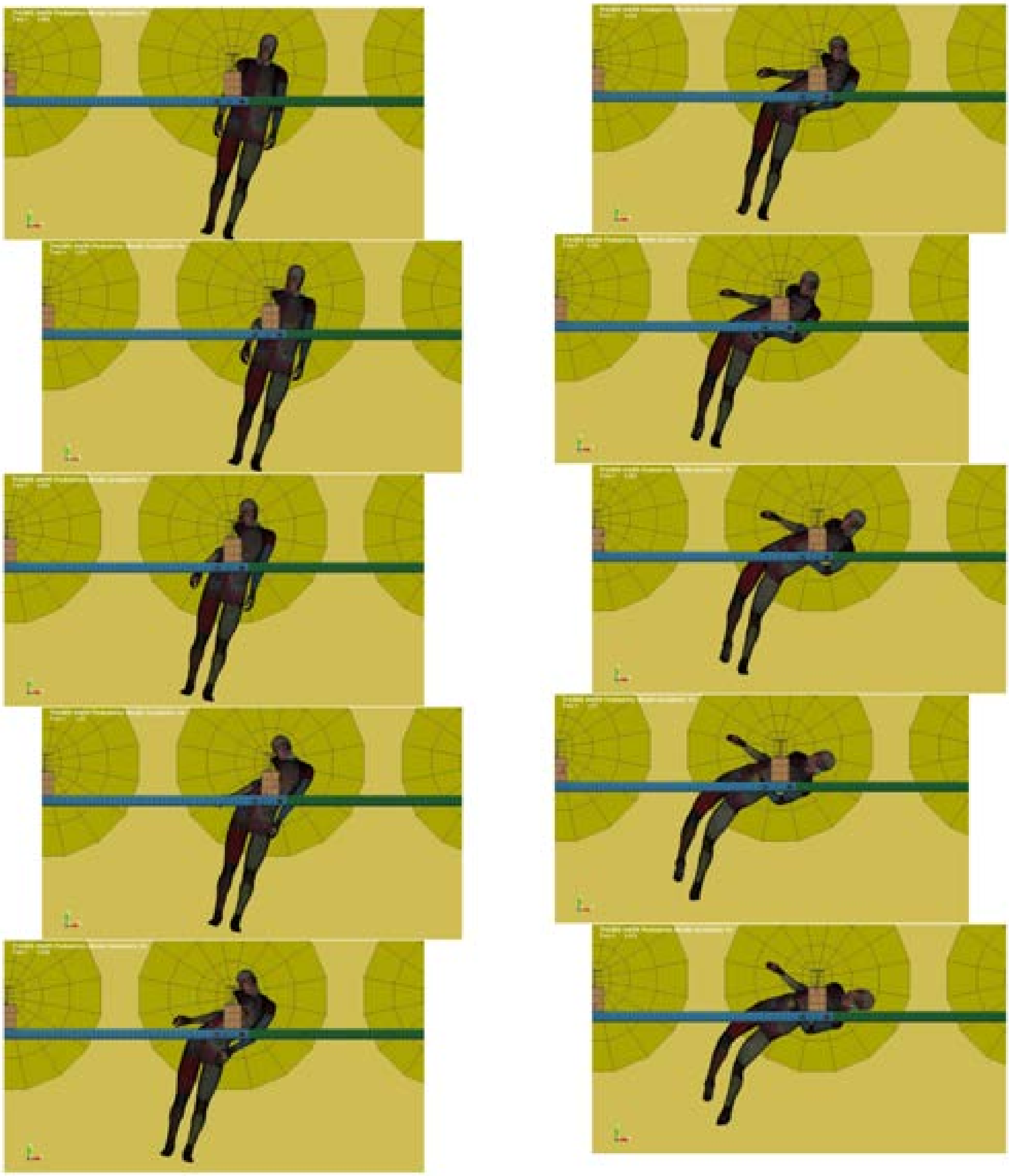

Figure 3. THUMS impact with a guardrail post in the thorax-leading lateral orientation at 40km/h. Each frame represents 0.008ms.

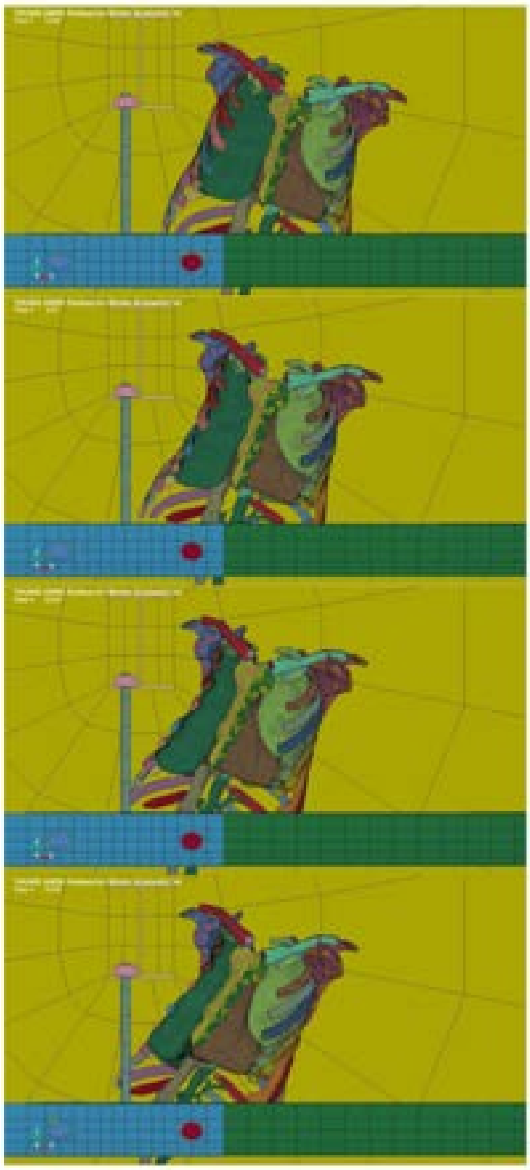

Figure 4. Deformation of the thoracic structures during the THUMS impact with a guardrail post in the thorax-leading lateral orientation at 40km/h. Each frame represents 0.004ms.

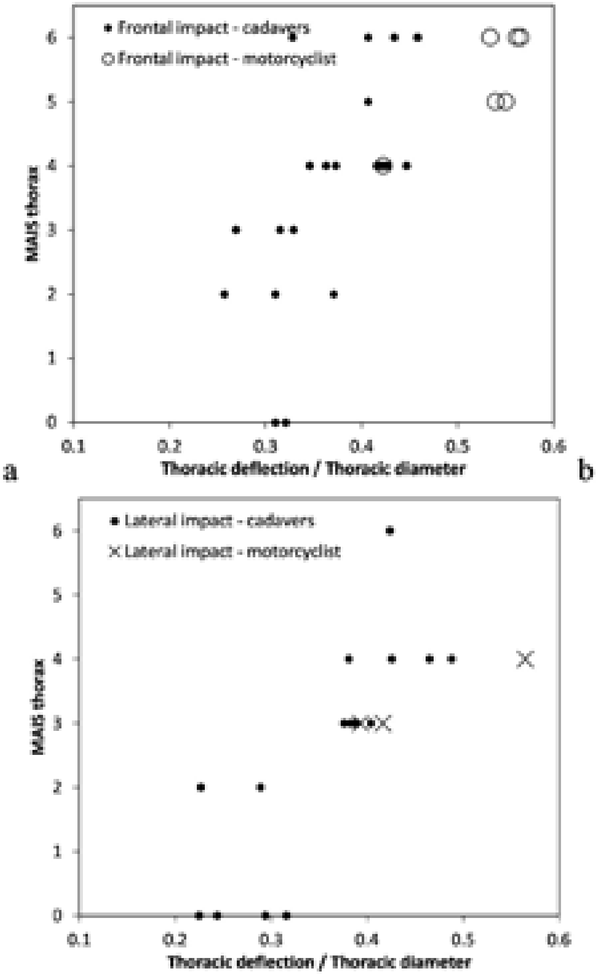

Figure 5. Comparison of the thoracic FEM normalised deflection and field-observed MAIS values from motorcyclist collisions with a guardrail post, with cadaver responses; a) frontal thoracic impact (Kroell et al 1974), b) lateral thoracic impact (Viano et al 1989)

It is likely that in the motorcycle crashes the motorcyclist underwent substantial tumbling in addition to sliding along the surface of the roadway prior to impact with the barrier, thus the motorcyclist may not have impacted the barrier post in either the idealised orientation or position that was assumed in the numerical models (ie position of the thorax relative to the post). Indeed the fact that the motorcyclist directly impacted the post was inferred from the on-scene police investigation reports and was not known for certain, except in one case where there was a witness to the crash. The direct thorax impact assumed in the numerical model may over-represent the severity of the impact, which may have led to an over-estimation of the thoracic compression. Additionally, the impact surfaces were different between the motorcyclists and the cadavers, where the former consisted of the leading edge of an I-section post, while the latter was a comparatively large surface area of diameter 150mm. For the lateral-post orientation, the upper arm directly contacted the leading edge of the post which distributed the impact load to the thorax. The use of an I-section post FE model assumed that the motorcyclist impacted the open side of the C-section post. Different impact surfaces may lead to different load concentrations, which might result in different relationships between local maximum deflection and injury severity. Analysis of the crash scene photographs and reconstructions indicated that the motorcyclists were facing the open side of the C-section posts in one of the three lateral-post impacts and four of the six frontal-post impacts. The FE models were modified to close the face of the I-section post such that it presents the same shape as the closed face of a C-section post. This made negligible difference to the lateral-post impacts, due to the load spreading influence of the upper arm. An average decrease in thoracic compression of 3.7% resulted for the frontal-post impacts, which is nearly negligible due to the fact that the leading corner of the post contacts high on the rib cage at the third rib (Figure 1), thus the presence of the closed face of the post above this point had little influence on the thoracic response.

Similarly, there is substantial uncertainty in the initial impact conditions, where the pre-crash speed is a police-reconstructed estimate and the coefficient of sliding friction is a mean value from a wide range of values reported in the literature. However, the impact angle and sliding distance were relatively well established from careful measurements of the markings on the roadway by on-scene police. The pre-crash speed may have been over-estimated by police and/or the sliding friction value may have under-estimated the real friction of the roadway, which may have led to an over-estimation of the severity of the impact and consequently the thoracic compression.

A further limitation of the study is that there were substantial physiological differences between the cadavers and the motorcyclists. The cadaver ages ranged from 19 to 81 years with a mean of 59 years, and 79% were male. The motorcyclist ages ranged from 21 to 70 years with a mean of 37 years, and all were male. It is possible that the THUMS average size male model predicted a relatively accurate magnitude of thoracic compression and that the motorcyclists did indeed undergo such a compression, however for physiological reasons such compression magnitudes did not result in as severe injuries in the motorcyclists as those that occurred in the cadavers. It is well known that thoracic injury severity, particularly that resulting from rib fractures and concomitant organ injuries, is closely associated with age [11]. For example at a normalised frontal thoracic deflection of around 0.3, the probability of sustaining more than six rib fractures is around 10% for a 30 year old while around 40% for a 70 year old.

Conclusions

Notwithstanding the rather substantial uncertainties associated with human body modelling of cadaver experiments and field-observed motorcyclist crashes, the numerical results are generally in agreement with the experimental and crash cases with regards to thoracic injury mechanisms and injury severity. The numerical model of a motorcyclist collision with a guardrail post in the thorax-leading orientation may therefore be considered a valid representation of an average size male motorcyclist subjected to such impacts. The validated model will be a useful tool to develop and assess barrier types and barrier modifications designed to improve the safety of roadsides for motorcyclists, with regards to the most frequent and serious injury mechanism of thoracic injury. Work is ongoing in this area, as are numerical validation studies of the next most frequently occurring serious injuries of injuries to the head and neck.

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Age and gender differences in perceptions of traffic risk and safety for older pedestrians in metropolitan Sydney

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Keywords

Aged, Behaviour, Perception, Risk, Safety, Survey, Traffic Crashes

Abstract

Older pedestrians are over represented in serious injury and fatality statistics compared to younger age groups and are considered to be at fault in over 72% of pedestrian-motor vehicle crashes. This study sought to investigate the perceptions of risk and safety in the local traffic environment as reported by older people in the course of everyday pedestrian journeys by asking them to complete a kerb-side survey. The majority of the older pedestrians interviewed (475 women: 265 men) considered that they engaged in safe pedestrian activity and that their own behaviour did not make them vulnerable road users. Perceptions of risk were predominantly associated with external factors such as motorist behaviour and traffic speed. Men tended to be more confident of their own abilities in traffic situations, reported less difficulty crossing roads and paid less attention to route selection than women. Increasing age (65 to 95 years) did not appear to change these perceptions. This is an important consideration for caregivers and medical practitioners when discussing road safety issues with older people, and a critical concern for professionals involved in the planning and implementation of traffic awareness and road safety campaigns for older people.