Protecting pedestrians in vehicle collisions: Results from 2 years of the Australian New Car Assessment Program and the analysis of actual accidents

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Abstract

The Australian New Car Assessment Program (ANCAP) has included the evaluation of vehicles' ability to protect pedestrians from injury, should a collision occur, since the year 2000. This work has been carried out in Australia by the Road Accident Research Unit at the University of Adelaide (RARU). The tests consist of sub-system tests that simulate the impact between a vehicle and the head, upper leg, knee and lower leg of a pedestrian, conducted to a protocol consistent with EEVC WG10 procedures. At the time of writing the results from 19 cars tested by RARU have been published by ANCAP, along with results of tests carried out to the same protocol by EuroNCAP. This paper will present a detailed analysis and summary of the results of the ANCAP testing, against the background of the analysis of actual accidents. Cars have generally performed poorly in these tests when measured against the requirements placed on them by ANCAP, although the experience of testing has demonstrated ways in which the designs of cars could be altered to improve the results of ANCAP tests, suggesting future trends in the design of vehicles for pedestrian protection. Meanwhile the analysis of actual accident data would seem to support the focus on these body regions by ANCAP. The reconstruction of actual collisions using the same testing protocol indicates that the risk of head injury predicted by the ANCAP protocol is valid. However, the same reconstruction data suggests that more evaluation is required to validate the test procedures as a measure of the risk of injury to the lower leg.

Introduction

The Australian New Car Assessment Program (ANCAP) provides consumers with information on the safety performance of new passenger vehicles on the market. While the focus of the ANCAP program has been on the safety of occupants, ANCAP also conducts testing on vehicles to ascertain their safety performance in the event of a collision with a pedestrian. The Road Accident Research Unit has been conducting the pedestrian sub-system tests for ANCAP, and at the time of writing has completed tests on 19 vehicles. This paper presents a detailed analysis and summary of the results of the ANCAP testing, against the background of the analysis of actual accidents.

The protocols being used for testing have been determined by EuroNCAP and are largely based on the work of the European Enhanced Vehicle-safety Committee (EEVC). Indeed the ANCAP pedestrian program is harmonised and coordinated with EuroNCAP to increase the number of test results available to consumers.

The protocol makes use of three sub-system tests. The sub-system tests consist of:

- A full-leg impactor that simulates the impact between the bumper of the car and the lower leg and knee of an adult pedestrian. Knee injury risk is measured by the deformation of steel “ligaments” in rotation and shear. The risk of lower leg fractures is measured by the acceleration of the “tibia” section of the legform.
- An upper leg impactor that simulates the impact between the leading edge of the bonnet of the car and the femur and pelvis of an adult pedestrian. The risk of femur and pelvic injury is assessed by the measurement of the impact forces and the bending moment applied to a steel “femur” in the impactor.
- Two headforms representing the impact between the upper surface (bonnet, windscreen and A-pillars) of the vehicle and the head of an adult and child pedestrian. Head injury risk is assessed by the calculation of the Head Injury Criterion value (HIC).

Figure 1 shows the different impactors and their impact locations. Figure 2 shows how the exterior surface is divided into test zones (see Williams et al., 1999 for vehicle marking procedure) and the numbers of tests made in each zone.

Table 1 summarises the ANCAP assessment protocol (see Hobbs et al., 2001 for assessment protocol details). The protocol defines a lower and higher performance limit for each measurement made in the test, such that each result falls in one of three categories: “fair”, “weak” or “poor”. Each test result is rated with a point score based on the specified performance limits and these point scores are tallied to arrive at a score for the vehicle’s overall performance, with a maximum of 36 points. In the legform tests, where the tests produce more than one measure of performance, the lowest scoring measure is used to rate the test.

Manufacturers may contribute to the process of assessment by nominating the locations of 3 adult headform tests, 3 child headform tests, as well as 1 test for both the lower and the upper legform. Based on the vehicle’s overall score, ANCAP assigns the vehicle a star rating. The maximum that may be achieved by a vehicle is 4 stars. The pedestrian star rating is independent from, and has no influence on, the star rating that is based on the offset frontal test and side impact test also performed by ANCAP.

Table 2 gives the definition of the star rating that derives from the total point score.

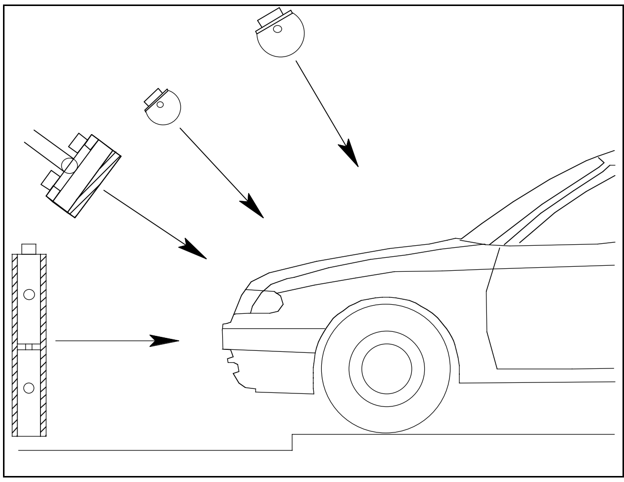

Figure 1 Schematic of the sub-system impactors and the impact locations on the vehicle

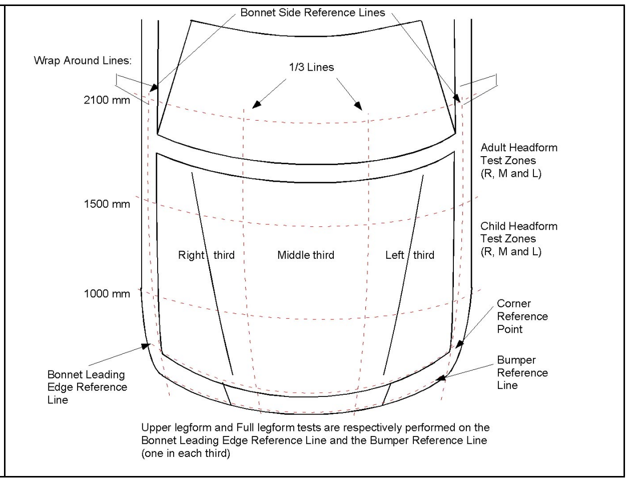

Figure 2 The exterior surface of the car divided into test zones

Table 1 The performance limits and the measurement criteria according to ANCAP based on EEVC WG10

Impactor type	Measurement Criteria	Performance Limits			Maximum point score
		Fair 2 points	Weak 2 - 0 points†	Poor 0 points	
Full legform	Tibia Acceleration (g)	a < 150	150 ≤ a < 230	a ≥ 230	6 from 3 tests
	Knee shear displacement (mm)	d < 6	6 ≤ d < 7.5	d ≥ 7.5	
	Knee bending angle (degrees)	angle < 15	15 ≤ angle < 30	angle ≥ 30	
Upper legform	Femur Forces (kN)	F < 4	4 ≤ F < 7	F ≥ 7	6 from 3 tests
	Bending Moment (Nm)	M < 220	220 ≤ M < 400	M≥ 400	
Adult Headform	HIC value	HIC < 1000	1000 ≤ HIC < 1500	HIC ≥ 1500	12 from 6 tests
Child Headform	HIC value	HIC < 1000	1000 ≤ HIC < 1500	HIC ≥ 1500	12 from 6 tests

† The point score in the "weak" range is determined by a sliding scale between 0 and 2.

Table 2 The star rating definition derived from the total vehicle point score

Range of points	Number of stars
27.5 - 36	4
18.5 - 27.49	3
9.5 - 18.49	2
0.5 - 9.49	1
0 - 0.49	0

Performance of vehicle in the Australian New Car Assessment Program

At the time of writing, 19 vehicles have been assessed for pedestrian protection by ANCAP. The makes and models are listed in Figure 3 to 5. The bulk of vehicles have scored 2 stars, the exceptions being the Mazda 323 Protégé, Mazda 121 and the Nissan Pulsar LX all of which scored 3 stars, and the Holden Barina XC which scored only 1 star. Figure 3 to Figure 5 provide more detail on the performance of vehicles in individual tests, the light coloured bars indicate a "fair" result, with progressively darker bars for "weak" and "poor" results. As an illustration, the Mazda 323 Protégé scored 4 points in the full legform section of the assessment (Figure 3). In two tests, all injury measures were in the "fair" range, while the third test the knee rotation was in the "weak" range and the other measures were in the "poor" range. The vehicles are listed in descending order of their performance in the relevant section of the assessment.

The 79% of vehicles that achieved a 2 star rating, did so predominantly on the results of the head impact tests. (A vehicle will generally achieve a base score of 12 points from the Headform tests as half of the head impact locations are chosen by the vehicle manufacturer. These points are chosen to give the best result.) The 3 vehicles that achieved 3 stars were able to do so by virtue of the fact that each car scored over 3 points for the full leg tests and achieved a score close to 1 point in the upper leg tests.

Full legform tests

Fifty percent of tests failed the knee-bending criterion in the full legform tests in a manner that bent the legform to its mechanical limits (30˚). However, only 14% of tests exceeded the knee displacement limit of 7.5 mm, and 35% percent of tests produced a tibia acceleration greater than 230 g (Figure 3). The poor performance in knee bending can be attributed to the protrusion of bumpers, and the stiffness of the relatively rigid steel cross member that is usually placed behind the bumper fascia.

Upper legform tests

None of the upper legform tests passed the “fair” criteria in either bending moment or femur forces (Figure 4). More than half the tests exceeded the criteria for a “poor” result for bending moment and femur forces (61% and 56%) giving 0 points for those particular test locations. In total, 68% of upper leg test scored no points. This meant that 9 out of the 19 vehicles received 0 points in this section of the assessment. Poor performance in the upper legform test may be attributed to the stiffness of the bonnet leading edge.

Headform tests

The result of a headform test is determined by the stiffness of the area being struck, with stiff areas producing high accelerations, and consequently, high HIC values. Areas that produce poor results include the A-pillars, the base of the windscreen and those parts of the bonnet that have stiff structures immediately below it, such as suspension towers and the engine block. In general the bonnet of a car is not inherently dangerous and areas on the bonnet that perform well usually have large clearances below.

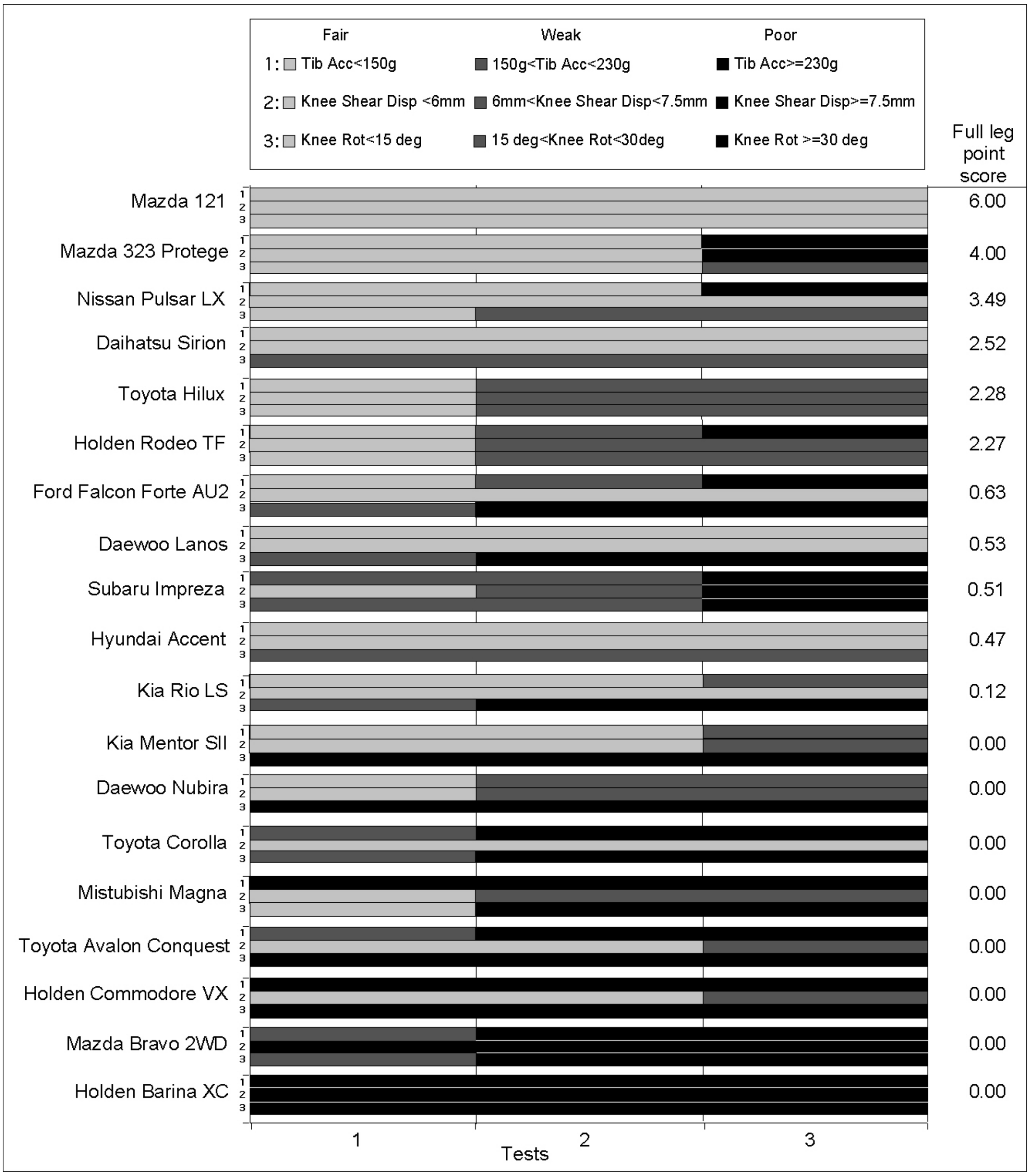

Figure 3 An overview of the ANCAP full leg test results.

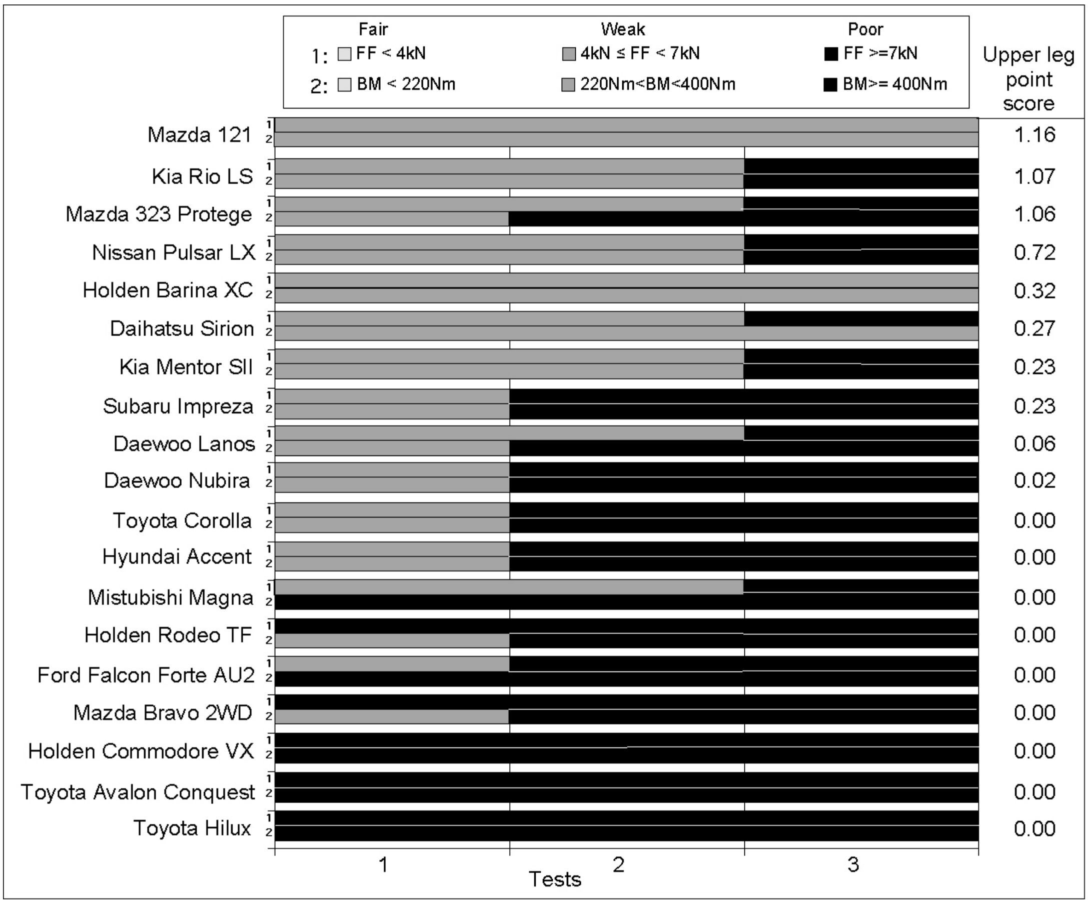

Figure 4 An overview of the ANCAP Upper leg test results

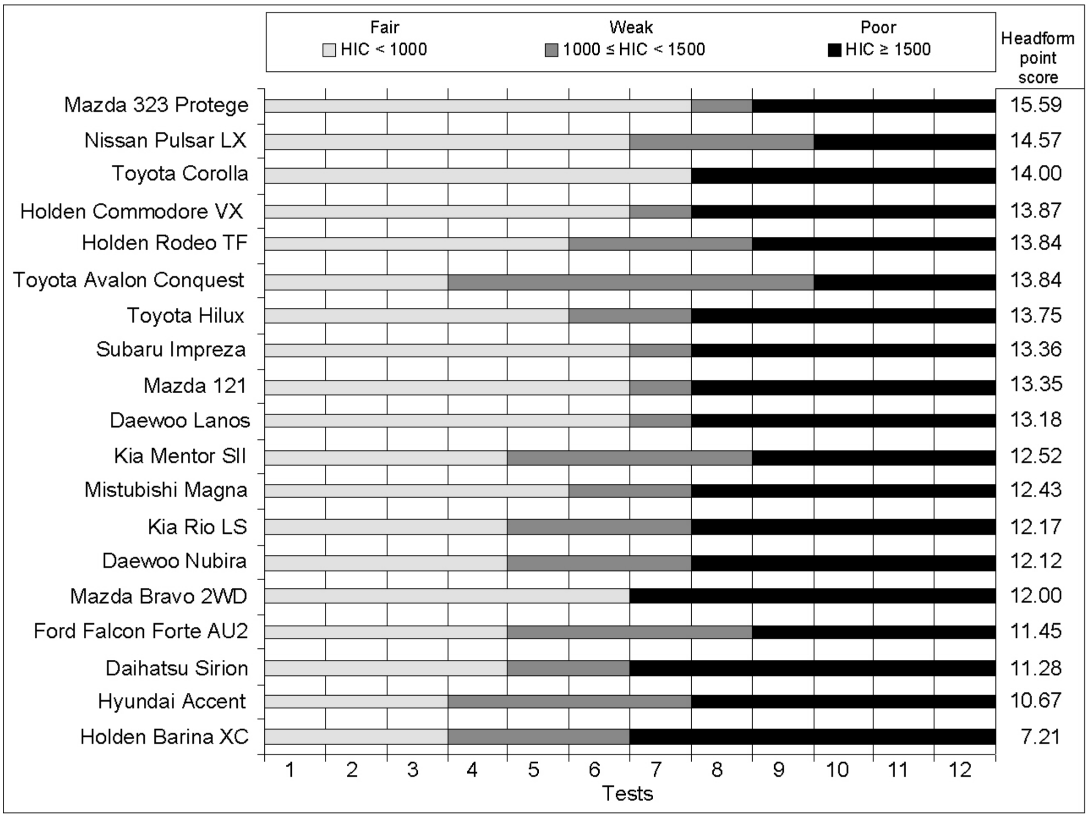

Figure 5 An overview of the ANCAP head impact test results.

ANCAP assessment and real-world injury data

Given that vehicles do not generally do well in the ANCAP tests, it is of interest to see if this performance is reflective of actual accident experience. Recently, the RARU undertook a study of the effects of vehicle design and impact speed on pedestrian injuries for the Australian Commonwealth Department of Transport and Regional Services (Anderson et al., 2000 and Anderson et al., 2002a). The study comprised of detailed at-scene investigations of eighty pedestrian collisions. The SA Ambulance Service notified the RARU of the accidents and, as such, the study covered a range of severities from minor injuries to fatalities. The injuries sustained by each pedestrian involved in the 80 cases were coded according to AIS90 (AAAM, 1998, 'The Abbreviated Injury Scale, 1990 revision').

Table 3 lists the incidence of MAIS3+ and MAIS 2+ injuries affecting body regions as defined by AIS90. (MAIS being the single most severe injury in separate body regions.) This table supports the focus of the test procedures on head and lower extremity injury. These body regions account for more than 50% of the body regions injured to MAIS2+ in the sample of cases. Note though, that when more severe injuries are considered (MAIS 3+), other body regions have a higher prevalence of injury than the lower extremities.

Table 3 Incidence of AIS3+ injuries by body region (using single most severe injury to the body region) in pedestrians struck by vehicles

Body region (by AIS code)	MAIS 3+		MAIS 2+	
1 Head	16	(43%)	25	(28%)
2 Face	1	(3%)	6	(7%)
3 Neck	0	(0%)	1	(1%)
4 Thorax	6	(16%)	6	(7%)
5 Abdomen	4	(11%)	7	(8%)
6 Spine	6	(16%)	7	(8%)
7 Upper extremities	0	(0%)	13	(15%)
8 Lower Extremities	4	(11%)	23	(26%)
Total	37	(100%)	88	(100%)

The incidence of specific injuries targeted by the ANCAP sub-system test procedures is listed in Table 4. The incidence of the injuries is expressed as a percentage of the total number of pedestrians struck in the sample of accidents. It may be seen that the incidence of serious head injuries, pelvic fractures and fractures of the leg below the knee are common. It may also be seen, however, that ruptured ligaments of the knee and fractures to the femur are rare.

Table 4 Incidence of injuries to pedestrians struck by vehicles, corresponding to the sub-system tests (one per injury type per pedestrian)

Injury type	Count	Proportions of total sample (N=67)
Head injury (MAIS 3+)	16	24%
Fractured femur	0	0%
Fractured pelvis	9	13%
Fractured tibia/fibula	14	21%
Ruptured ligament in knee	1	2%

Ten of the eighty collisions were reconstructed using the ANCAP sub-system impactors. This paper presents only a summary of the results of the reconstructed crashes. For a detailed description of the selection, modelling and the physical reconstruction of those ten cases, see Anderson et al., 2002a and Anderson et al., 2002b. Reconstructions were based on scene and vehicle examinations, interviews, computer modelling and the physical reconstruction of impacts between the relevant body regions and the front of the vehicles. The same make and model of vehicle involved in the collision was used for the reconstruction of each case.

The results of the full leg impact reconstructions are shown in Figures 6 to 8. The figures plot the values of tibia acceleration, knee bending angle and knee shear displacement for each test against the severity of the leg injuries in the associated crashes. The severity of injury below the knee appears to be positively associated with higher tibia accelerations in the tests (Figure 6). However, there seems to be little association between knee injury severity and the parameters that describe the kinematics of the knee in the test (Figures 7 and 8). (Note that several reconstructions gave minimum values of severity, and others were reconstructed over a range of possible severities.)

Figures 9 and 10 show the relationship between the reconstruction of the upper leg impact and the injuries produced by the associated impact in each case. Although all injuries were associated with impacts that produced a weak or poor result, the reconstructions were too few to make any conclusions about the relationship between the results of the tests and real life injury.

The relationship between the results of the head impact reconstructions and the head injuries sustained by the pedestrians in the study is presented in Figure 11. The figure plots the values of the Head Injury Criterion for each test against the severity of the head injury. There appears to be a positive association between the value of HIC and the severity of the injury. Further, there is a statistically significant positive association between the severity of the head injury in the cases and the severity of the impact according to the assessments used by ANCAP.

Table 5 summarises the severity of the injuries in the cases by the impact severity estimated by the reconstruction process. Fisher's exact test applied to this data supports the hypothesis that head injuries MAIS 3 or greater are associated with HIC values greater than 1000 (p = 0.0238), which according to ANCAP assessment is classified as 'weak' or 'poor'.

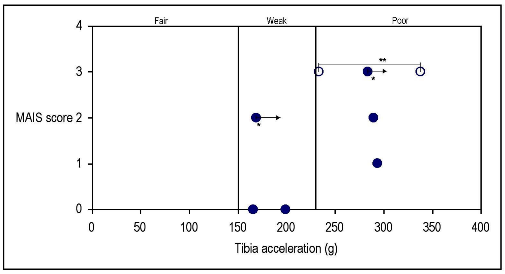

Figure 6 Lower leg injury severity in the cases studied, and the tibia acceleration measured in the impact reconstructions‡

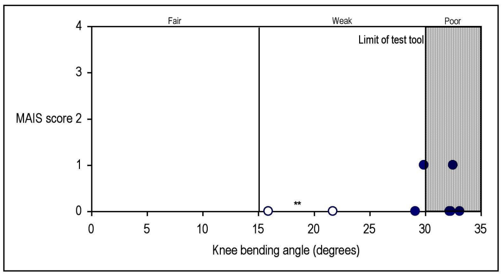

Figure 7 Knee injury severity in the cases studied, and the knee bending angle measured in the impact reconstructions. ‡

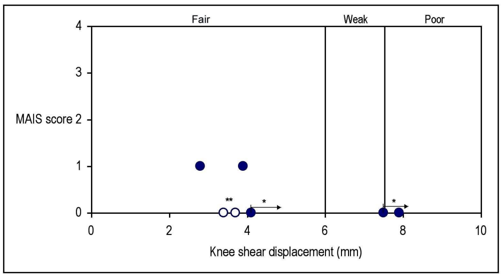

Figure 8 Knee injury severity in the cases studied, and the knee shear displacement measured in the legform in the reconstructions. ‡

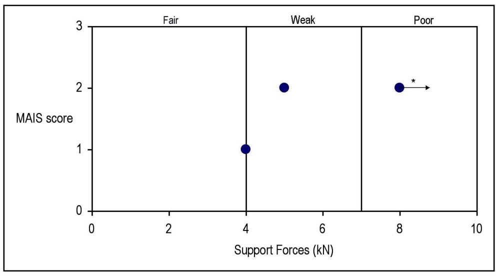

Figure 9 Upper leg/pelvis injury severity in the cases studied, and the upper legform support forces in the reconstruction. ‡

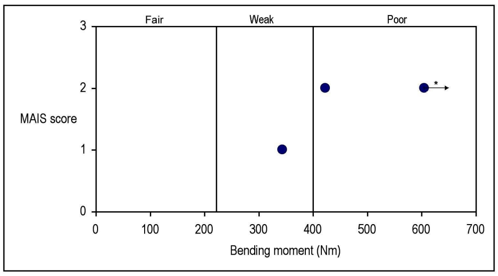

Figure 10 Upper leg/pelvis injury severity in the cases studied, and bending moment in the upper legform in the reconstruction. ‡

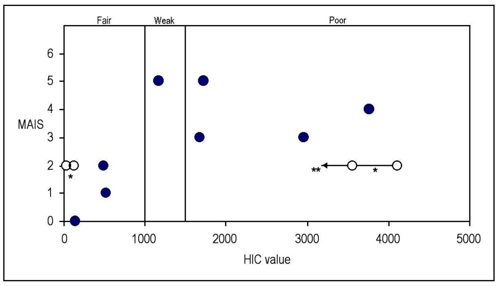

Figure 11 Head injury severity in the cases studied, and the HIC values measured in the impact reconstructions. ‡

‡ (** Tests over a range of severities; * minimum values)

Table 5 Summary of the data on impact severity and the related level of injury

		Head injury severity		
		AIS≤2	AIS>3	Total
Result of reconstruction	HIC<1000	4	0	4
	HIC≥1000	1	5	6
	Total	5	5	10

p = 0.0238 by Fisher's exact test

Discussion and conclusions

The pedestrian tests conducted by the Australian New Car Assessment Program is an initiative designed to help drive improvements to the safety of pedestrians in real world crashes. The results of the RARU's at-scene crash investigation indicate that ANCAP's focus on the head and lower extremities is justified. Further, the relationship between the results of reconstructions of actual head impacts show that the severity of head injuries sustained by pedestrians has a positive and statistically significant association with the value of HIC in an equivalent test. The sub-system head impact tests seem to be a valid representation of the real risk of head injury to pedestrians.

Only 2% of the crash involved pedestrians in our sample sustained any knee ligament damage, while the vast majority of vehicles tested by ANCAP achieved only weak or poor results for the test that measures the risk of this injury. Further, our reconstructions of actual accidents could not establish any relationship between knee injuries and the result of a test that was a reconstruction of that impact. These two findings indicate that the level of bending and shear measured in the legform knee joint greatly overestimates the risk of ligamentous damage to the knee.

The severity of injuries below the knee, such as tibia/fibula fractures, was positively associated with higher tibia accelerations in the reconstruction tests. However, the tolerance level may be too low or the accelerations measured by the legform may be too high. The latter may be a consequence of the softness of the legform's knee joint. With refinement of the legform, the results of the tibia acceleration appear to have the potential of being a good assessment of the risk of below-the-knee injury.

None of the vehicles tested by ANCAP could be classified as 'fair' on the basis of the upper legform test. While pelvic fractures appear common, femur fractures are not. However, the reconstruction study did not provide enough data to establish a relationship between the test result and actual injury risk.

Some of the tests used by ANCAP appear to have a good ability to describe the risk of actual injury. Importantly, this includes head injury risk, which is by far the most critical and damaging aspect of pedestrian injury. Nevertheless, other injury modes do not appear to be predicted so well. This may, in part, be a reflection of changing patterns of pedestrian injury; the sub-system tests were devised on accident data collected in the late 1970s when the front structures of vehicles were quite different. Continued development and appraisal of these important tests is warranted on the basis that, if the intention is to use the tests to drive vehicle design to be more pedestrian friendly, the tests must reflect the risk of injury as accurately as possible.

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