Pedestrian protection in vehicle impacts: Further results from the Australian New Car Assessment Program

Giulio Ponte, Andrew van den Berg, Luke Streeter, Robert Anderson
Centre for Automotive Safety Research
University of Adelaide
South Australia, 5005
Tel: +61 8 8303 5997
Fax: +61 8 8232 4995
E-mail: giulio@casr.adelaide.edu.au

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Abstract

Since the year 2000, The Centre for Automotive Safety Research has been carrying out the pedestrian component of the Australian New Car Assessment Program (ANCAP), to evaluate the level of protection offered to pedestrians by new cars. The assessment uses sub-system tests that simulate the impact between a motor vehicle and the head, upper leg, knee and lower leg of a pedestrian. Until 2002 these tests were conducted to a EuroNCAP protocol consistent with EEVC WG10 procedures. The results of these 19 tests have been presented previously. Since 2002, ANCAP has adopted the revised EuroNCAP protocol, which is based on the EEVC WG17 procedures. The revised protocol uses more stringent assessment criteria. Eighteen vehicles have been tested to the new protocol to date. This paper will outline differences between the old and new protocols and present results from the most recent ANCAP pedestrian safety assessments.

Introduction

Since early 2000, The Australian New Car Assessment Program (ANCAP) has tested popular new passenger vehicles to assess their safety performance in the event of a collision with a pedestrian. Initially, ANCAP followed the European New Car Assessment Programme pedestrian testing protocols Version 2 [1], which used as its source the report of European Enhanced Vehicle-safety Committee (EEVC) Working Group 10 [2]. A summary of the results from the first two years of ANCAP pedestrian testing has been presented previously and was compared against the analysis of real world pedestrian crash investigation and reconstruction [3].

In 2002, ANCAP adopted a revised EuroNCAP pedestrian testing protocol Version 3.1.1 [4], (later superseded by Version 4.0 and now by Version 4.1), in which the test methods are largely based on the work of EEVC Working Group 17 [5]. The new protocol introduced the use of revised headforms and a revised full legform. Additionally, the protocol introduced new procedures for selecting test points and for compiling the rating from individual tests.

Pedestrian Protection Rating System

Table 1 shows the criteria for the subsystem tests and the corresponding point scores for the previous and current protocols [6,7]. The criteria for scoring the maximum of 2 points per individual test have remained the same except in the case of the upper legform testing, where the allowable femur forces and the bending

moments have been increased. The criteria for all other lower levels of performance have been made more stringent.

Table 1 - The test criteria for the different testing protocols [6,7]

Impactor type	Measurement Criteria	Testing Protocol Version		Criteria limits	
			2 points	0 - 2 points	0 points
			Fair	Weak	Poor
Head	HIC value	V 2.0	HIC < 1000	1000 ≤ HIC < 1500	HIC ≥ 1500
		V3.1.1, V4.0, V4.1	**HIC < 1000**	**1000 ≤ HIC < 1350**	**HIC ≥ 1350**
Full leg	Tibia Acceleration (g)	V 2.0	Atibia < 150	150 ≤ Atibia < 230	Atibia ≥ 230
		V3.1.1, V4.0, V4.1	**Atibia < 150**	**150 ≤ Atibia < 200**	**Atibia ≥ 200**
	Knee shear displacement (mm)	V 2.0	Displ. < 6	6 ≤ Displ. < 7.5	Displ. ≥ 7.5
		V3.1.1, V4.0, V4.1	**Displ. < 6**	**6 ≤ Displ. < 7**	**Displ. ≥ 7**
	Kneed bending angle (deg)	V 2.0	Angle < 15	15 ≤ Angle < 30	Angle ≥ 30
		V3.1.1, V4.0, V4.1	**Angle < 15**	**15 ≤ Angle < 20**	**Angle ≥ 20**
Upper leg	Femur Forces (kN)	V 2.0	FF < 4	4 ≤ FF < 7	FF ≥ 7
		V3.1.1, V4.0, V4.1	**FF < 5**	**5 ≤ FF < 6**	**FF ≥ 6**
	Bending Moment (Nm)	V 2.0	BM < 220	220 ≤ BM < 400	BM≥ 400
		V3.1.1, V4.0, V4.1	**BM < 300**	**300 ≤ BM < 380**	**BM≥ 380**

The child headform and adult headform tests each contribute a maximum 12 points to the assessment and each legform contributes a maximum of 6 points, giving a maximum assessment score of 36 points. The point score is then converted to a 'star rating' as shown in Table 2.

Table 2 - Points score and corresponding pedestrian protection star rating

Points	Star Rating
28 - 36	4
19 - 27	3
10 - 18	2
1 - 9	1
0	0

Selection of Subsystem Impact Test Locations

Headform impact testing

The child and adult headforms are designed to measure the acceleration of the headform impact with the vehicle (usually an impact on the bonnet).

Version 2.0 of the headform subsystem testing protocol can be summarised as follows (full details can be found in reference 1): the bonnet of the vehicle is divided longitudinally into three areas. The child headform impact zone is then defined as the three areas across the bonnet bounded by the 'wrap around' distances at 1000 mm and 1500 mm. The adult headform impact zone is defined as the three areas bound by the wrap around lines at 1500mm and 2100mm. Six test points are selected (in each impact zone), three by ANCAP (potentially the most injurious points) and three by the manufacturer (potentially the least injurious points).

In Versions 3.1.1 to 4.1 of the EuroNCAP pedestrian testing protocol the child and adult test areas are defined in the same way as in Version 2.0, but instead of dividing each area into thirds the areas are divided into sixths (Figure 1). In total there are 6 child headform tests and 6 adult headform tests selected by ANCAP. The points chosen by ANCAP are those potentially most injurious in each sixth of the child and

adult test areas. Each sixth is divided into quarters and labelled as in Figure 1. If the manufacturer believes that the point selected by ANCAP is not representative of the entire sixth they can nominate any of the remaining quadrants in that sixth for an additional test. ANCAP then selects the potentially most injurious point on a visual basis in the manufacturer nominated quadrants.

If test points in laterally symmetrical sixths are predicted by both ANCAP and the manufacturer of the vehicle to be identical in response, then only one point needs to be tested, and the result is applied to both locations.

Not all points are tested. Points on the windscreen clear of interior vehicle structures and the windscreen surround receive a default pass. Points on the A-pillar receive a default fail (If a manufacturer believes the A-pillar will not fail, ANCAP will do the test). As mentioned above if points are laterally symmetrical, one point is tested and the other receives the same score.

The test score resulting from the manufacturer nomination process is combined with that of the ANCAP nominated test in a manner that weights each score according to number of quadrants nominated by the manufacturer (see next section).

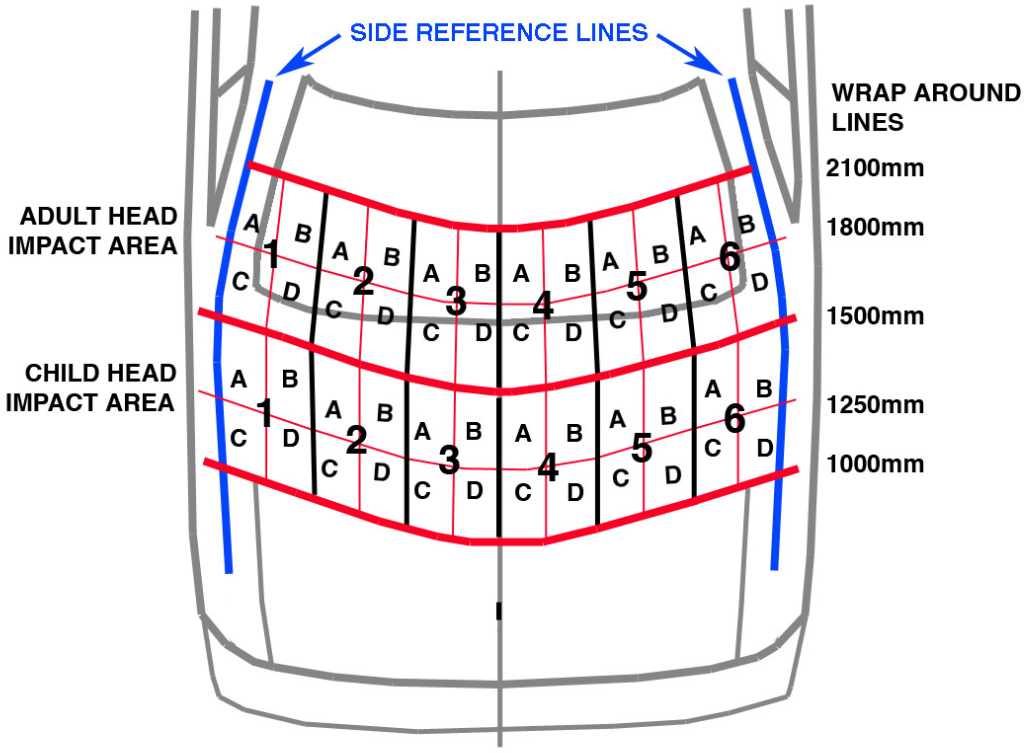

Figure 1 - Top view of a vehicle marked according to the EuroNCAP Pedestrian testing protocol Version 3.1.1 onward for the head impacts (Adapted from [4]).

Weighting ANCAP and manufacturer nominated head impact test results

In Version 2.0 of the protocol there were 6 tests conducted using the child headform and 6 using the adult headform, and the scores were summed. From Version 3.1.1 onward there can be between 6 to 12 tests conducted with each headform. Each sixth is scored out of a possible 2 points. If a manufacturer has nominated an additional test in a sixth, the score for that sixth is determined according to the following equation:

$$\text{Head Impact Score} = \text{ANCAP Score} \times \frac{4 - N}{4} + \text{Manufacturer Nomination Process Score} \times \frac{N}{4}$$

where N is the number of quadrants nominated by the manufacturer for that sixth (N = 1, 2 or 3).

Upper legform impact testing

The upper legform is designed to measure forces at the top and bottom of the femur and the bending moment at three points along the femur. The test criteria are based on the sum of the forces measured on the femur and the highest of the three bending moments. The test score is based on the poorest result from these two measures.

The leading edge of the bonnet of the vehicle is divided into three zones. In Version 2.0 of the protocol ANCAP selected two injurious impact locations in two of the three zones and the manufacturer selected the least injurious impact location in the remaining third. From Version 3.1.1 onward each of three zones is further divided into halves, resulting in six zones (Figure 2). ANCAP selects the potentially most injurious location in each zone with geometrically symmetrical impact locations receiving the same score.

Where a manufacturer believes that the chosen ANCAP impact point is not representative of the performance of the entire zone, they may nominate the other half of the zone for testing. The actual location of the test is chosen by ANCAP at the point most likely to cause injury within the nominated zone. The score for each zone is found by averaging the two results.

The tests conducted in each zone contribute a maximum of two points and therefore the upper legform tests contribute a maximum of 6 out of a possible total of 36 points in the assessment.

Full legform impact testing

The full legform measures tibia acceleration, knee shear displacement and knee bending angle. The test score is based on the poorest result from these three measures.

In protocol Version 2.0 the bumper reference line defines the top of the bumper. In protocol Version 3.1.1 onward an additional reference line has been added: the lower bumper reference line, which is defined by the bottom of the bumper (see reference 3 for full details). Full legform tests are only conducted when the lower bumper reference line is within 500 mm of the ground. Above 500 mm the upper legform is used for testing. All vehicles tested by ANCAP under the latest protocol have had

lower bumper reference lines under 500 mm, so the upper legform has not yet been used in this way.

The vehicle's bumper reference line is divided into three zones. In Version 2.0 of the protocol, ANCAP selected two potentially injurious impact locations in two of the zones and the manufacturer selected the least injurious impact location in the remaining third. In the current testing procedure each of the three zones is further divided into halves, resulting in six zones (Figure 2). ANCAP selects the potentially most injurious location in each zone with geometrically symmetrical impact locations being treated as for the headform and upper legform tests.

Where a manufacturer believes the impact point chosen by ANCAP in a particular third is not representative of the performance of the third, they may nominate the remaining half for impact testing. The selection of the impact point and the scoring process are as for the upper legform.

Each third contributes a maximum of two points to the ANCAP assessment, and therefore the full legform tests contribute a maximum of 6 out of the 36 points available in the assessment.

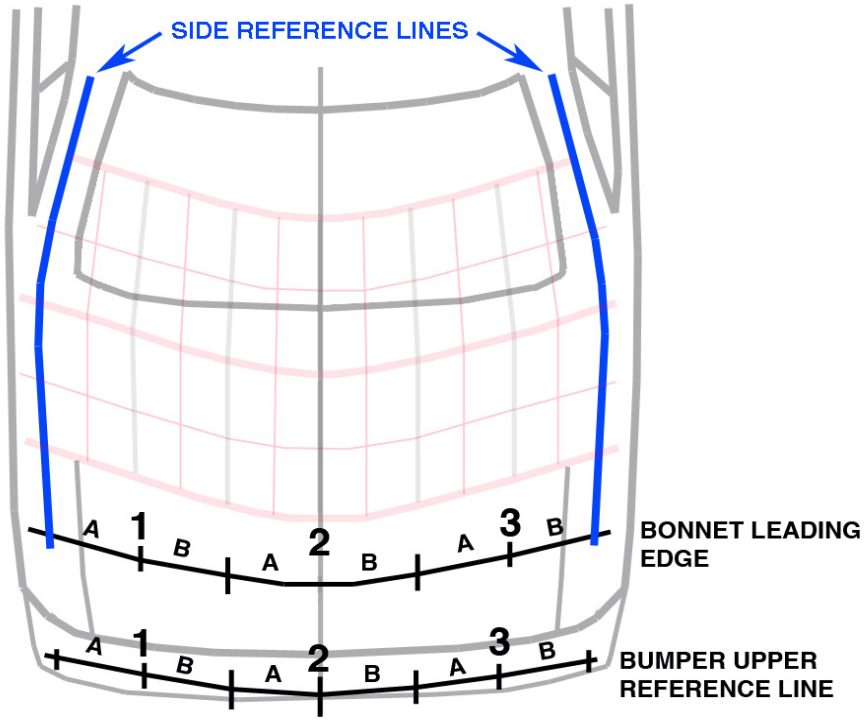

Figure 2 - Top view of a vehicle marked according to the EuroNCAP Pedestrian testing protocol Version 3.1.1 onward for the leg impacts (Adapted from [4]).

The Influence of the Manufacturer's Involvement in Test Site Selection

The protocols since Version 3.1.1 have encouraged the manufacturer to be more involved in the assessment of the level of pedestrian protection afforded by the vehicle. By default, the protocol assumes that a test location chosen by ANCAP is

representative of that entire test region. Manufacturer nomination of additional test zones allows for a finer discrimination of the performance of the vehicle, in terms of the pedestrian testing protocols. When a manufacturer has conducted their own development and/or testing for pedestrian protection, it is reasonable to assume that they are best-placed to advise ANCAP of the better-performing regions of the vehicle. It is therefore desirable that, in a protocol that assumes that manufacturers will continue to improve protection for pedestrians, they are encouraged to become involved to the extent that the protocols permit.

In the following section, the results of assessments made using the newer protocols (since Version 3.1.1) are presented in a way that highlights the improvement in the ANCAP score when a manufacturer participates in the process. The implications of this improvement in score is discussed at the end of the paper.

Results

As of June 2004, ANCAP has assessed 18 vehicles using protocol Versions 3.1.1 onward. The makes and models of these vehicles and their performance are listed in Table 3. This table also compares the final assessment with the point score and star rating that would have been received if the manufacturers had not been involved in the testing.

According to ANCAP criteria the Subaru Liberty was the highest performing vehicle with 3 stars, scoring 19 points out of 36. The Mitsubishi Lancer (17 points), Honda Jazz (15 Points) and the Toyota Rav 4 (10 points) received 2 stars. The remaining vehicles received 1 star or less. For the assessments in which the manufacturer nominated test zones, the point score increased in every case. The star rating improved by one star, in six of the assessments including two of the top four vehicles.

In general, the vehicles with lower scores had less manufacturer input than the vehicles with higher scores. The six poorest performers had the least contribution by the manufacturer, with one exception. Three of these vehicles had no manufacturer nominated impact testing and for two vehicles the manufacturer nominated only three additional impact tests.

Table 3 - Overall scores and input from the manufacturer

Vehicles	Total final score (star rating)	Zones selected by the manufacturer	Total score without manufacturer nomination (star rating)
Subaru Liberty	19 (***)	12	15 (**)
Mitsubishi Lancer	17 (**)	12	10 (**)
Honda Jazz	15 (**)	13	10 (**)
Toyota Rav 4	10 (**)	12	6 (*)
Toyota Echo	9 (*)	8	3 (*)
Subaru Forester	8 (*)	12	2 (*)
Daewoo Kalos	8 (*)	8	3 (*)
Mazda Mazda3	8 (*)	11	3 (*)
Toyota Camry	7 (*)	7	6 (*)
Holden Cruze	5 (*)	16	0 (***no stars)***
Hyundai Getz	5 (*)	6	0 (***no stars)***
Mitsubishi Outlander	5 (*)	12	0 (***no stars)***
Hyundai Accent	4 (*)	0	-
Mazda Tribute	4 (*)	3	2 (*)
Mitsubishi Magna	4 (*)	0	-
Ford Falcon BA	3 (*)	8	0 (***no stars)***
Holden Monaro	2 (*)	0	-
Holden VY Commodore	0 (***no stars***)	3	0 (***no stars)***

The three top performing vehicles scored most points through the headform impact tests, as would be expected from the number of points allocated to those tests, and by scoring at least some points in each of the legform tests. Half of the vehicles only scored points from headform impact tests, while the Hyundai Getz and Holden Cruze obtained their star rating only from default passes on the windscreen. Table 4 shows the number of headform test points on each vehicle that were assessed as “fair”, “weak” or “poor”. Unsurprisingly, the manufacturer nominated zones were more likely to produce a “fair” result, although the ANCAP nominated zone often produced a “poor” result in the test. The Mitsubishi Lancer, which gained nearly 7 points, received the largest benefit from manufacturer nomination.

Table 4 - Number of headform impact test points that were assessed fair, weak and poor for each vehicle, and the related point score.

Vehicle	ANCAP			Manufacturer			No. Of manuf. Tests	Score without manuf. points	Final score
	Fair	Weak	Poor	Fair	Weak	Poor			
Subaru Liberty	4		8	2	2	4	8	8.00	10.85
Mitsubishi Lancer		4	8	8		4	12	3.08	10.05
Honda Jazz		5	7	6		5	11	5.88	9.01
Toyota Rav 4	3		9	5	3	4	12	6.00	9.89
Toyota Echo		3	9	8			8	2.68	8.60
Subaru Forester	1		11	6	2	4	12	2.00	8.45
Daewoo Kalos			12	6			6	0.00	5.00
Mazda Mazda 3		3	9	5	2	2	9	3.47	8.16
Toyota Camry	3		9	2	3	2	7	6.00	6.86
Holden Cruze			12	6	1	5	12	0	5.21
Hyundai Getz			12	6			6	0	5.00
Mitsubishi Outlander			12	6	2	4	12	0	4.63
Hyundai Accent		2	10				0	2.14	2.14
Mazda Tribute		2	10		3		3	0.41	2.07
Mitsubishi Magna		2	10				0	1.76	1.76
Ford Falcon BA		2	10	1	6	1	8	0.45	2.63
Holden Monaro			12				0	0	0
Holden VY Commodore			12		1	2	3	0	0.08

Table 5 - Upper legform test results

Vehicle	ANCAP			Manufacturer			No. Of manuf. Tests	Score without manuf. points	Final score
	Fair	Weak	Poor	Fair	Weak	Poor			
Subaru Liberty	3			2			2	6.00	6.00
Mitsubishi Lancer		3					0	3.47	3.47
Honda Jazz	1		2				0	2.00	2.00
Toyota Rav 4			3				0	0	0
Toyota Echo			3				0	0	0
Subaru Forester			3				0	0	0
Daewoo Kalos	1	2		1			1	3.40	3.40
Mazda Mazda 3			3			2	2	0	0
Toyota Camry			3				0	0	0
Holden Cruze			3			1	1	0	0
Hyundai Getz			3				0	0	0
Mitsubishi Outlander			3				0	0	0
Hyundai Accent	1		2				0	2.00	2.00
Mazda Tribute			3				0	0	0
Mitsubishi Magna			3				0	0	0
Ford Falcon BA			3				0	0	0
Holden Monaro		3					0	1.98	1.98
Holden VY Commodore			3				0	0	0

Tables 5 and 6 show similar information to Table 4 for the upper legform and full legform tests. It can be seen that manufacturers rarely nominated extra tests in this

area, probably reflecting the uniformity of the structures being tested and the poor rating that these structures usually receive. There were some vehicles that appeared to have structures designed to protect the legs of pedestrians. However, usually these structures did not extend across the entire vehicle, with the result that the ANCAP test point produced a poor result.

Table 6 - Full legform test results

Vehicle	ANCAP			Manufacturer			No. Of manuf. Tests	Score without manuf. points	Final score
	Fair	Weak	Poor	Fair	Weak	Poor			
Subaru Liberty		1	2		2		2	1.48	1.80
Mitsubishi Lancer	1	2					0	3.52	3.52
Honda Jazz	1		2	2			2	2.00	4.00
Toyota Rav 4			3				0	0	0
Toyota Echo			3				0	0	0
Subaru Forester			3				0	0	0
Daewoo Kalos			3			1	1	0	0
Mazda Mazda 3			3				0	0	0
Toyota Camry			3				0	0	0
Holden Cruze			3			3	3	0	0
Hyundai Getz			3				0	0	0
Mitsubishi Outlander			3				0	0	0
Hyundai Accent			3				0	0	0
Mazda Tribute	1		2				0	2.00	2.00
Mitsubishi Magna	1		2				0	2.00	2.00
Ford Falcon BA			3				0	0	0
Holden Monaro			3				0	0	0
Holden VY Commodore			3				0	0	0

Discussion and Conclusions

The ANCAP pedestrian testing is conducted so that consumers can be informed on how well different vehicles perform when tested against the same set of testing procedures, in an environment where there is no regulation compelling manufacturers to improve pedestrian safety. It can be seen that the vehicles that received high scores in the ANCAP pedestrian program, under protocols since Version 3.1.1, did so following greater manufacturer input than for vehicles that performed poorly. This is because the current testing protocol penalises manufacturers that do not get involved in the testing protocol, by allowing ANCAP to choose the most injurious points, and the vehicle to be assessed solely on ANCAP's selections. All manufacturers have an equal opportunity to participate in the testing. Manufacturers that choose to participate (in the manner that the protocols permit) are better placed to score a result that is more representative of the vehicle performance (and more likely an improved test score) than by ANCAP's selection alone. Effectively, manufacturers that do not understand how their vehicles will perform and/or do not choose to participate are penalised.

In several overseas jurisdictions manufacturers are being pressured to incorporate higher levels of pedestrian safety in their vehicle design by relevant regulatory bodies. Accordingly, these manufacturers may have already undertaken design changes and conducted their own in-house testing. These manufacturers are in the best position to know how well their vehicle is likely to perform in the ANCAP testing. Manufacturers that have access to their own vehicle test results and details of the their vehicle design can enable them to predict the score an area will receive. Consequently, they may know how likely they are to improve the score with an

additional test. As the manufacturer has to pay for the additional test there is only an incentive for them to request additional tests when they believe it will improve the score. For example if they believe that the ANCAP test will score 2 points there is no reason for them to nominate another test. Also if they believe the ANCAP test will score zero there is no reason to nominate another test unless they believe it will produce a non-zero score. Other test points may return a lower HIC, but still provide no score if the HIC is greater than 1350. This could be a reason why some manufacturers have had either limited or no involvement in the assessment of their vehicles.

The change in protocol from Version 2.0 to Version 3.1.1 generally resulted in lower scores and a larger spread of scores. The two main reasons for this were the more stringent criteria and the change in the manner in which test points were selected. The new testing protocol creates an incentive for manufacturers to become involved in the assessment process. We have noted a large range of responses from manufacturers to the ANCAP assessments, some sending representatives from overseas to observe tests, often armed with specific knowledge of what the test results should be. Other manufacturers show little or no interest in participating and some do not seem to be fully aware of the testing protocols, nor are they aware of the characteristics of their vehicles under test.

Declaration

The Centre for Automotive Safety Research (CASR) provides testing services for the Australian New Car Assessment Program. CASR is paid by the manufacturers for additional tests of their nomination.

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Views expressed in this paper are those of the authors and do not necessarily represent those of the Australian New Car Assessment Program, car manufacturers or the University of Adelaide, or the Centre's sponsors.

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