Working Group on Accident Mechanics
University of Zürich and ETH Zürich
Gloriastrasse 35
CH-8092 Zürich
Switzerland

GDV Institute for Vehicle Safety
Leopoldstr. 20
D-80802 München
Germany

Autoliv Germany
Otto Hahn Str. 4
D-25337 Elmshorn
Germany

University of Technology
Dept. of Mechanics
Kopernikusgasse 24
A-8010 Graz
Austria

Proposal for the ISO/TC22 N 2071 / ISO/TC22/SC10 (Collision test procedures)

Test procedure for the evaluation of the injury risk to the cervical spine in a low speed rear end impact

Working Draft #5

The test procedure has been developed by ETH, GDV, and Autoliv.
Authors: M. Muser (Zurich), H. Zellmer (Elmshorn), F. Walz (Zurich)
In collaboration with W. Hell and K. Langwieder (Munich)
The test procedure has been harmonised with the document 'A sled test procedure for dummy tests in rear impacts' by K. Steiner and H. Steffan, TU Graz.

1. Scientific background

Most head restraints of current cars are capable to minimise severe neck injuries such as bony fractures, luxations and ligament ruptures. However, so called minor soft tissue neck injuries of an AIS 1 injury severity degree still occur in considerable numbers. In many countries, the number of soft tissue injuries is even increasing. The majority of persons with such minor neck injuries recover soon without ongoing symptoms. Some victims, however, suffer serious impairment lasting for many years after even a "minor" event, also called “low speed rear end impact”. These injuries are difficult to diagnose - even a careful medical examination including CT scan and MRI often reveals no visible reason for a reported disorder - and the complexities involved are often misunderstood. Therefore, legal and insurance related disputes are common.

It has been shown in the relevant scientific literature that:

- Soft tissue neck injuries predominantly occur in the struck car in rear end impacts, less frequently in frontal and side impacts.
- Discussions about better seat and head restraint design in order to reduce injury rates have been ongoing for a long time.
- Measurements of head restraint geometry revealed that the majority of current cars exhibit only “acceptable” or even “poor” head restraint design. This shortcoming is in part due to the lack of standards and widely accepted test procedures.
- Many organisations interested in seat design (manufacturers of automobiles or seats, universities, accident investigators) have devised their own dynamic test procedures.
- To date, no standard test procedure is available that covers the minor neck loading in the typical “low speed rear end impacts”.
- Until recently no anthropomorphic test device was suitable for the measurement of the biomechanical spine loading during a low speed rear impact; today, a specific dummy neck (TRID-neck) is available and entire rear-end dummies will be available in the near future.
- Collision analyses show that the majority of the neck injuries discussed here occur during rear end impacts which result in a delta-v of 10 to 15 km/h for the struck car.

- Some prototypes and even production models have shown that a significant reduction of neck loads in dynamic rear end impacts is possible.

2. Scope

The test procedure simulates a low speed rear end impact resulting in a delta-v of the struck car of 15 km/h. Its main purpose is the comparison of different front seat systems under standard conditions with respect to their protection potential and the associated risk for soft tissue neck injuries.

The test procedure is designed for the fiftieth percentile male person/dummy. It is assumed that positive features of seats observed for this group of persons will also yield benefits for other (e.g. fifth percentile female) groups.

The injury protection potential of front seat systems in other collision situations (e.g. higher delta-v/car accelerations possibly resulting in a collapse of the seat back) is not covered by this procedure.

3. Normative references

The test procedure outlined below refers in part to the following standards and recommended practices:

SAE J 826: H-Point-Machine

SAE J211/1 Electronic Instrumentation

SAE J1727 Injury Calculation Guidelines

ECE-R 94 Positioning of Dummies

4. Definitions

4.1. NIC

The neck injury criterion (NIC) is calculated as follows:

$NIC(t) = a_{rel}(t) \cdot 0.2 + \left(v_{rel}(t)\right)^2$, where

$a_{rel}(t) = a_x^{T1}(t) - a_x^{Head}(t), \qquad v_{rel}(t) = \int a_{rel}(t)dt,$ and

$a_x^{T1}(t)$ = acceleration versus time measured in the antero - posterior (x) direction at the height of the first thoracic vertebra (lower neck accelerometer)

$a_x^{Head}(t)$ = the acceleration versus time measured in the antero - posterior (x) direction at the height of the c.o.g. of the head (head accelerometer), i.e. near the first cervical vertebra

The acceleration signals shall be filtered according to CFC180. The maximum value of NIC(t) within an interval of 150 ms after the beginning of the sled acceleration shall be determined and documented as the NIC_{max} value. If the head, after contacting the head restraint, reverses its direction of relative movement at a point in time before 150 ms, the upper end of the interval of NIC(t) for the determination of NIC_{max} shall be limited by this point in time.

4.2. HIC, a(3ms)-values

The head injury criterion and the 3 millisecond exceedence values shall be calculated according to SAE J1727.

5. Testing equipment

5.1. Test track:

The test shall be performed on a sled decelerated using an adequate braking system or on a hydraulically accelerated sled (HyGe system).

5.2. Anthropomorphic test device (ATD):

A BioRID dummy or an anthropometric test device offering similar biofidelity shall be used. (The biofidelity of the Part 572 subpart E (Hybrid III) fiftieth percentile male dummy with standard or TRID-Neck is consideredto be insufficient)

5.3. Test objects

Front seats of passenger vehicles in standard positions as described in section 6.

6. Requirements

6.1. Anthropomorphic test device

The ATD shall be instrumented as described in tables 6.1 und 6.2. The head of the ATD is equipped with a device suitable for eletronic detection of the time $\mathbf{T_k}$ of the first contact of the head and the head restraint.

Position	Measurement	Axes	Filter
Head	Acceleration	x/y/z	CFC 1000[1]
Upper neck	Force	x/z	CFC 1000
	Moment of torque	y	CFC 600
Lower neck	Acceleration	x	CFC 180
Chest	Acceleration	x/y/z	CFC 180
Pelvis	Acceleration	x/y/z	CFC 1000

Table 1: Standard Instrumentation

Position	Measurement	Axes	Filter
Head	Rotational acceleration	y	CFC 1000
Upper neck (C1)	Force	y	CFC 1000
	Moment of torque	x/z	CFC 600
Lower neck	Force	x/y/z	CFC 1000
	Moment of torque	x/y/z	CFC 600

Table 2: Optional Instrumentation

6.2. Film targets

Film targets shall be mounted on the side of the head at the location of the head c.g. and at a second location on the head in order to determine head rotation. A second set of film targets on the first thoracic vertebra shall be mounted to allow for determination of the velocity and rotation of this vertebra.

At least three other film targets shall be mounted on the seat as depicted in Figure 1.

[1] Please note that, for NIC calculation, the x-axis signal needs to be filtered using CFC180 as well.

6.3. Test temperature

The ambient temperature during the test shall be 20 ± 5° Celsius.

6.4. Head axis alignment

The positioning of the dummy shal be adjustet such that, in the final seated position, the x-axis of the head accelerometer is horizontal to ± 1°.

7. Test preparations

7.1. Mounting of the seat on the sled

The mounting supports on the sled and the adjustment mechanisms of the seat shall be adapted such that the designated reference seating position for the 50th percentile male occupant is replicated as speficied by the manufacturer.

In cases where such specifications are not available, the seat shall be mounted on the sled and adjusted such that:

- the dimensions A and B in Figure 1 are maintained. The angle of the seat ramp shall be 12° ± 1°.
- the torso line reads 25° against the vertical.
- the seat height adjustment is in its lowest position
- the seat angle adjustment is in the lowest position
- the lordosis support at maximum retraction

The dimensions A and B as well as the torso line and seat ramp angle shall be documented in the protocol. Documentation provided by the manufacturer specifying the reference seating position shall be an integral part of the protocol.

The H-point machine shall be used to adjust and verify the specified dimensions.

7.2. Positioning of the ATD on the seat

The ATD is positioned according to the procedures used in frontal impact tests (cf. ECE R-94). The feet shall be positioned on the foot rest, the heels touching the floor plate.

The measured H-point of the ATD shall not differ horizontally and vertically more than 20 mm from the H-point location previously determined by the H-point machine.

The ATD may be secured using a loosely fitting 3-point belt system. The belt system shall not exert significant forces on the dummy during the test before the rebound phase is completed, i.e. the dummy has, in the rebound phase, reached the same position relative to the sled as it had before the test.

7.3. Additional considerations

In cases where, due to the reclining movement of the seat during the test, a contact between the seat back and structural parts of the target vehicle (e.g. the rear wall in a two-seat sports car) is to be expected, such structural parts shall be replicated on the sled.

The body of the target vehicle may be mounted on the sled in order to replicate the seating position and the structural parts mentioned above.

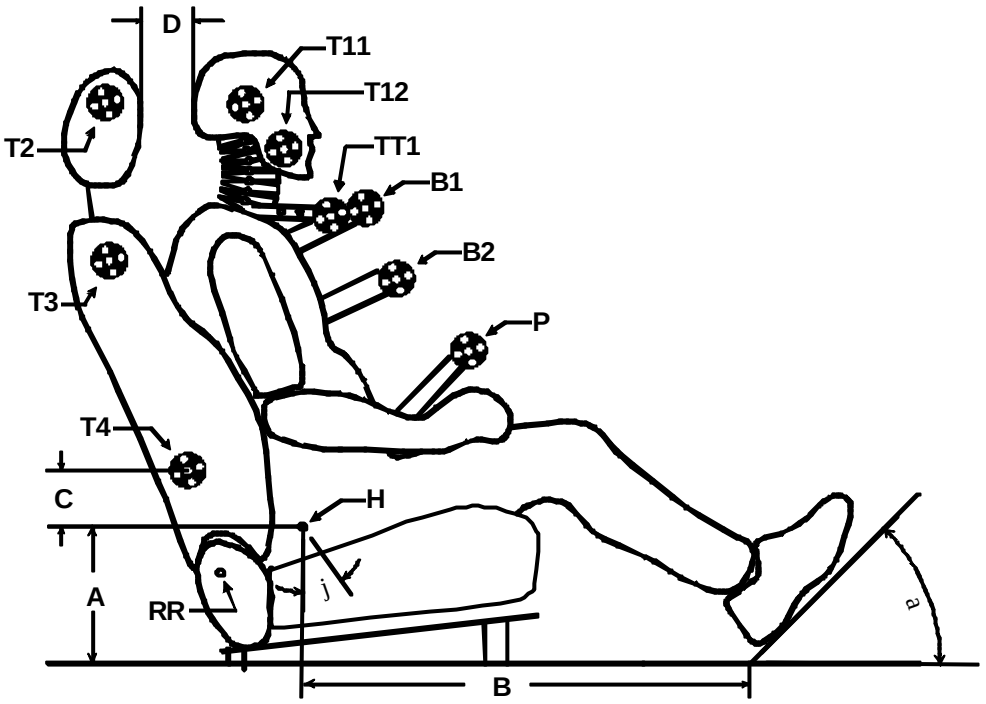

Fig. 1: Measurements on the seat and positioning of the ATD, using the BioRID dummy. The targets B1, B2, and P are optional. T11 and T12 designate the head targets described above, TT1 is the target used to determine T1 velocity.

Designation	Description	Test device	Dimension
A*	Vertical distance floor-H-point	H-Punkt-Machine	(275 + 15) mm
B	Horizontal distance toepan-H-point	H-Punkt-Machine	(850 ± 100) mm
C	Vertical distance H-point / target T4	ATD	(100 ± 5) mm
α	Angle footrest-floor		40° - 45°
e	Pelvis angle	ATD	25° + 2°

Table 3: Measurements on the test set-up

* May be replaced by target vehicle reference seating position values, cf. section 7.1.

7.4. Test preparations

7.4.1. Head restraint adjustment

Adjusted head restraint test (option)
The head restraint shall be adjusted as specified in the reference seating position designated by the manufacturer.

If such specifications are not available, an adjustable head restraint shall be adjusted vertically until its top edge aligns with the top of the head. If this is not possible, the position nearest to the one mentioned above, i.e. normally the designated highest possible position, shall be selected. If the head restraint is adjustable in the horizontal direction, it shall be brought into the position that yields the smallest horizontal distance between the back of the head and the surface of the head restraint.

If a locking mechanism for the head restraint is available, this mechanism shall be engaged (i.e. locked).

Worst case head restraint test (option)
An adjustable head restraint shall be adjusted to its lowermost position. If the head restraint is adjustable in the horizontal direction, it shall be brought into the position that yields the highest horizontal distance between the back of the head and the surface of the head restraint.

If a locking mechanism for the head restraint is available, this mechanism shall be engaged (i.e. locked).

7.4.2. Film targets on the seat

For a subsequent film analysis, the following film targets shall be applied to the seat

T2: on the side face of the head restraint, at the same height as the head c.g.

T3: on the back rest, at the same height of the shoulder joint.

T4: on the back rest, according to figure 1 relative to the H-point.

7.4.3. Test protocol

The measured coordinates / angles of H-point, pelvis and thorax angle, and all film target locations shall be documented in a protocol e.g. as in appendix A

The distance **D** (back of the head >> head restraint) is measured and included in the protocol.

7.5. Camera positions

First camera: stationary, side view showing the seat and ATD during the deceleration/acceleration phase of the test.

Second camera: mounted on the sled, side view showing the torso, head, and head restraint.

It shall be ascertained that the seat back, the head restraint, and the upper body parts of the ATD are visible on the film/video during a time interval equal or longer than 400 ms after the onset of the sled deceleration/acceleration (t0).

The camera frame rate shall be equal or greater than 500 frames/sec. It is recommended to use a setting of 1000 frames/sec.

8. Test conditions

8.1. Test velocity

The test velocity shall be 16 ± 1 km/h. If a decelerated sled is used, the test velocity shall be measured immediately before the impact using a suitable measurement device. In the case of an accelerated (HyGe principle) sled, the test velocity shall be measured immediately after the acceleration phase has been completed.

8.2. Deceleration/Acceleration pulse

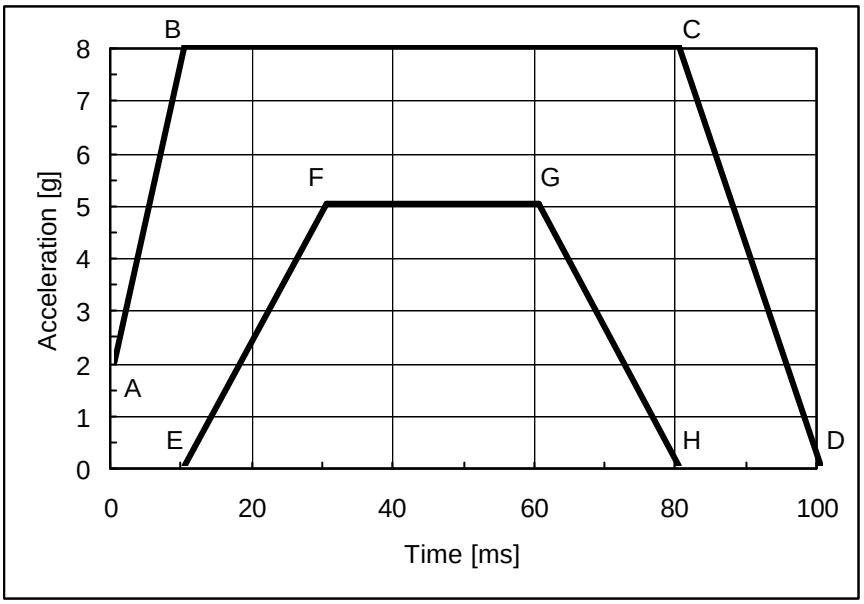

Figure 2: Corridor for the deceleration/acceleration pulse

Point	Time[ms]	a [g]	Point	Time [ms]	a [g]
A	0	2	E	10	0
B	10	8	F	30	5
C	80	8	G	60	5
D	100	0	H	80	0

Table 4: Corridor for the deceleration/acceleration pulse

8.3. Active devices

Protection devices that require a trigger signal in order to deploy during the collision shall be installed such that deployment occurs under the same conditions as in the target vehicle.

If such devices are triggered electronically, the trigger unit may be mounted on the sled. As an alternative, the trigger point can be specified as a time delay with respect to t0. In this case, the manufacturer shall prove that the trigger time corresponds to the trigger time that would be measured in the target vehicle under collision circumstances equal to those simulated by the sled test described here. This can be demonstrated e.g. by a sled test with a narrower tolerance corridor for the acceleration/time history, in which the g-levels for B and C in figure 2 are set to 6.5 g and for F and G to 5.5 g, respectively

If such devices are triggered mechanically, it shall be ascertained that the triggering mechanics are mounted in a position corresponding to the mounting arrangement in the target vehicle.

The triggering configuration and the status of the device after the test (deployed/not deployed, time of deployment, remarks) shall be documented in the test protocol.

9. Data recording

The measurement data shall be recorded according to SAE J211/1. Measurement data shall be considered for evaluation until the point in time at which the head c.g. film target (T1) reaches the position x0 during the rebound phase, i.e. its position shows same horizontal (x-)coordinate relative to the sled as at the beginning of the deceleration/acceleration phase.

9.1. ATD data

The measurement channels as described in tables 6.1 and 6.2 and the sled deceleration/acceleration shall be recorded electronically as a function of time. Data shall be recorded during a minimum of 400 ms after the onset of the sled deceleration/acceleration (t0).

Where multiaxial accelerations are measured, the resulting accelerations shall be calculated, and the 3-ms-exceedence, HIC, and NIC values shall be calculated. The moments of torque measured at the neck shall be documented without any corrections applied.

The point in time $\mathbf{T_k}$ where the ATD head touches the head restraint for the first time shall be determined.

Film analysis shall be used to determine the following values:

- Maximum extent of the rearward motion of the film targets T1 through T4 (horizontal and vertical coordinates).
- Velocity relative to the sled of T1 in the rebound phase at the time when $x_{(T1)} = x0$ (cf. above).
- Velocity relative to the sled of the lowest visible neck segment in the rebound phase at the time when $x_{(Neck)} = x0$ (cf. above).
- Maximum flexion and extension angles of the head relative to the thorax, time points at which these maxima are reached.

9.2. Post-test measurements

After the test, the coordinates of the film targets T2 through T4 shall be determined

10. Lowest threshold test

10.1. Procedure

An additional test at a test speed currently considered to designate the threshold below which injuries are improbable shall be performed. This test shall follow an identical protocol as described in sections 1 through 9, except that:

The test velocity specified in section 8.1 shall be 10 (-0 / + 1) km/h.
Figure 2 and Table 4 in section 0 are altered as follows:

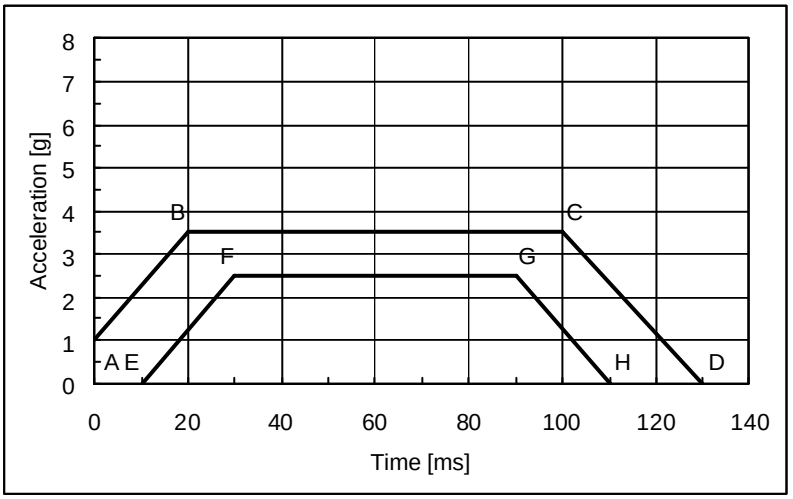

Figure 3: Corridor for the deceleration/acceleration pulse

Point	Time[ms]	a [g]	Point	Time [ms]	a [g]
A	0	1	E	10	0
B	10	3.5	F	30	2.5
C	80	3.5	G	70	2.5
D	120	0	H	90	0

Table 5: Deceleration/acceleration pulse for the lowest threshold test

10.2. Small female ATD

If an ATD is available that represents the fifth percentile female and is suitable for rear end impact testing, this ATD shall be used in place of the fiftieth percentile male ATD specified above.

11. ATD calibration

t.b.d.

12. Changes

Working draft 2: first version used for tests 6/99

Working draft 3:	translation into english, section 1 added, minor changes 10/99 first version presented to ISO
Working draft 3b:	section 2 third paragraph added section 7.1 changed. manufacturer specifications take precedence over 'standard' seating geometry section 7.3 added section 7.5 two paragraphs added section 8.3 added section 9.1 added specification of the minimum recording time
Working draft 3c:	section 8.3, 2nd paragraph changed
Working draft 4:	Harmonisation with TU Graz test procedure: section 7.4.1 added subsection 'worst case test' section 10 inserted: delta-v-10-km/h test changed title page and acknowledgements
Working draft 4b	changed corridor for 10 km/h test
Working draft 4c	section 9.1: added velocity $x_{(Neck)}$ section 7.2: clarified requirements for the belt system
Working draft 5	section 5.2: remove Hybrid III dummy, replace with BioRID section 6.1: change table 1 and 2 to adapt for BioRID. Remove section on rotational accelerations. Section 6.4: rename ‘head axis alignment’, adapt for BioRID move Figure and table 3 to section 7. Section 7.4.1: head restraint positioning as specified by manufacturer Section 7.1: new figure and target designations for BioRID section 8.1: test velocity 16 +-1 km/h (10 mph) section 8.2: new crash pulse corridor

APPENDIX A: TEST PROTOCOL (Recommendation)

Test center: **Test No.:** **Date:**

SEAT:

Manufacturer: Target vehicle:

Model: Model year:

ATD measurement pre-test:

	Description	**H-point machine**	**ATD**	**Difference**
A	Vertical distance floor-H-point	mm	mm	mm
B	Horizontal distance toepan-H-point	mm	mm	mm
C	Vertical distance H-point / target T4		mm	
	Torso line	°		
	Seat plane angle	°		
e	Pelvis angle		°	
D	Hor. distance head/head restraint		mm	

Film target coordinates (static):

Target	**pre-test**		**post-test**		**difference**	
	X [mm]	Z[mm]	X [mm]	Z[mm]	X [mm]	Z[mm]
T1						
T2						
T3						
T4						

Film target coordinates (film analysis) at maximum rearward excursion:

Target	**pre-test**		**post-test**		**difference**	
	X [mm]	Z[mm]	X [mm]	Z[mm]	X [mm]	Z[mm]
T1						
T2						
T3						
T4						
T1	Rebound velocity at x=x0		m/s		time =	ms

ATD standard measurements:

	Value	measured at time [ms]
Time T_k of first contact head-head restraint		
NIC [m^2/s^2]		
My upper neck Extension [Nm] (bei t < T_k)		
My upper neck Flexion [Nm] (bei t < T_k)		
My upper neck Extension [Nm] (bei t > T_k)		
My upper neck Flexion [Nm] (bei t > T_k)		
Fx uper neck [N]		
Fz upper neck [N]		
Head resulting a3ms [g]		
HIC		
Chest resulting a3ms [g]		
Pelvis resultinga3ms [g]		

ATD additional measurements

	Value	measured at time [ms]
My lower neck Extension [Nm]		
My lower neck Flexion [Nm]		
Head rotational acceleration [rad/s^2]		
Fx lower neck [N]		
Fz lower neck [N]		

Sled velocity: _____ m/s,

Crash pulse within prescribed corridor: Y / N

Remarks: