Side Impact Crashworthiness Evaluation 2.0
Rating Guidelines

Version I

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INTRODUCTION

When evaluating a vehicle's side impact crashworthiness, the Insurance Institute for Highway Safety (IIHS) examines and rates three components: driver and passenger injury measures, head protection, and structural performance. This protocol describes our ratings criteria for each of these components. It also describes how we determine a vehicle's overall side rating, which is based on a vehicles' three component ratings and our weighting principles.

Other supporting documents for our side impact crash test are available from the Technical Protocols section of the IIHS website.

INJURY MEASURES

In IIHS's side impact crash test, two SID-IIs dummies representing small (5th percentile) women are positioned in the driver seat and the left-rear passenger seat.

Injury measures obtained from these instrumented SID-IIs dummies are used to determine the likelihood that occupants in these positions would have sustained significant injury to various body regions. Thirty-one different measures are recorded by each dummy in IIHS's side impact crash test, including:

- Head acceleration (three directions from the head's center of gravity)
- Axial force, anterior-posterior force, lateral-medial force, anterior-posterior bending moment, lateral-medial bending moment, and twist moment acting at the connection between the dummy's head and neck
- Spine lateral accelerations measured at T1, T4, and T12
- Shoulder lateral deflection, anterior-posterior force, lateral-medial force, and vertical force
- Thoracic rib (three) and abdominal rib (two) deflections and accelerations
- Pelvic acceleration (three directions)
- Pelvic lateral forces measured at the acetabulum and ilium

These 31 measures are grouped into three body regions: head and neck, torso, and pelvis. Injury parameters are calculated for each of the three body regions, including three parameters for the head and neck, three parameters for each thoracic and abdominal rib in the torso, and one parameter for the pelvis.

The time interval used to rate injury measures for each dummy is limited to the loading phase of the crash and not during dummy inboard rebound. Injury measures throughout the dummy usually peak while the dummy is being loaded by side airbags, the intruding structure, or interior trim components; but in some cases, head accelerations and neck forces and moments have peaked during rebound. This is due to dummy kinematics that may not be repeatable (e.g., the back of the dummy's head catching the head restraint, which causes the neck to twist as the dummy rebounds inboard, or head contact with the front passenger seat and/or seat back).

In addition to summary metrics for each of the recorded data channels, the following calculations are made: vector resultant of the head acceleration; 3 ms clip of the vector resultant head acceleration; head injury criterion (HIC), 15 ms; thoracic and abdominal rib deflection rate (calculated by differentiating the rib deflection data); thoracic and abdominal viscous criterion, and combined pelvic force.

Each body region receives an injury protection rating of good, acceptable, marginal, or poor based on the injury parameters for that region. For any body region to receive a good rating, the scores for all injury parameters in that region must indicate good results. If any parameter indicates an acceptable result, then the rating for that body region is acceptable. If any parameter indicates a marginal result, then the rating for that body region is marginal. Thus, the overall injury rating for any body region is the lowest rating scored for an injury parameter within that region.

Table 1 shows the injury parameter values associated with the possible ratings: good, acceptable, marginal, and poor. Injury results that round to the cutoff values shown in Table 1 will receive the better of the two ratings they separate.

Table 1
Injury Parameter Cutoff Values Associated with Injury Protection Ratings*

Body Region	Parameter	Good – Acceptable	Acceptable – Marginal	Marginal – Poor
Head and neck	Head injury criterion (HIC) 15	623	779	935
	Neck axial tension (kN)	2.1	2.5	2.9
	Neck compression (kN)	2.5	3.0	3.5
Torso*	Average rib deflection (mm)**	28	38	48
	Worst rib deflection (mm)***		Refer to footnote.	
	Deflection rate (m/s)	8.2	9.8	11.5
	Viscous criterion (m/s)	1.0	1.2	1.4
Pelvis	Combined acetabulum and ilium force (kN)	4.0	5.0	6.0

* If shoulder deflection exceeds 60 mm or bottoms out, the torso rating is decreased by one category.

**Applies to tests where the maximum rib deflection does not exceed 50 mm.

***If any of the rib deflections exceed 50 mm, the deflection-based rating will be based on peak deflection. Peak deflections from 51 to 55 mm result in a marginal deflection-based rating for the torso. If any peak deflection is greater than 55 mm, the rating is poor.

It is not possible for an injury-coding scheme to foresee all the possible combinations of outcomes that could suggest injury risk in a crash.

The information in Table 1 reflects current available information and is subject to change. In evaluating a particular crash, we may deviate from strict adherence to these guidelines based on other test-related information (i.e., other measures in the dummy, observations about dummy movement, and performance of vehicle structure). The injury parameters used and the ratings boundary values may be revised to reflect new biomechanical information; thus resulting in a new version of the protocol.

Head and Neck

Head injury risk is evaluated mainly on the basis of head injury criterion (HIC) with a 15 ms limit on the period over which it is calculated. A value of 779, which is the maximum allowed in side airbag out-of-position tests with 5th percentile female dummies (Side Airbag Out-of-Position Injury Technical Working Group, 2000), marks the boundary between an IIHS rating of acceptable and marginal.

For an average-sized adult male, a HIC-15 of 700 is estimated to represent a 5% risk of a severe injury (Mertz et al., 1997). This value was scaled to give the injury assessment reference value (IARV) of 779 for a 5th percentile female. The scaling method used takes into account size and brain tissue strength variation with age (Mertz et al., 1997). A "severe" injury is one with a score of 4+ on the Abbreviated Injury Scale (AIS) (Association for the Advancement of Automotive Medicine, 1990).

The HIC is calculated as follows:

$$HIC = \left[\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \qquad \text{(Eq. 1)}$$

where,

a(t) = resultant head acceleration;
t_1, t_2 = start and stop times of the integration, which are selected to give the largest HIC value. For the HIC analysis, t_1 and t_2 are constrained such that $(t_2 - t_1) \leq 15$ ms.

Neck injury risk is evaluated on the basis of upper neck axial force, which has been shown to be the best indicator of serious (AIS ≥ 3) neck injury (Mertz et al., 1997; Mertz & Prasad, 2000). Axial forces of 2.1 and 2.5 kN mark the boundaries between IIHS ratings of good and acceptable for tension and compression, respectively. These values also are the IARVs for out-of-position testing of side airbags with 5th percentile female dummies and represent about a 3% risk of serious neck injury (Mertz et al., 1997).

Torso

The three thoracic and two abdominal ribs of SID-IIs are considered together as the torso. Considering the relatively narrow thorax and abdomen regions of SID-IIs separately may be overly precise, given the broad range of occupant statures and possible seating heights.

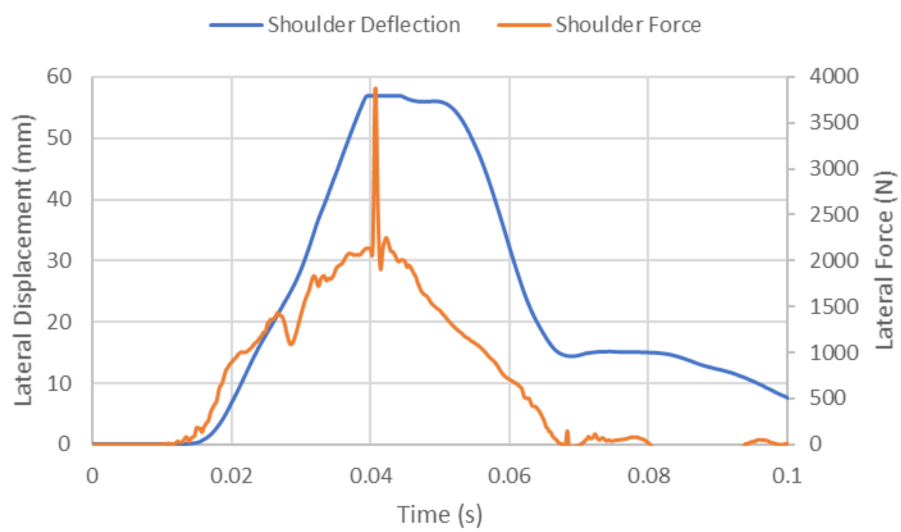
Torso injury risk is evaluated on the basis of thoracic and abdominal deflections, deflection rates, and viscous criterion measures. The overall torso rating is based on the worst rating from these three metrics; however, a downgrade of one rating category is assigned if the shoulder rib bottoms-out or its deflection exceeds 60 mm, which is within 1–5 mm of the shoulder rib bottoming-out point. Bottoming-out of the rib typically is identified by a flat-topping in the deflection along with a spike in the shoulder force (see Figure 1).

Shoulder

Biomechanical test data suggest that the shoulder complex is capable of transmitting relatively high forces in side impact crashes, but the human tolerance for such loading is not well established. Thus, shoulder loading is not evaluated separately.

However, when the shoulder "rib" of SID-IIs is compressed to approximately 59–65 mm, it contacts a hard stop against the torso where it can transmit artificially high forces into the torso. The purpose for the shoulder-bottoming downgrade is to discourage overloading the shoulder, which may result in an artificial reduction in loading elsewhere on the torso.

Figure 1
Example of Shoulder Bottoming from Shoulder Deflection and Force Data



Torso: average deflection

If the maximum thoracic and abdominal rib deflections are less than or equal to 50 mm, the deflection criteria is based on the average of the peak deflections from each rib. An average peak rib deflection less than or equal to 28 mm marks the boundary between good and acceptable.

In the absence of an excessively high single rib deflection, the average rib deflection is used to better correlate with the existing biomechanical test data where large regions of the thorax or abdomen were compressed equally to obtain the human tolerance limits. According to injury risk curves that have been scaled for a 5th percentile female, 28 mm of deflection corresponds to a 10–22% risk of serious thoracic injuries (Pintar et al., 1997; Viano et al., 1995). An analysis comparing injury measures in the original IIHS side crash test with real-world driver deaths in left-side crashes showed that a 10-mm increase in average torso deflection resulted in a 12% increase in driver death risk (Teoh & Arbelaez, 2019).

Torso: peak deflection

If any of the five peak rib deflections exceed 50 mm, the deflection-based rating is evaluated from the peak deflection value instead of the average rib deflection.

Although much of the biomechanical tests used to establish human rib deflection tolerance involved distributed loading, Viano (1991) has shown that severe localized deflections are possible with some interior trim designs. When thoracic rib deflection is 50 mm in SID-IIs (about 62 mm in BioSID), there is an 80% risk of serious rib fracture injuries; at 55 mm, the risk increases to about 90%. Peak deflections from 51 to 55 mm result in a marginal deflection-based rating for the torso. If any peak deflection is greater than 55 mm, the rating is poor.

Deflection rate

A rib deflection rate of 8.20 m/s marks the boundary between an IIHS rating of good and acceptable. This deflection rate boundary is the same as the Hybrid III 5th percentile female sternal deflection rate, which is associated with about a 5% risk of AIS 4+ thoracic injury in frontal impacts (American Automobile Manufacturers Association, 1998; Mertz et al., 1997).

The lateral deflection rate reference value is equal to the frontal deflection rate reference value based on research that has shown similarities in injury severities between thoracic compression rates for frontal and side impacts (Mertz & Weber, 1982).

The velocity (deflection rate) for each rib is calculated by differentiating the rib deflection data:

$$V(t)_i = \dot{D}(t)_i \qquad \text{(Eq. 2)}$$

where,

$D(t)_i$ = the deflection of rib *i* at time *t*, measured with linear potentiometers and filtered to SAE CFC 180 (mm).

Viscous criterion

Another rate-dependent injury criterion, viscous criterion, also is calculated from rib deflection measurements. Viscous criterion is the product of rib deflection, normalized by the chest half-width, and the rib deflection rate.

According to Viano et al. (1995), a viscous criterion value of 1.0 m/s represents an approximate 5% risk of AIS 4+ thoracic injury. A viscous criterion of 1.0 m/s marks the boundary between an IIHS rating of good and acceptable.

The viscous criterion (VC) for each rib is calculated as follows:

$$VC(t)_i = 1.0 * V(t)_i * \frac{D(t)_i}{138mm} \qquad \text{(Eq. 3)}$$

where,

$V(t)_i$ = the velocity of rib *i* at time *t*, from Eq. 2 (m/s)
$D(t)_i$ = the deflection of rib *i* at time *t*, measured with linear potentiometers and filtered to SAE CFC 180 (mm).

Pelvis

Pelvic injury risk is evaluated on the basis of the combined acetabulum and ilium force. The risk function was determined by rescaling pelvic impact data from Zhu et al. (1993) and Bouquet et al. (1998).

In the Bouquet et al. study (1998), pelvic loads were distributed over a wide area (200 × 200 mm square), which included the iliac crest and the greater trochanter. In the Zhu et al. study (1993), the height of the load distribution was considerably lower (102 mm), but the load was measured over an area that covered more than just the greater trochanter. The area over which force was measured in these studies corresponds to a wide pelvic distribution, which is captured closest in SID-IIs by combining the acetabulum and ilium load cell forces. Non-normalized applied force data from these studies were rescaled using the equal stress-equal velocity scaling procedure presented by Eppinger et al. (1984). This procedure also was used by Zhu et al. to scale data to the 50th percentile male standard mass.

An analysis comparing injury measures in the original IIHS side crash test to real-world driver deaths in left-side crashes showed that an increase of 1.0 kN in combined pelvic force resulted in an increase of driver death risk by 8% (Teoh & Arbelaez, 2019). Logistic probability analysis of each data set showed the risk of AIS 2+ pelvic fracture reached approximately 10% at 4.0 kN, 23% at 5.0 kN, and 45% at 6 kN. The instantaneous combined acetabulum and ilium force of 4.0, 5.0, and 6.0 kN mark the boundary between IIHS ratings of good and acceptable, acceptable and marginal, and marginal and poor, respectively.

The combined acetabulum and ilium force ($F_P(t)$) is calculated as follows:

$$F_P(t) = F_A(t) + F_I(t) \quad \text{(Eq. 4)}$$

where,

$F_A(t)$ = the acetabulum force at time t,
$F_I(t)$= the ilium force at time t.

Negative values of acetabulum and ilium force in the SID-IIs dummy are possible, but are an artifact of dummy design and are therefore ignored (equal to zero force) in the equation above (Eq. 4).

EVALUATION OF HEAD PROTECTION

The injury measures obtained from SID-IIs dummies seated in a standard driver's position and second-row outboard seat position are good indicators of the injury risk for a person of about the same size in the same seating positions.

However, good injury results for the standard dummy and seating position are not sufficient by themselves to indicate low injury risk for occupants of different sizes and/or seating positions in the same crash. For example, the dummy's head moving outside the occupant compartment and/or incomplete head protection coverage indicate the potential for injuries that are not necessarily captured by recorded injury measures on a single dummy.

To provide some assessment of the potential injury risk for drivers of other sizes and/or seating positions, IIHS reviews the kinematics (high-speed video analysis) of the SID-IIs during the side impact crash, together with the performance of the restraint system (seat belts, head protection system, seat, and door).

A good rating is scored if the head is effectively protected by the head protection system (typically an airbag). We score deficiencies in head protection based on the severity of the perceived injury risk. Details of the head protection criteria and associated ratings are described in the following section.

Criteria for Head Protection Ratings

Each dummy is scored separately based on the protection provided to that occupant's seating position.

Good

- A good rating is scored when the head protection system, typically a deployed airbag, contains the dummy head within the vehicle and prevents hard contact with the intruding barrier face and interior surfaces.
- Any coincidental contact with the vehicle interior during outboard loading of the head protection system is not downgraded, as long as the resultant head acceleration is at or below 70 G.
- Any contact during rebound is also excluded from evaluation.

Acceptable

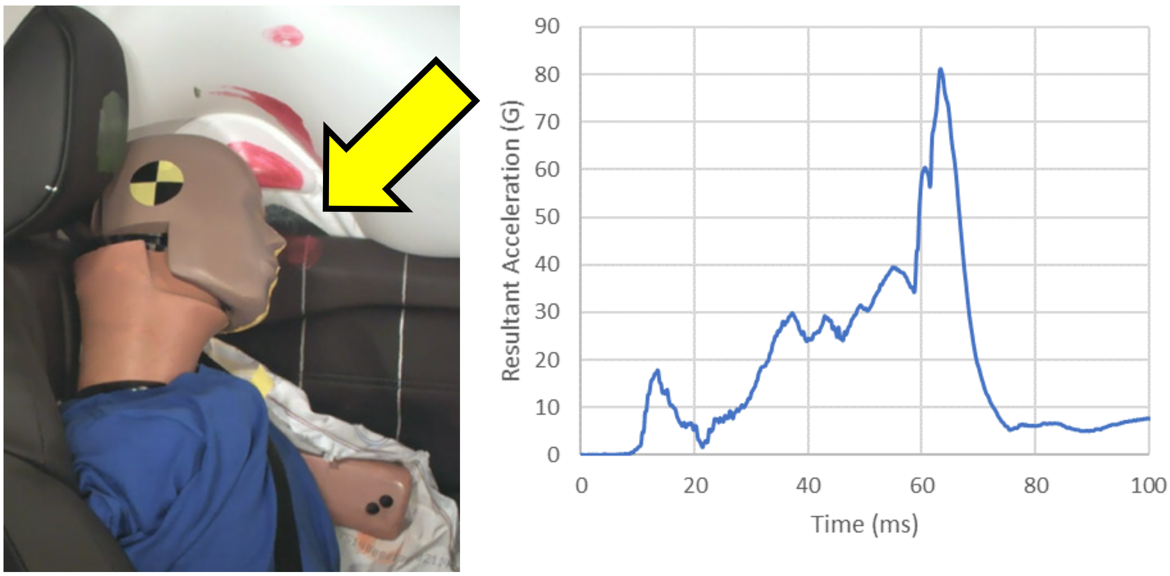
- An acceptable rating is scored when the dummy's head does not receive adequate protection from the head protection system but is protected from exposure to outside objects by an intervening FMVSS 201-compliant surface or structure.
- Any contact with this FMVSS 201-compliant surface or structure must have a resultant head acceleration at or below 70 G.
- This rating does not apply to seating positions where a window or other vehicle opening is not equipped with a head protection system.

Marginal

- A marginal rating is scored when the dummy's head contacts the vehicle interior surface with an associated resultant head acceleration greater than 70 G (see Figure 2 for an example).
- Examples include direct contact of the dummy's head with interior structures such as the door trim; A-, B-, or C-pillar trim; D-ring; roof rail, or other vehicle interior components.

- Indirect contact with interior structures, while the side head protection system (typically an airbag) is interposed between the dummy's head and interior surface, also qualifies.
- Evidence from video footage, postcrash photographs, paint transfer, and/or dummy data may be used to assign a marginal head protection rating.
- A marginal head protection rating is also scored when the dummy's head contacts any non-FMVSS 201 interior surface, regardless of resultant head acceleration.

Figure 2
Example of Marginal Head Protection



Note: The driver dummy's head contacts the door sill trim during the loading phase, with an associated resultant head acceleration peak of 80 G.

Poor

- A poor rating is scored when the head protection system does not protect or contain the head in the vehicle, leaving it exposed to contacts with objects outside of the vehicle including fixed objects like trees, posts, or striking vehicles.
- Examples of scenarios resulting in poor head protection include late, non-deploying or mis-deploying head-protecting airbags that expose any part of the head to objects outside of the vehicle, including the moving deformable barrier (MDB).
- Additionally, a poor head protection rating is scored if there is evidence of any direct head contact with the MDB including video footage, paint transfer, deformation on the MDB, and/or dummy data that indicates the head bottoming-out an airbag and contacting the MDB.

EVALUATION OF INTRUSION MEASUREMENTS

The initial structural rating is based on a comparison of B-pillar intrusion measurements with rating guidelines. This rating may then be modified (downgraded) based on additional observations about the structural integrity of the occupant compartment (Table 2).

The vertical range considered for the structural rating extends from a point 100 mm below to a point that is 540 mm above the H-point measurement taken with the seat in the full-rear and full-down positions. The maximum height for the intrusion measurement corresponds to the shoulder height of a 95th percentile male.

Table 2
Structural Intrusion ratings

Intrusion	Good	Acceptable	Marginal	Poor
B-pillar to seat centerline distance (cm)	> 18.0	14.0–17.9	10.0–13.9	< 10.0

Observation	
Door opening	Downgrade the structural rating by one category.
Fuel spill	Downgrade according to the type and severity of the spill.
High-voltage system	Downgrade according to the type and severity of the compromise.

A vehicle may be downgraded when a door opens during the crash test: A door opening creates a risk for both ejection and a lack of structural protection for the occupant if a secondary crash occurs.

Fuel and High-Voltage System Integrity Leading to Downgraded Rating

If a significant fuel leak or compromise of a high-voltage system (i.e., an electric drivetrain) is observed during a test, both the structural and overall ratings may be downgraded to poor.

Significant fuel leaks are those that exceed the leak rate allowed after tests that assess fuel system integrity under U.S. Federal Motor Vehicle Safety Standard (FMVSS) No. 301.

High-voltage systems must meet the electrolyte spillage, battery retention, and electrical isolation requirements in FMVSS 305 to avoid a downgrade. Additionally, the temperature of the high-voltage battery is monitored both with a thermocouple and a thermal imaging camera, before and after a crash test. If an increase in temperature is detected, the vehicle is moved immediately outdoors where continued monitoring takes place. The following list summarizes these requirements:

- **Electrolyte spillage:** No more than 5 liters of electrolyte from propulsion batteries shall spill outside the passenger compartment, and no visible trace of electrolyte shall spill into the passenger compartment.
- **Electric energy storage/conversion system retention:** Electric energy storage/conversion devices mounted outside the occupant compartment shall remain attached to the vehicle by at least one component anchorage, bracket, or any structure that transfers loads from the device to the vehicle structure, and shall not enter the occupant compartment.

- **Electrical isolation:** After the test, one of the following requirements must be met:
  - Electrical isolation between the high-voltage source and vehicle chassis must be greater than or equal to 500 ohms/volt for all high-voltage sources without continuous monitoring of the electrical isolation. The isolation must be greater than or equal to 100 ohms/volt for all DC high-voltage sources with continuous monitoring of electrical isolation; or
  - The voltages from high-voltage sources measured according to the procedure specified in FMVSS 305 must be less than or equal to 30 VAC for AC components, or 60 VDC for DC components.
- **Temperature increase:** While postcrash activities commence, the battery temperature is monitored with the onboard thermocouple for at least 4 hours. The battery temperature must remain below 25.5 degrees Celsius.

  If the battery temperature increases to 25.5 degrees Celsius, an onboard temperature alarm sounds and the vehicle is evacuated immediately from the facility. If over the next 2 hours of monitoring, both with the thermocouple and thermal imaging camera, if the battery temperature begins to stabilize and there are no visible signs of smoke or fire, postcrash activities can continue and no downgrade will be scored.

  A measured temperature above 25.5 degrees Celsius, or visible smoke or fire, will result in a poor overall vehicle rating.

WEIGHTING PRINCIPLES FOR THE OVERALL RATING

The overall rating in our side impact crash test is based on a vehicles' three component ratings (driver and passenger injury measures, head protection, and structural performance) and the weighting principles we apply.

General Principles

The rating system is based on demerits, with every vehicle beginning with a good overall rating. The test is intended to determine if there are reasons to lower the rating. The demerit scheme that matches these principles is shown in Table 3.

Table 3. Weighting of Individual Components
IIHS Crashworthiness Evaluation—Side Impact Crash Test

	Rating			
Component	**Good**	**Acceptable**	**Marginal**	**Poor**
Driver dummy				
Injury measures				
Head and neck	0	2	10	35
Torso	0	2	10	35
Pelvis	0	2	6	10
Head protection	0	2	10	22
Passenger dummy				
Injury measures				
Head and neck	0	2	10	35
Torso	0	2	10	35
Pelvis	0	2	6	10
Head protection	0	2	10	22
Vehicle structure	0	2	10	22
Overall rating cutoffs	**0–8**	**9–20**	**21–34**	**35+**

The head/neck and torso ratings are based on the risk of life-threatening injuries and carry the most weight. Poor ratings for these vital body regions will result in a poor overall rating.

The pelvis ratings are based on risk of skeletal injury. Pelvis fractures typically are not life threatening; however, they can lead to long-term disability due to permanent damage of the articulating surfaces in the hip joint and in some cases can be life-threatening.

The head protection rating category is intended to encourage head-protecting systems (typically an airbag) with proper deployment timing and coverage that can prevent potentially injurious head contacts with vehicle interior structures and intruding objects outside the vehicle including other vehicles, trees, and poles.

The vehicle structure rating is intended to limit occupant compartment intrusion at the B-pillar, where occupants of a stature different from the SID-IIs dummies might be sitting. Because good dummy measures cannot indicate general good crashworthiness, a vehicle with a marginal structure rating cannot be rated good overall and can only be rated acceptable with few indicated problems according to the dummy readings.

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