REVIEW OF CADAVER RESPONSES TO LATERAL IMPACT AND DERIVED BIOFIDELITY TARGETS FOR DUMMIES

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Abstract

The paper reviews the cadaver data base that has been used to design and develop the European side impact dummy. The production dummy called EUROSID-1 is briefly described. The quality and usefulness of the available cadaver data is reviewed and ranked in terms of its importance in determining the biofidelity response targets for a side impact dummy. Brief comparisons and comments are made on the proposed ISO TC22/SC12/WG5 requirements and the performance of EUROSID-1

1. INTRODUCTION.

EUROSID is the EURopean Side Impact Dummy and has been developed in four European countries. EUROSID-1 is the production version of the dummy and the successor to the production prototype dummies manufactured during 1987/9. EUROSID-1 is essentially the same as the production prototype dummy, but some improvements have been incorporated to overcome some of the criticisms made of the production prototype dummies and to improve its biofidelity. The main improvements have been a reduction in the rib mass, a revised flesh system and pelvis construction. Abdomen force measurement has been included.

The designed dynamic performance of EUROSID was based on published data. This data unfortunately covered only a small cadaver data base and not all of the cadaver data nor test conditions were appropriate for the specification of a crash test dummy. Some of the uncertainties in the data are due to difficulties in test reproducibility, others relate to the impact environment, such as impact velocity, test specification or body contact areas.

EEVC Working Group 9, which guided the final development of EUROSID-1, has been reviewing the biomechanical references in relation to lateral impact and have derived a set of targets for the dynamic performance of a side impact dummy. In the process WG9 has made use of the normalisation techniques developed by ISO [1] WG9 in their examination of the cadaver data and injury mechanisms have prioritised the response targets based on several factors. The factors used are -

a) The quality of the published cadaver data.
b) The severity of the cadavers' injuries.
c) The replicability of the cadaver test
d) The appropriateness of the cadaver test with respect to the in vehicle environment.
e) The severity and risk of injury to the vehicle occupant.

EUROSID has been developed to monitor injury severities up to an AIS 3 level, and above this severity the dummy's response need not necessarily be fully biofidelic. In terms of impact severity EUROSID has been developed to be used in the EEVC Side Impact Test Procedure [2], in which a stationary vehicle is struck laterally at 90° from 50km/h by a Mobile Deformable Barrier representing a 'standard' car. In terms of injury risk and severity the most important body areas are the head, thorax, abdomen and pelvis. The neck, shoulder and arms, lumbar and legs are all considered as second priority body parts the biofidelity of which can only be addressed when further knowledge and resources are available.

This paper concentrates on the basic review of the cadaver data and the derivation of biofidelity targets. A further EEVC WG9 paper will be published within the next year comparing the performance of the production EUROSID-1 dummy with the targets presented in this paper.

2.   REVIEW OF THE CADAVER AND VOLUNTEER DATA BASE

Several research groups have performed impacts on cadavers at a range of severities or have performed tests on human volunteers at lower severities. Because of the injury severities or test procedures adopted not all of the data is appropriate for use in developing design targets. The following review is not an exhaustive analysis of all of the available data but covers the main data bases that could be used for developing biofidelity design targets.

2.1.   Head impact response

Two cadaver data bases are available, one based on rigid surface impacts performed by Hodgson and Thomas [3] and the other based on the padded surface impacts of Association Peugeot-Renault (APR) [4]. In both test series whole cadavers were dropped with only their the heads being impacted.

2.1.1   Hodgson and Thomas tests.

Seven embalmed cadavers were strapped on their sides to a pallet that was free to pivot about one end. The cadaver's head and neck were allowed to extend over the free end. The pallet was released from a prescribed height to produce the desired head impact. The head impact velocity was between 1.65 and 1.92 m/s. The head acceleration was measured on the side of the head opposite the impact side. No skull fractures were observed.

2.1.2 APR tests.

Five cadaver tests were performed by APR. The cadaver was suspended horizontally above the impact surface by ropes. When the ropes were released, the cadaver dropped freely, the head impacting the surface. The body movement was stopped by a flexible foam "mattress". The head/horizontal angle at impact was between 1° and 10°. The acceleration of the centre of gravity was calculated from a 9-accelerometer array.

The first APR test involved dropping a cadaver from 0.3m onto a rigid impact surface. Since no head injuries were observed the drop height was increased to 1.3m for the second test and 1.2m for the remaining three tests. These later four cadavers were dropped onto a rigid surface covered by a 5mm thick rubber pad. Two cadavers obtained skull fractures and all four cadavers showed brain injuries (AIS 2-3).

2.2. Neck tests.

Two series of human volunteer tests and one set of cadaver tests have been performed. All the lateral neck bending tests have been performed on impact sleds.

2.2.1 Ewing tests.

Ewing [5] conducted a series of human volunteer tests using a HYGE accelerator. The volunteers were seated in an upright position on a rigid chair with their shoulder and hip against a vertical lightly padded wooden board, facing sideways to the direction of sled travel. They were restrained by several straps and belts. The maximum sled acceleration was 7.1 - 7.3 g and the sled velocity change 6.8 - 7.0 m/s. The volunteers were instrumented to calculate the head c.g. acceleration and to analyze the head motion. Results from 9 volunteer tests are available.

2.2.2 Patrick and Chou tests.

Patrick and Chou [6] conducted a series of human volunteer tests using a rigid seat attached sideways to the direction of travel of a deceleration sled. The volunteer was sitting on the seat with his shoulder and hip against a vertical rigid side board and was restrained by several straps. Responses for internal neck bending moments and forces, and head c.g. accelerations from one volunteer test (5.8 m/s, 6.7 g impact) are available.

2.2.3 APR tests.

APR [7] conducted four cadaver tests with initial sled velocities of 6.1 - 8.6 m/s and maximum sled decelerations of 12.1 - 14.6 g. The test conditions are similar to that of 2.2.1. The cadavers were instrumented to measure or calculate the head motion and acceleration.

2.3. Shoulder tests.

One dynamic cadaver test programme has been performed by Association Peugeot Renault (APR) [Ref 8] and one simple quasi-static volunteer programme by the Transport and Road Research Laboratory (TRRL) [Ref 9].

2.3.1 APR impactor tests.

APR [Ref 8] performed four lateral impactor tests at velocities of 4.6 4.2 4.5 4.5 m/s, tests were performed using the Part 572 23.4 kg guided certification impactor. The impact angle was 0° (purely lateral) for three cadaver tests and 15° forward for one further test. The upper arm was positioned along the thorax for three tests and 20° forward for the remaining test. Two cadavers received rib fractures. Impactor forces were determined as well as lateral displacements of the impactor, shoulder and spine. Photographic targets were fixed to the impactor, as well as to the skin covering the sternum and humerus bone of the cadavers to measure the shoulder deflection.

2.3.2 TRRL volunteer tests.

Five adult volunteers were tested, at the Transport and Road Research Laboratory [Ref 9]. They were laterally squeezed between a rigid wall and a plunger, quasi-statically. Biacromial width reductions of 111mm (SD 23mm) were noted under a low lateral compressive force of about 200N. No further details were published.

2.4. Thorax tests

Three research groups have performed lateral cadaver impactor tests from different velocities.

2.4.1 Highway Safety Research Institute

HSRI [Ref 10. Ref 11.] performed pendulum impacts at velocities of 0.9 m/s, 4.3 m/s and 6.1 m/s. No injury data is given for the 0.9 m/s impacts. Four tests were performed at 4.3 m/s and two at 6.1 m/s.

2.4.2 General Motors

GM [Ref 12.] have performed impactor tests at a range of impactor velocities (3.62 - 6.73 m/s) and impact direction using a standard mass impactor. The numbers of ribs fractured in these tests ranged from 0 to 7. Most of the tests have not been purely lateral but partial frontal impacts from an angle of 30° forward. Few lateral impact tests have been performed.

2.4.3 Institut National de Recherche sur les Transports et Leur Securite.

INRETS [Ref 13.] have performed two lateral impact tests but used a different faced impactor rather than the conventional 6" diameter flat faced impactor. The INRETS impactor had a spherical face of radius 600mm and diameter 120mm.

No comments are made whether this modified face had any additional influence on the impact injuries.
CHECK impactor

2.5. Abdomen tests.

APR [Ref 14. Ref 15.] performed a cadaver test programme in which 11 unembalmed cadavers were dropped laterally on a simulated armrest, consisting of a rigid hardwood impact surface secured to a supporting platform. The supporting platform consisted of either rigid hardwood, polystyrene or phenespan. The armrest protruded 31 to 55 mm above the surrounding surface. The cadavers were suspended 1 or 2 m above the armrest and were positioned such that their right sides would impact the armrest at the level of the 9th ribs ensuring liver involvement. The armrest was secured to a piezo-electric load cell, accelerometers were attached to the 10th thoracic vertebrae and the 9th rib on both sides of the cadavers.

2.6. Pelvis tests.

INRETS performed impactor tests on 22 cadavers, each one being impacted several times at increasing speed until pelvic fracture occurred. The absence of fracture after each test was checked with X ray [Ref 16.]. The cadavers were seated without lateral support and impacted with a rigid or padded faced impactor. Impactor acceleration and pelvic acceleration at the sacrum was measured. The INRETS impactor had a mass of 17.3 kg and a spherical face of 175 mm radius, and outer diameter of 120 mm. (Note. The dimensions of the impactor used in these test is that used for the actual cadaver tests and not as previously described.)

2.7. Whole body tests.

Three types of whole body cadaver test have been carried out. a) Sled based impacts. b) Free fall drop tests and c) Vehicle based impacts.

2.7.1 Sled tests.

Impact sled tests have been performed by HSRI [Ref 17.] and the University of Heidelberg [Ref 18. Ref 19.]. The sled tests simultaneously loaded the thorax/shoulder area and the pelvis area. The impact surface was either a rigid flat wall or a rigid wall onto which two shaped deformable pads had been attached at thorax and pelvis levels, mounted on the impact sled. The HSRI tests were performed against a plain uninstrumented wall whereas the later Heidelberg tests were against two force measuring plates located adjacent to the shoulder/thorax and the pelvis. The HSRI tests can be combined with the Heidelberg tests and used to extend the cadaver injury data base at similar impact severities. Within the two programmes tests at three different conditions are reproducible: into the rigid surface at 6.7 and 8.9 m/s and into the pads at 8.9 m/s. Forces were independently

measured at the thorax and pelvis levels. The impact velocities of 6.7 and 8.9 m/s were the impact sled velocities but recent analyses have shown that the cadavers impacted the wall during a rebound phase of the sled and that the actual cadaver to sled impact velocities were 7.6 and 10.3 m/s. [Ref 20.]

2.7.2 Drop Tests.

Free fall cadaver drop tests have been performed by APR [Ref 21.] [Ref 22.]. The cadavers were suspended horizontally by ropes and allowed to free fall either onto a rigid or a padded surface. The arms were set at a range of positions. Of the comprehensive test matrix two of the test conditions have been selected for general examination and publication. A free fall impact from a height of 1m onto a rigid surface and a 2m free fall impact onto two deformable pads located adjacent to the thorax and pelvis.

2.7.3 Vehicle impact tests.

Vehicle based impact tests in which real accidents have been replicated have been performed by several research groups. In these tests cadavers have been substituted for the human occupants in the real accident. One such test programme has been performed by FAT [Ref 23.] [Ref 24.] based on the Opel Kadett. Other tests have been performed by KOB [Ref 25.] in which 5 selected accidents were reconstructed three times each with cadavers.

3. DISCUSSION OF THE CADAVER DATA.

For cadaver data to be useful for defining the biofidelity targets for a test dummy the data must meet several requirements;

a) The cadaver test must be well specified, repeatable and reproducible.

b) The test environment should be an appropriate one and relate to the crash environment in which the human surrogate is to be used (ie. in the vehicle environment), thus velocity and effective masses should be appropriate.

c) The injury mechanisms and injury severities should be commensurate with the real injuries found in humans in the accident studies.

d) The cadaver sample should be a reasonable representation of the real world population that is injured in accidents.

It is unlikely that all of these requirements would be satisfactorily met, therefore informed judgements must be made to rank the usefulness of the data, the most appropriate data being used for biofidelity targets.

3.1. General observations.

3.1.1 Impactor and Component Tests.

The main advantage of these types of test is that the body part being examined is locally loaded and interaction between adjacent body parts is minimised. One of the main disadvantages is that most research groups use only the Part 572 dummy certification, 23.4 kg, 6" diameter impactor and only vary impact velocity. This can be appropriate for some type of impact but limits the impact range and can cause penetrating type injury.

3.1.2 Drop Tests.

The free fall drop test onto a flat surface is a simple uncomplicated test environment in which little extra specialist equipment is required. Unfortunately due to lack of control throughout the impact wide variations are possible. In the APR tests described in 2.7.2 the cadavers were suspended horizontally by supporting ropes under the shoulder, hips and legs. In this attitude the cadavers' body mass and shape distribution and becomes non symmetrical about the superior inferior axis. Excessive amounts of soft tissue adjacent to the struck surface are noted in the published photographs. The required simple support system could not support the cadaver in the necessary flat horizontal plane required for accurate biofidelic study. The suspended attitude of the cadaver and lack of control during the fall and impact resulted in poor quality output data, therefore the free drop tests are not considered a useful test condition for setting biofidelity targets and are therefore not used except for the abdomen since no other, more useful, cadaver data is available.

3.1.3 Sled Tests

In some ways the sled tests are similar to the free fall drop tests, in that they are flat surface whole body tests, but their main advantage is that in there is no artificial support system for the cadaver and that the cadaver is symmetrical about its superior inferior axis at the point of impact. In the sled tests the whole body is loaded at approximately the same time. They are of limited use in specifying the performance of individual body parts because different body parts collapse at different rates, causing interaction effects. Even so they can be used to study limited interactional effects across the body and global biofidelity performance. It should be noted however that the two basic test conditions, rigid and padded wall, load the cadaver in two different ways. When the plate is fitted with a pad it permits possible shoulder impact to occur late in the impact, whereas in the rigid wall the wall force is initiated by the shoulder followed by loads emanating from impact by the arm and thorax. Although some cadaveric acceleration records have been published it is felt that only the wall force is useful for determining biofidelity targets for the thorax.

3.1.4 Vehicle Tests

Vehicle based cadaver tests, like sled and drop tests, are whole body tests that can be useful for studying global performance and interaction effects but are of limited value for determining the performance of individual body parts. Their

main advantage is that the cadaver or dummy is loaded in the same manner as a live human would be, in a similar accident, with the correct effective masses and velocity profiles across the body. Unfortunately variability is likely to be greater because of the complex nature of the test environment and differing collapse modes possible within the vehicle added to the already wide variation found within the cadaver population. To reduce the variation several repeated tests have to be attempted in order to determine a general cadaveric response.

3.2. Observations by body area.

3.2.1 Head.

The database of the Hodgson and Thomas head impact test appears to be reasonably large; seven cadavers. The maximum resultant head accelerations are in the range that might be expected in 50 km/h side impacts (96 - 135 G). The responses are not disturbed by structural failure of tissues. However, the test conditions are not simple to reproduce and a simple, head only, drop test has to be adopted to attempt to replicate the original test conditions. The average equivalent drop height of these seven cadaver tests appears to be 171 mm.

Three different drop heights and two different impact surfaces (rigid and padded) have been used for the five cadavers tested by APR. No data is given for two of the tests. One of the cadavers received a skull fracture. The remaining three cadavers were dropped using the same test, one of cadavers receiving a skull fracture. All cadavers received brain injuries. It therefore appears that these tests are more severe than is necessary to assess the biofidelity of dummies heads. As for the Hodgson tests, the test condition is not a simple one. A replicating drop test using only the head would require a guidance system, since the drop height is 1200 mm. Even then the repeatability would be doubtful since the impact would be on the flat side of the dummy head. Furthermore the specifications of the thin rubber pad used by APR appears to be very important in this test set-up, since the head is almost rigid and the responses would strongly depend on the padding characteristics.

3.2.2 Neck.

The kinematic and dynamic response of the head is dependent on the design of the neck. Also the upper thorax performance is affected by the head/neck response. Therefore the neck must exhibit an acceptable level of biofidelity. Human volunteer data bases are considered more important for defining neck performance than cadaver data bases because of the lack of muscle tone in cadavers. Furthermore, all of the APR cadaver tests (2.2.3) showed a (different) abnormality thus raising some doubt about their suitability. The results of only one test from the Patrick and Chou volunteer tests is available. This is considered to be too limited a data base for it to be of much use. The Ewing volunteer test series is well defined and consists of 9 tests.

3.2.3 Shoulder.

Unfortunately, each APR cadaver test on the shoulder had an abnormality either in the test condition or test response. Published results for test MS204 showed a deflection of 100mm whereas the for the other tests deflections of 34 - 37mm were reported. However, the 15° impact angle used in test MS204 had very little effect on the resulting force / time response of the cadaver. It is not clear if the thickness of the flesh on the outside of the upper arm/shoulder was taken into account when determining shoulder deflection. Film targets were located on the arm flesh , sternum and on the impactor. It is believed that the shoulder deflection measured was 'internal' and not 'external'. Additionally rib fractures were seen in test MS202 and MS204.

APR Test No	Impact Velocity (°)	Impact Angle (°)	Arm Position (°)	Injuries
MS201	4.6	0	0	-
MS202	4.2	0	0	3 # ribs
MS203	4.5	0	20	-
MS204	4.5	15	0	3 # ribs

Table 1. APR shoulder impact test matrix.

The tests at TRRL were quasi-static tests with limited value for determining biofidelity targets. They are helpful for determining minimum deflection criterion.

3.2.4 Thorax.

Of the three impactor cadaver data bases only the HSRI data is considered of sufficient quality for defining lateral biofidelity design targets. Table 2. summarises the test data for the four mid speed impacts. Tests at the other velocities are not used in this analysis because of the lack of data and too few tests. The variability in test conditions in the GM data is considered too great and too few of the GM tests are pure lateral impacts. Pulse characteristics are too different for the two impact directions to be combined. GM attempted to velocity normalise the tests to two standard velocities of 4.3 and 6.7 m/s. It is not thought advisable to velocity normalise an impact in which structural failure of the rib cage occurs, since when rib failure occurs the basic stiffness of the rib cage would be reduced. This stiffness change would violate the basic assumptions used in velocity normalisation. The INRETS impacts, being based on a different faced impactor and on a small sample are not used.

Test No	Age/Sex	Velocity (m/s)	NRF	AIS
76T062	69/M	4.3	7	5
76T065	63/M	4.3	0	1
77T071	60/M	4.3	0	.1
77T074	60/M	4.3	2	2

NRF = Number of rib fractures.

Table 2. HSRI thorax impactor injuries.

3.2.5 Abdomen.

The eleven cadavers tested by APR were tests under four test conditions.

- 1m drop on armrest supported by rigid material
- 1m drop on armrest supported by crushable material
- 2m drop on armrest supported by rigid material
- 2m drop on armrest supported by crushable material

The properties of the crushable materials are not defined, so this test condition cannot be duplicated. For one of the remaining six tests, no force versus time responses were available. The 9th rib and 10th thoracic vertebrae accelerations are not appropriate parameters for assessing an abdomen since they are determined by impact to the thorax rather than impacts to the abdomen. (see also Section 4.1.3).

The cadavers were severely injured by these drop tests; up to 12 rib fractures and an abdominal AIS 5. It seems that the 2m drop tests are more severe than necessary to assess biofidelity.

The three remaining 1m drop tests used a rigid armrest with heights of 3.1, 4.1 and 5.1cm. The abdominal penetration was at least as great as the height of the armrest. However, the abdomen was protruding in these tests due the specific drop test set-up.

The value of this cadaver database can be considered as limited and only useful insomuch as there are no other usable data.

3.2.6 Pelvis.

Considering that some fractures may have been underestimated in the INRETS data, it is realistic not to consider the tests in which the peak force is decreased for a higher speed test than for the previous tests on the same cadaver. Most of the tests were performed with a rigid impactor but few of them used a padded one. Only the rigid impact tests are numerous enough to be considered. With

this filtering of the data it is possible to use the results of 35 tests performed on 15 cadavers. Data on these tests is shown in Table 3.

3.3. ISO review.

ISO Working Group 5 (TC22/SC12) has also studied the cadaver data but have not qualified the analysis in any way, although this is under review. Most of the data have been incorporated into a wide ranging set of requirements with no ranking of importance. Some cadaver tests have not been used in the ISO analysis, while others thought inappropriate in this analysis have been incorporated. The review reported in this paper has incorporated some of the ISO analysis and clarified some of the test specifications.

3.4. General review conclusions.

It is clear that not all of the cadaver data are useful for defining biofidelity targets and that some of the data must be disregarded for various reasons. Working Group 9 has prioritised the cadaver data and test procedures with the following conclusions:

3.4.1 Head.

The head is considered to be an important body part. Of the available cadaver data only the Hodgson and Thomas cadaver data is considered to be useful for defining biofidelity targets, but even in this case the test condition for the dummy tests must be modified from the original cadaver tests (see Annex 1.1). An equivalent dummy test to the cadaver tests requires a drop height of 171mm. However, in order to have a test procedure similar to ISO [1] a 200mm head only drop test is defined.

3.4.2 Neck.

The neck is not considered to be an important body part, by itself, since serious injury is less frequent than to the head, thorax, abdomen and pelvis. None of the available cadaver and volunteer tests are easy to replicate with a dummy. The Ewing test data is believed to be the only useful data for defining biofidelity design targets.

3.4.3 Shoulder.

Based on injury severity and injury risk the shoulder is not considered to be an important body part. Since the action of the shoulder can influence the performance of associated body parts it is felt that it should have a level of biofidelity. Only limited data on the shoulder are available. Both of the data bases are considered useful for defining shoulder biofidelity but due to their quality can only be used to give general design targets. This is considered to be sufficient.

3.4.4 Thorax.

The thorax is considered to be a high priority body area. Although three impactor data bases exist only data from the HSRI test programme are currently considered suitable. With further comparative evidence on the effects of impact direction it might be possible to include some of the GM data with the HSRI data in an a later analysis. Since only two impacts have been performed at a higher velocity these have not been used to derive higher velocity impactor targets.

The APR drop tests are not considered suitable for the specification of biofidelity targets for the reasons explained in Section 3.1.2.

The Heidelberg sled tests were performed on relatively few cadavers at each test configuration and appropriate data are only available for a small number of these tests since the early tests were not performed into an instrumented wall. There are too few cadaver results, especially at a velocity 10.3 m/s into the padded wall on which to specify targets with confidence. Even so all three test conditions are considered useful as defining general targets. The 7.6 m/s rigid wall impact is considered to be the most important test condition followed by the 10.3 m/s padded wall. The 10.3 m/s rigid impact has been included as a test for dummy integrity at higher energy levels. Strict biofidelity at this higher severity level is not considered to be very important.

3.4.5 Abdomen.

In occurrence and severity abdominal injuries in side impacts rank about equal to the head, thorax and pelvis. A biofidelity specification for the abdomen section, at least up to the specified injury tolerance limit, is required. A major problem exists in defining what the abdomen section actually covers. Normally the dummy abdomen section has to cover a larger area than the abdominal space defined for a 50th percentile human. The lower ribs of the human being, which cover some abdominal organs, belong to the abdomen section of a dummy.

A cadaver database is available for defining the performance of the abdomen. The biofidelity of the abdomen is a high priority target body area, the available cadaver data appears to be of limited value. The biofidelity targets can therefore unfortunately only be viewed as second priority at this time.

3.4.6 Pelvis.

The pelvis is an important body part. The pelvis impactor data base is fairly large in terms of the number of impacts on fifteen cadavers. It is considered appropriate to include the data from all the tests of increasing severity on the same cadaver, until the observed occurrence of pelvic fracture or when the impactor force at a higher speed developed a lower force, indicating a suspected fracture. Results on cadavers with a fractured pelvis are not considered to be appropriate since the stiffness of the structure is different.

Again, as for the thorax, the **APR** drop tests are not considered to be suitable for the specification of pelvis biofidelity. The comments made regarding the rigid and padded wall (Section 3.4.4) also apply to the pelvis.

4. BIOFIDELITY DESIGN TARGETS.

The data from the selected tests described above have been used to determine a set of biofidelity targets for the dynamic performance of side impact dummies. These targets have been divided into two priority areas related to the risk and severity of injury and also to the validity and quality of the cadaver data. It is difficult to establish an acceptable performance target range for a dummy that would represent the average member of the population at risk, especially where the cadaver data base is limited to only two or three tests. In this review performance targets have been derived in a two part process. Firstly the normalised cadaver responses were time shifted to a 'best fit' position based on the peak response and overall pulse shape. A mean response curve was then derived. The width of the tolerance curve was based on an examination of the cadaver results for tests in which there were sufficient data for statistical analysis. This analysis suggested that the coefficient of variance for cadaver tests was of the order of 20 to 30%. Therefore, for the purposes of establishing basic target corridors, a band width of ± 25% of the peak mean value was applied to the whole time history of mean normalised cadaver curve, this approximating to a tolerance band of ± one standard deviation. A ± 25% tolerance band was constructed around the mean response curve. To enable the corridor to be easily specified a straight line corridor was then constructed through the ± 25 % responses.

The specifications of the biofidelity test procedures closely follow the original cadaver tests and are given in the Annex. The cadaver data have been normalised to reduce cadaver and test variability based on the ISO procedures. To conform with the cadaver data most of the dummy responses should also be normalised in a like manner to reduce test variability.

It should be noted that not all the cadavers responses lie within the biofidelity targets detailed in the following sections. The targets are mathematically derived from a mean cadaveric response in the specified test. It is expected that some part of the cadaver's response might lie outside of the target corridor if either the test condition or the cadaver's response is highly variable.


4.1. High Priority targets.

4.1.1 Head.

Only one target is given for the head, in a 200 mm rigid surface drop test, with tests performed to the procedure described in Annex 1.1. The resultant peak head acceleration should be 112g ± 29g.
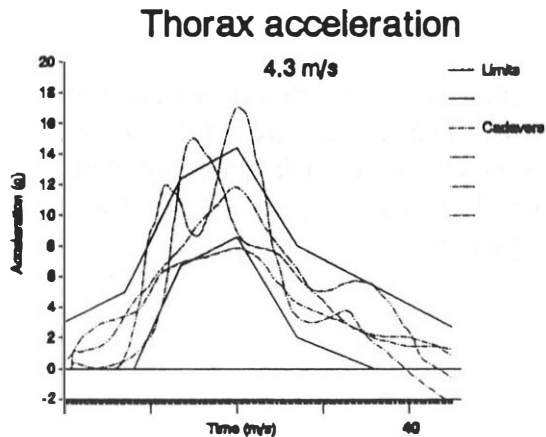
4.1.2 Thorax.

4.1.2.1. Impactor.

In tests performed according to the procedure described in Annex 1.5 two targets are given. Normalised impactor force vs normalised time response is shown in Figure 1. and Table 4. - and normalised dummy T1 lateral acceleration vs normalised time response - Figure 2. and Table 5.

Figure 1. Thorax impactor deceleration target.
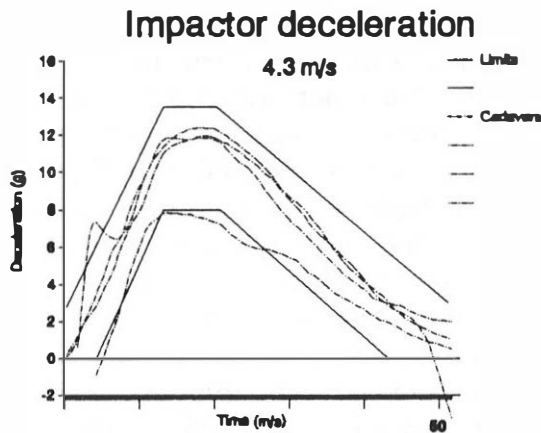
Time (ms)	Lower (g)	Upper (g)
0		2.8
4	0	
13	8	13.5
20		13.5
20.5	8	
43	0	
51		3.0

Table 3. Thorax impactor deceleration corridor coordinates.

Figure 2. Thorax impactor T1 lateral acceleration.

Time (ms)	Lower (g)	Upper (g)
0		3.0
7		5.0
8	0	
13.5	6.7	12.4
20	8.6	14.4
27	2.0	8.0
36	.0	
45		2.7

Table 4. Thorax impactor T1 acceleration corridor coordinates.

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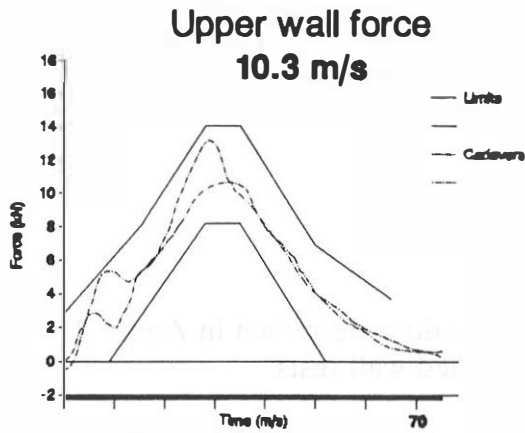
Figure 4. Thorax rigid wall force
(10.3 m/s)

Table 6. Thorax rigid wall force corridor coordinates. (10.3 m/s)

Time (ms)	Lower (kN)	Upper (kN)
0		2.8
9	0	
15		8.0
28	8.2	14.0
35	8.2	14.0
50		6.9
52	0	
65		3.7

b. Padded Wall.

The normalised thorax wall force vs normalised time at 10.3 m/s into the APR padding is shown in Figure 5. and Table 8.
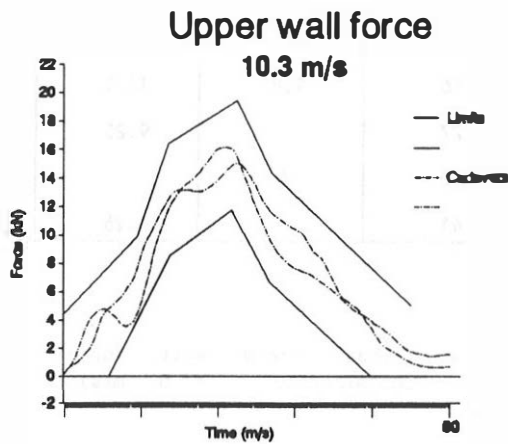

Figure 5. Thorax padded wall force
(10.3 m/s)

Time (ms)	Lower (kN)	Upper (kN)
0		4.5
6	0	
9.5		9.9
13.5		16.4
14	8.6	
22	11.75	
22.5		19.4
27	6.7	14.4
40	0	
45		5.0

Table 7. Thorax padded wall force corridor coordinates. (10.3 m/s)

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NOTE. No allowance has been made for muscle tone for the thorax response targets. Some authors [Ref 26.] have suggested that muscle tone would increase the force levels of the thorax in live humans, but the size of this increase is not known for lateral impacts. Therefore, unmodified target corridors are given, but it should be noted that some excursions above the top limit would not necessarily indicate a non-humanlike performance in a dummy.

4.1.2.2. Sled.

In tests performed according to the procedure described in Annex 1.8 simple wall forces are specified, for the rigid and padded wall tests.

a. Rigid Wall.

The normalised thorax wall force vs normalised time at 7.6 m/s is shown in Figure 3. and Table 6. and the normalised wall force vs normalised time at 10.3 m/s is shown in Figure 4. and Table 7.

Figure 3. Thorax rigid wall force. (7.6 m/s)
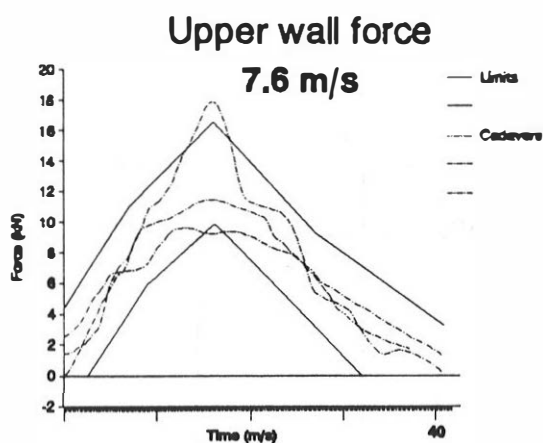
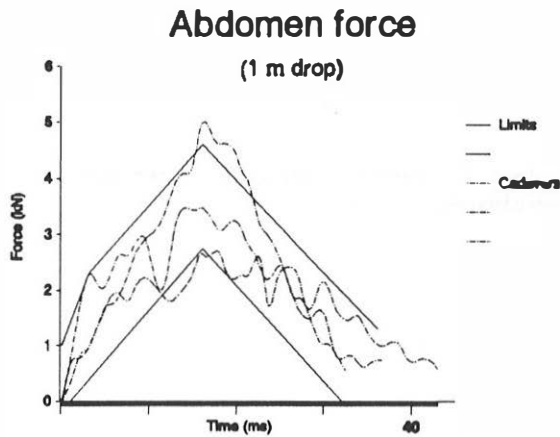| Time (ms)	Lower (kN)	Upper (kN)
0		4.5
2.5	0	
7		11.0
9	6.0	
16	9.8	16.5
27		9.25
32	0	
41		3.25

Table 5. Thorax rigid wall force corridor coordinates. (7.6 m/s)

4.1.3 Abdomen.

For the 1m drop tests on the abdomen with the procedure defined in Annex 1.6, the normalised dummy response targets are:

- Normalized impact force : Figure 6. and Table 9.
- Abdominal penetration   : ≥ 41mm

Figure 6. Abdomen drop test force/time target. (1m)

Time (ms)	Lower (kN)	Upper (kN)
0		1.0
1	0	
3		2.3
16	2.75	4.6
32	0	
36		1.3

Table 8. Abdomen drop test force/time corridor coordinates. (1m)

4.1.4 Pelvis.

4.1.4.1. Impactor.

The pelvis impactor test procedure is defined in Annex 1.7. A simple peak normalised force / impactor velocity corridor is shown in Figure 7. and Table 10. The corridor is based on a least squares linear regression model of the impactor results shown in Table 3. (Force {KN} = -0.62 + 1.066 (Impactor velocity {m/s}). No fixed impact velocity is prescribed for the tests except that the velocity must be between 6.0 m/s and 10.0 m/s.
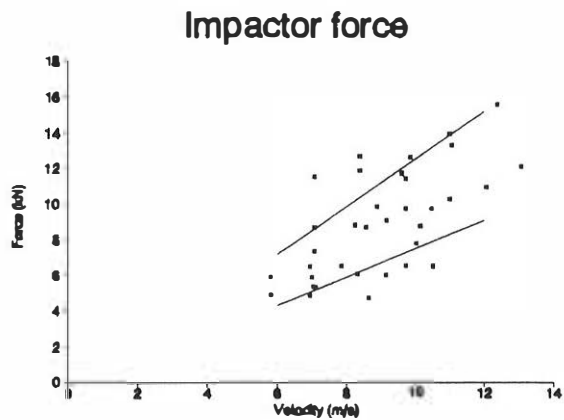
Impactor force

Velocity (ms)	Upper (kN)	Lower (kN)
6	9.13	4.33
10	12.55	9.53

Figure 7. Pelvis impactor force/velocity corridor.

Table 9. Pelvis impactor corridor coordinates.

4.1.4.2. Sled.

Two configurations of sled test are specified in Annex 1.8.

a. Rigid Wall.

A normalised pelvic acceleration target corridor in the range 7.6 to 10.3 m/s has been defined assuming that a linear relationship exists between pelvic acceleration and impact velocity. Pelvis acceleration target limits at the two specified impact velocities are -

Normalized pelvis acceleration at 7.6 m/s   52.7 - 87.9 g.
Normalized pelvis acceleration at 10.3 m/s   79.5 - 132.5 g.

A normalised wall force vs normalised time target at 7.6 m/s is shown in Figure 8. and Table 11. and at 10.3 m/s in Figure 9. and Table 12.
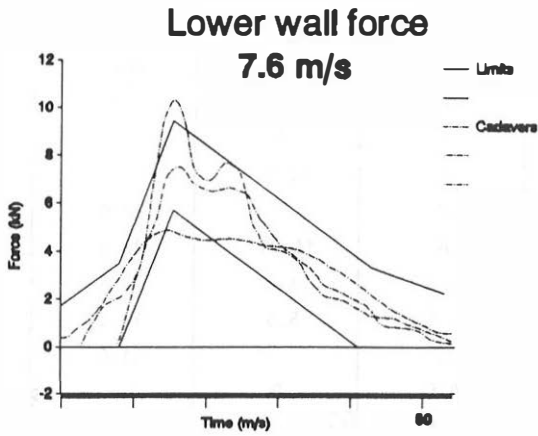
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Lower wall force
7.6 m/s

Time (ms)	Lower (kN)	Upper (kN)
0		1.75
8	0	3.5
15.5	5.7	9.4
41	0	3.3
53		2.25

Figure 8. Pelvis rigid wall force. (7.6 m/s)

Table 10. Pelvis rigid wall force corridor coordinates. (7.6 m/s)

Lower wall force
10.3 m/s

Time (ms)	Lower (kN)	Upper (kN)
0		2.0
5	0	
17		12.0
18	7	
23	7.9	13.1
32	2.5	
35		6.0
38	0	
46		3.5
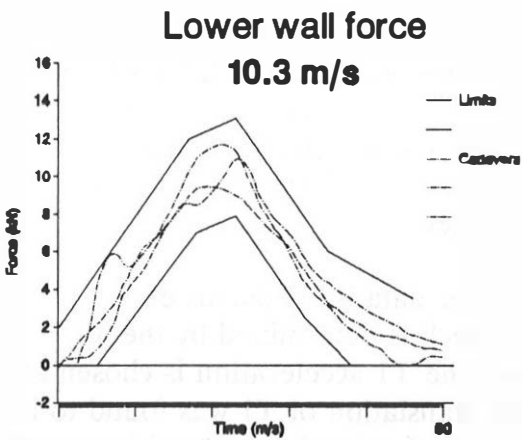
Figure 9. Pelvis rigid wall force. (10.3 m/s)

Table 11. Pelvis rigid wall force corridor coordinates. (10.3 m/s)

b. Padded Wall.

Normalized pelvis acceleration 10.3 m/s   65.8 - 109.7 g.

A normalised wall force vs normalised time target at 10.3 m/s is shown in Figure 10. and Table 13.

Lower wall force
10.3 m/s

Figure 10. Pelvis padded wall force. (10.3 m/s)
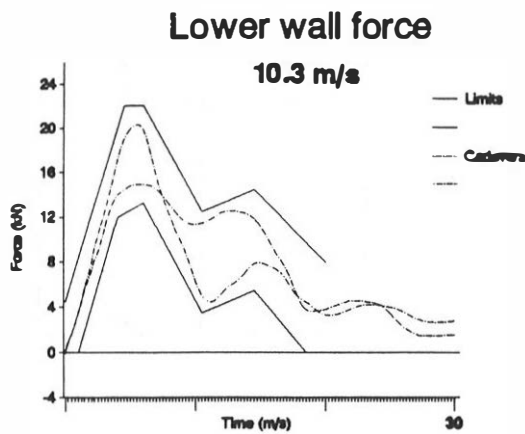
Time (ms)	Lower (kN)	Upper (kN)
0		4.5
1	0	
4	12.0	
4.5		22.0
6	13.25	22.0
10.5	3.2	12.5
14.5	5.5	14.5
17		11.0
18.5	0	
20		8.0

Table 12. Pelvis padded wall force corridor coordinates. (10.3 m/s)

4.2. Low Priority targets

4.2.1 Neck.

The neck is considered to be a low priority area since it is a body part with no injury criterion. Even so it is important that the neck does exhibit a level of biofidelity as it can affect the performance of the upper thorax and trajectory of the head both of which have specified injury criteria. As the kinematics of the head/neck system are considered to be of some importance, flexion angles and trajectories of the head are defined as biofidelity targets.

Analysis of the original human volunteer data by Wismans et. al. Ref 27. has shown that the response of the head and neck is determined by the T1 lateral acceleration and velocity change. Therefore the T1 acceleration is chosen as an input requirement for the neck. The horizontal translation of T1 was found to be the only significant motion of the torso. Requirements for head motion with respect to T1 were derived.

In Annex 1.2 the original human volunteer test set-up is described with an alternative test procedure, because the original test set-up is hard to replicate with a dummy. The original test procedure uses a complete dummy mounted on a seat which is rigidly mounted onto a sled. As well as the sled deceleration T1 lateral acceleration is also specified as an input requirement for the original test procedure. Because of test variability, caused by insufficiently specified padding and straps, the alternative procedure uses only the T1 lateral acceleration as an input requirement for acceleration. In addition to the TI lateral acceleration the T1 velocity change, T1 rotations and the initial position of the head-neck system are specified in the alternative procedure.

If tests are performed in accordance with the procedures described in Annex 1.2 the dummy responses should be:

- Maximum angular flexion of the inferior-superior axis of the head relative to inferior-superior axis of the thorax should be between 44 and 59 degrees (head rotation)

- Maximum horizontal displacement of the centre of gravity of the head relative to T1 transverse axis should be between 130 and 162 mm

- Maximum downward vertical displacement of the centre of gravity of the head relative to T1 transverse axis should be between 64 and 94 mm.
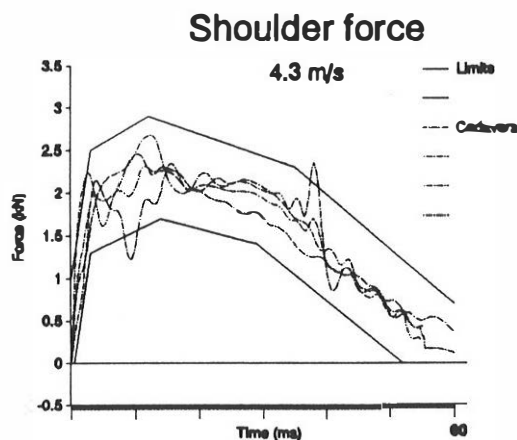
4.2.2   Shoulder.

Since clear dynamic displacement data is not available no displacement/time corridor is specified. The targets for the shoulder are an impactor force/time corridor and a minimum displacement requirement.

4.2.2.1. Dynamic Targets.

For impactor tests performed in accordance with the procedure described in Annex 1.3 the dummy responses should be:

Normalized shoulder deflection: at least 32 mm
Normalized impact force   : Figure 11. - Table 14.

Figure 11. Shoulder impactor force/time corridor.

Time (ms)	Lower (kN)	Upper (kN)
0		1.0
0.5	0	
3	1.3	2.5
12		2.9
14	1.7	
29	1.4	
35		2.3
52	.0	
60		0.7

Table 13. Shoulder impactor force corridor coordinates.

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4.2.2.2. Static Targets.

Lateral displacement of the shoulder plunger relative to the spine under a 200 N lateral force: 55 mm.

5.   **FUTURE WORK**

A comprehensive test programme has now commenced within the EEVC Working group 9 laboratories evaluating the first four production EUROSID-1 dummies. All tests will be performed on two different dummies at two separate laboratories. The dummies are being tested according to the test procedures detailed in this report. The results of this test programme and comparisons with the biofidelity targets will be published in 1991.

6.   **ACKNOWLEDGEMENTS**

Participating members of EEVC Working Group 9 are -

J Bloch   D Cesari
G Ferrero   K-P Glaeser
C A Hobbs   G D Suthurst
E G Janssen   M G Langdon
R W Lowne (Chairman)   A Pastorino
A K Roberts (Secretary)   M Beusenberg

ANNEX

1. EEVC WORKING GROUP 9 BIOFIDELITY TEST PROCEDURES.

All of the biofidelity tests should be performed in a temperature controlled environment regulated between 20°C ± 2°C. It should be noted that some of the test procedures may be different from those specified in the EUROSID Users' Manual. (eg: The impactor specification for the dynamic shoulder test). The procedures described in this paper are based as close as possible on the original cadaver tests with appropriate setting up procedures.

1.1. Head drop test procedure.

1.1.1 Test description.

The test is to be conducted using only the dummy's head. The head is to be positioned with a 200 mm ± 2 mm space between it and a flat, rigid impact surface. The impact surface is to be horizontal and the head oriented so that its mid-sagittal plane makes an angle of 35° with the impact surface and its anterior-posterior axis is horizontal. A 'quick release' mechanism is required to drop the head onto the impact surface. The added mass of the support mechanism should not exceed 70 gm.

1.1.2 Test Instrumentation.

The dummy head is instrumented with a triaxial accelerometer located at its centre of gravity.

1.1.3 Data Processing.

Accelerations are to be filtered using to CFC 1000. No normalisation procedures are defined for this configuration.

1.2. Neck test procedure.

1.2.1 Test description

If a full dummy test similar to the one Ewing et al. is used, the sled deceleration should lie within the corridor specified in Figure 12. and Table 15. The measured T1 lateral acceleration must also meet the corridor specified in Figure 13. and Table 16. Since neck biofidelity is considered, the T1 lateral acceleration is of more importance than the sled deceleration. Therefore slight deviations in sled deceleration from the corridor specified in Figure 12. and Table 15. will be tolerated provided the T1 lateral acceleration meets the corridor specified in Figure 13. and Table 16. Sled velocity for the Ewing test should be 6.9 ± 0.2 m/s. (Note: The sled deceleration and T1 lateral acceleration corridors are not

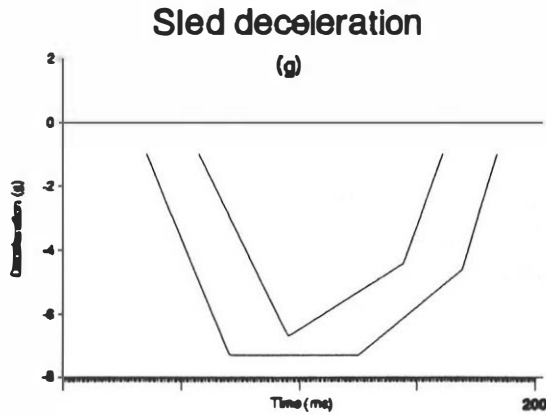based on a ± 25% corridor since they are input requirements rather than output requirements).

Sled deceleration
(g)

Figure 12. Sled deceleration for the Ewing neck test.

Table 14. Sled deceleration corridor coordinates for the Ewing neck test.

Time (ms)	Upper (g)	Lower (g)
35		-1.0
57	-1.0	
71		-7.3
95	-6.7	
125		-7.3
144	-4.4	
161	-1.0	
169		-4.6
184		-1.0

Neck T1 Lateral Decel.
(g)
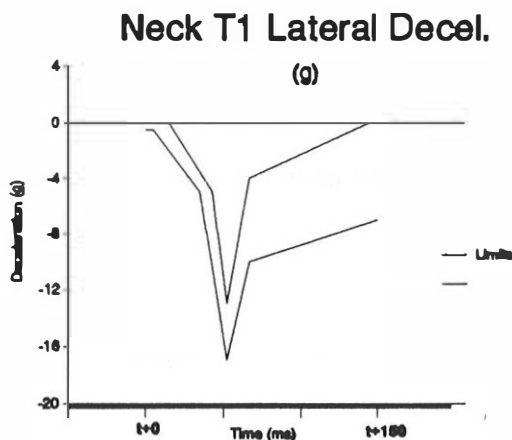
Figure 13. T1 lateral acceleration for neck test.

Table 15. T1 lateral acceleration corridor coordinates for neck test.

Time (ms)	Upper (g)	Lower (g)
t	0.0	-0.5
t+ 5		-0.5
t+ 15	0.0	
t+ 35		-5.0
t+ 43	-5.5	
t+ 52	-13.0	-17.0
t+ 67	-4.0	-10.0
t+145	0.0	
t+150		-7.0

For the Ewing sled test procedure time 't' for the T1 lateral acceleration should be taken 50 ms after t = 0 of the sled deceleration corridor. For the following alternative neck test procedure time 't' can be chosen arbitrarily.

An alternative test procedure is allowed provided the T1 lateral acceleration meets the corridor specified in Figure 13. and Table 16. In the analysis of the original data T1 rotations were neglected, in addition T1 translations other than lateral were neglected. Therefore an alternative neck test procedure should ensure no rotations at T1 and only lateral translation of T1. The velocity change of

T1 as well as the initial head-neck position relative to T1 also determine the head-neck response and thus should be prescribed as well. Details of the original and alternative test procedure for the assessment of the biofidelity of the neck follow.

1.2.1.1. Full dummy test according to Ewing et al.

The complete dummy is to be seated in a nominally upright position in a test seat, functionally similar to the one used by Ewing [Ref 5]. The test seat should be rigidly mounted on a sled, facing sideways (90°) to the direction of sled travel. A vertical, lightly padded, side board is to be rigidly attached to the seat to restrict upper torso rotation and pelvis translation of the dummy. The top of the sideboard should extend to a level 40 to 50 mm below the top of the dummy's shoulder. The dummy should be positioned against the vertical sideboard such that the midsagittal plane of the dummy is vertical and perpendicular to the direction of sled travel. The thorax movement is to be restrained with a strap attached to the back of the seat to limit shoulder forces. The pelvis is to be restrained by a lap belt and an inverted 'V' pelvis strap tied to the lap belt. Both arms should be positioned alongside the thorax and restrained with suitable straps. The anterior-posterior axis of the head is to be horizontal.

1.2.1.2. Alternative test procedure

An alternative procedure can be used provided the T1 acceleration meets the corridor specified by Figure 13. and Table 16. Other input requirements are the degrees of freedom of T1, the velocity change of T1 and the initial head-neck position. All T1 rotations should be restricted to a minimum ($0° \pm 2°$) as well as T1 translations perpendicular to the direction of sled travel ($0 \pm 5mm$). The head-neck position should be such that the anterior-posterior axis of the head is horizontal and the midsagittal plane of the head vertical. This can be achieved by mounting a head-neck assembly rigidly onto a sled, provided the sled is decelerated according to the T1 lateral acceleration corridor.

1.2.2 Test instrumentation

The dummy is to be instrumented with a uniaxial accelerometer at the base of the neck (T1) with its sensitive axis directed laterally. Also the sled deceleration is to be measured (Ewing procedure). Photographic targets for measuring head c.g. translation in horizontal and vertical direction relative to T1, head rotation (angular rotation of the inferior-superior axis of the head relative to the vertical) and the horizontal translation of the base of the neck (T1) relative to the sled are necessary. Sufficient cameras are required to record all the dummy and head displacements. Neck accelerations should be measured to CFC 180.

1.2.3 Data processing

No normalisation procedures are defined for the neck test.

1.3.   Shoulder impactor test procedure.

1.3.1   Test description.

The shoulder impactor test shall be performed on a complete dummy using a linearly guided impactor. The impactor mass shall be 23.4 kg with a smooth flat face 6" diameter, the edge of the impact face being relieved with a 6mm radius. The dummy shall be sat upright with no additional lateral supports on a flat horizontal rigid surface with the legs straight and parallel. The arms shall be positioned parallel to the thorax. The axis of the impactor shall be aligned with the shoulder pivot ± 10 mm and at 90° to the mid sagittal plane. Impact velocity at the point of impact shall be 4.5 m/s ± 0.1 m/s.

1.3.2   Test instrumentation.

For/aft impactor acceleration shall be measured according to CFC 180. Photographic targets should be fixed to the impactor and the dummy upper thoracic spine to calculate the shoulder deflection relative to the spine from high speed film. The external shoulder displacement is defined as the lateral displacement of the face of the impactor relative to the upper thoracic spine perpendicular to the anterior posterior axis of the dummy.

1.3.3   Data processing.

Impactor acceleration shall be normalised according to the procedure described in Annex 2.3.1.1 based on a thorax standard mass (M_s) of 20.5 kg. ·

1.4.   Shoulder quasi-static test procedure.

Rigidly support the thorax of the dummy in a vertical position to prevent lateral translation of the spine. Adjust the upper arm to a position of 40° forward. Apply a pure lateral force to the outer extremity of the shoulder, adjacent to the arm pivot, with a 50 mm diameter plunger. Allow the shoulder and plunger to displace in any direction and record the maximum lateral displacement of the plunger with a applied lateral force of 200N.

1.5.   Thorax impactor test procedure.

1.5.1   Test description.

The thorax impactor test shall be performed on a complete dummy using a linearly guided impactor. The impactor shall have a mass of 23.4 kg and a smooth flat face 6" diameter. The dummy shall be sat upright with no additional lateral support on a flat horizontal rigid surface with the legs straight forward and parallel. Both arms shall be positioned vertically upright above the head. The axis of the impactor shall be aligned with centre of the rib cage (vertically and laterally), at 90° to the mid-sagittal plane. Impact velocity shall be 4.3 m/s ± 0.1 m/s.

1.5.2 Test instrumentation.

The fore/aft impactor acceleration and the T1 lateral acceleration shall be measured according to CFC 1000 and filtered with a 100 Hz Finite Impulse Filter (FIR) [1].

1.5.3 Data processing.

Impactor and dummy accelerations shall be normalised according to the procedure described in Annex 2.3.1.2 based on a thorax standard thorax mass (M_s) of 27 kg.

1.6. Abdomen drop test procedure.

1.6.1 Test description.

The dummy is to be suspended above the impact surface with its midsagittal plane horizontal and its abdominal region in line with the top surface of the armrest. The armrest should contact the abdomen section just superior to the iliac crest and without interfering with the lower thoracic ribs. The simulated armrest is constructed of rigid hardwood. The armrest is 7 cm in width and should protrude 4.1 cm above the surrounding surface. The length of the armrest must be sufficient to prevent the dummy from striking the ends. The arm on the impact side is positioned 40° forward such that no contact with the arm takes place. It is The surrounding surface is made of hardwood and should be large enough to prevent the dummy from striking the edges. A quick-release mechanism is to be used to drop the dummy from a distance of 1 m measured between abdomen and armrest.

1.6.2 Test instrumentation.

The simulated armrest is to be mounted on a piezoelectric load cell. If a piezoelectric load cell is not used the armrest must also be fitted with a uniaxial accelerometer, mounted vertically. Additionally lateral acceleration at T12 should also be recorded for normalisation procedures. Forces and accelerations should comply with CFC 180.

1.6.3 Data processing.

If a piezoelectric load cell is not used the load cell must be inertia compensated according to Equation 1. High speed camera coverage is required to determine abdominal penetration. Abdomen penetration is defined as the vertical displacement of the thoracic spine (directly over the armrest) relative to the top surface of the armrest measured from the time of first contact of the abdominal surface with the armrest. Impactor forces are to be normalised according to the procedure described in Annex 2.3.2 based on an abdominal standard mass (M_s) of 16.4 kg.

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[1] The FIR filter programme is available to EUROSID users from TNO.

1.7. Pelvis impactor test procedure.

1.7.1 Test description.

The pelvis impactor test is performed on a complete dummy. The dummy should be sat on a fixed seat shown in View 1. The foam material used for the seat was a polyether foam 40 mm thick having a density of 47.0 kg/m³. The upper arms should be positioned alongside the thorax (0°) and no addition lateral support to the dummy is to be given. The legs of the dummy shall be positioned perpendicular to the impact direction and parallel with each other. The linearly guided impactor shall have a mass of 17.3 kg and a smooth spherical impact face of radius 175 mm and a outer diameter of 120 mm. Impact velocity must be between 6.0 m/s and 10.0 m/s, the axis of the lateral impact being centred on the hip pivot point.
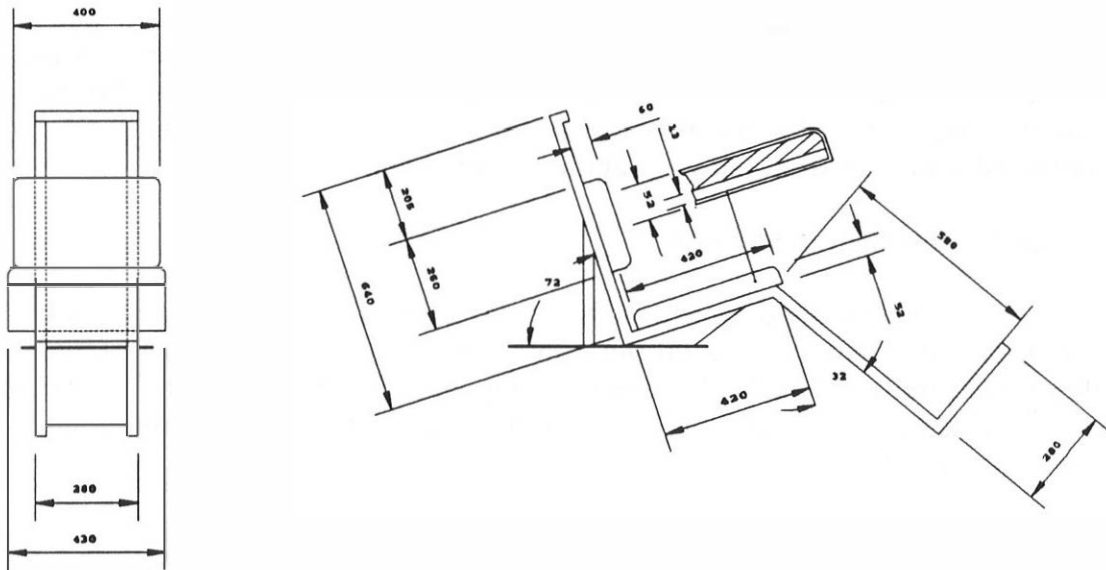
View 1. Pelvis impactor test seat.

1.7.2 Test instrumentation.

Impactor acceleration and pelvic acceleration shall be measured according to CFC 1000.

1.7.3 Data processing.

The impactor acceleration shall be normalised according the procedure described in Annex 2.3.1.3. based on a pelvic standard mass of (M_s) of 14.5 kg.

1.8. <u>Whole body sled test procedure.</u>

1.8.1 Test description.

The whole body tests can be performed on either a standard deceleration impact sled or on a HYGE impact sled. The sled must be fitted with a rigid vertical impact wall onto which two force measuring plates are fitted. Perpendicular to the rigid wall a rigid low friction bench seat is attached, in line with the motion of travel of the sled. The dimensions of the test seat and force measuring load cells are given in View 2. (The sliding test seat used by the University of Heidelberg for the cadaver tests was 1.5 m in length.) The dummy must be supported vertically on the non struck side during the acceleration phase of a non HYGE impact sled. The arms of the dummy are to be placed alongside the thorax (0°). Impacts are to be performed into the rigid wall at two impact velocities 7.6 and 10.3 m/s. One further test is to be performed at 10.3 m/s into the same wall onto which two foam blocks are mounted. Impact velocity tolerance shall be ± 0.1 m/s. The specified impact velocity includes any rebound velocity that may exist with a deceleration type sled. On both types of test sled the dummy must strike the wall at the prescribed velocity. The block specification is described in Annex 3. The pads are to be located in the middle of each force plate, parallel to the top and bottom edges.

Note. It is advisable to restrain the legs from excessive lateral articulation after the dummy strikes the wall in order to prevent damage to the knee joints.

1.8.2 Test Instrumentation.

Plate forces shall be measured CFC 1000 and lateral dummy accelerations at T1 and at the pelvis CFC 180. The force measuring plates are to be inertia compensated by placing an accelerometer in the centre of.each force plate its axis perpendicular to the surface of the plate.

1.8.3 Data Processing.

The resultant, inertia compensated, forces are to be derived - Equation 1.

View 2. Impact sled seat
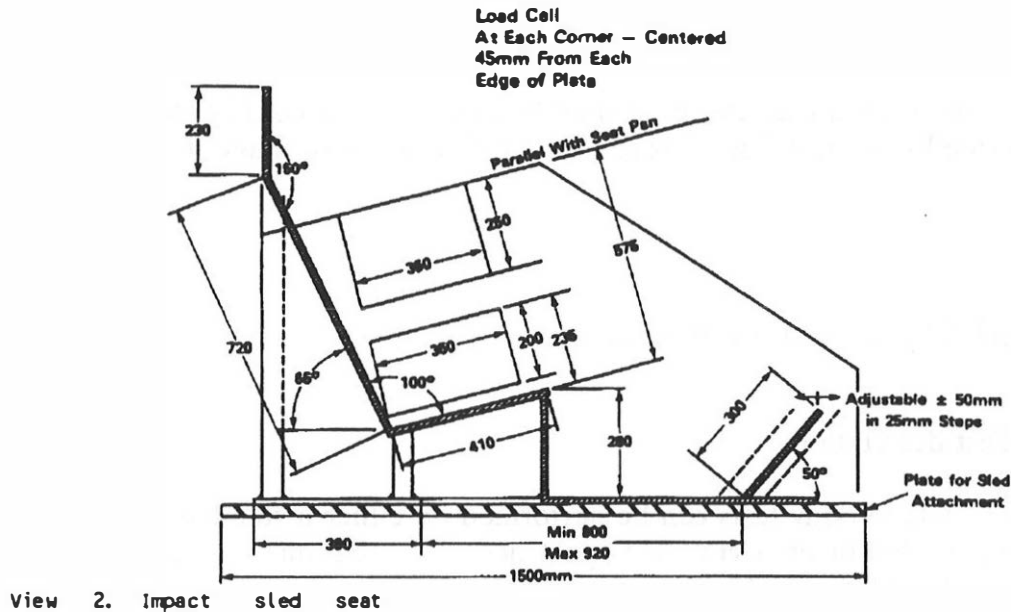
$$F_i = \sum F_{plate} + (M_{plate} A_{plate})$$

Where F_i = Inertia compensated plate force
F_{plate} = Plate force
M_{plate} = Mass of plate
A_{plate} = Acceleration of plate, where acceleration is positive in the direction of impact of the dummy

All forces and dummy accelerations must be normalised according to the procedure described in Annex 2.3.3 the thorax with a standard mass (M_s) of 27.0 kg and the pelvis with a standard mass M_s of 14.5 kg, and both filtered with a 100 Hz FIR filter.

2. INSTRUMENTATION AND DATA PROCESSING.

To permit comparisons between cadaver and dummy tests and dummy to dummy tests common data processing procedures must be adopted. The following sections detail the methods that should be used to enable valid comparisons to be made. They are mainly based on the cadaver tests and the normalisation procedures developed by Mertz [29].

2.1. Instrumentation.

All instrumentation and filtering is to meet the ISO standard - ISO 6487:1987. [28] and recommended Channel Filter Classes (CFC).

2.2.   Filtering and data comparison.

Wall forces for the sled impacts and impactor forces for the thorax impactor tests must be filtered using a 100hz Finite Impulse Filter (FIR). (A copy of a recommended FIR Fortran filtering programme called 'THRXINJ' is available to EUROSID users from IW-TNO, the suppliers of the dummy.)

Time zero does not exist for most of the biofidelity assessment tests, therefore all responses should be time shifted to match the shape of the target corridors.

2.3.   Normalisation Procedures.

To reduce variations in cadaver output and test conditions all data channels for the targets have been normalised according to a procedure developed by Mertz and Lowne [29] and detailed in the ISO requirements. For the biofidelity tests all of the data must be normalised in a similar way to reduce test variability. Normalisation procedures are defined for the appropriate test condition. Impactor normalisation is based on a two mass spring model and the sled/drop tests on a single mass spring model, since the effective mass of the striking object is infinite.

To perform normalisation a standard mass for the associated body part is required. In this analysis the effective mass for each cadaver has been derived. For the thorax impactor tests this was selected when the impactor velocity was at a common velocity with the lateral velocity of the body part, for the shoulder and pelvis at the end of the main pulse. In the sled tests the effective mass is taken at the end of the main wall force pulse. The standard body part mass was then determined using for each group of cadavers in the test - Equation 2. In determining the standard masses for the thorax and pelvis in the wall tests an average standard mass for all three test conditions has been taken although the data suggests that different values for the three different test conditions would be appropriate. Table 17. gives the standard masses derived from this analysis. These standard masses should be used for the dummy normalisation procedures. It should be noted that variation in the standard masses does not alter the relationship between the different dummy results but only the biofidelity targets described in this paper and the absolute magnitude of the response characteristic (Force or Deceleration). For cadaver/dummy comparisons to be made normalisation of the cadaver and dummy data must be based on the same standard mass. The body part standard masses used in this analysis will in some instances be different from those of other analyses since the cadaver sample on which this study is based is different.

$$M_s = 76 * AV[\frac{Effective \ body \ part \ mass}{Total \ cadaver \ mass}]$$ Equation 2. Standard Mass.

Test Procedure	Body Part Standard Mass (kg)
Shoulder impactor	20.5
Thorax impactor	27.4
Abdomen drop	16.4
Pelvis impactor	14.5

Rigid   an   padded   wall
    Upper   force
    Lower   force
	37.0
	24.0

Table   16.   Normalisation   standard   masses.

2.3.1   Impactor normalisation.

2.3.1.1. Shoulder.

a) Determine the effective mass of the shoulder area. - Equation 3. The effective mass should be taken at the end of the initial impactor pulse.

$$M_e = \frac{\int F \, dt}{V_0}$$ Equation   3.
                                       Shoulder   effective   mass.

Where M_e = Effective mass of the body part (kg)
         F = Impactor force (N)
         V_0 = Lateral impact velocity (m/s)

b) Determine the body part mass ratio - Equation 4. with the value of effective mass taken at the end of the main impact pulse.

$$R_m = \frac{M_s}{M_e}$$ Equation   4.
                             Mass   ratio.

Where R_m = Body part mass ratio
         M_s = Standard body part mass (kg)
         M_e = Effective mass of the body part (kg) - Equation 3.

c) Determine the impactor force, deflection and time normalisation factors - Equation 5.

$$R = \sqrt{R_m}$$

Where   R   = Normalisation factor for impactor force, shoulder deflection
                and time.
         R_m = Body part mass ratio

d) Determine the normalised impactor force, time and deflection for the
dummy by multiplying the impactor force, time period and shoulder deflection by the
normalisation factor. - Equation 6.

$$D_{nr} = D_r * R$$

Where D_{nr} = Normalised response
         D_r = Recorded response
         R   = Normalisation factor

2.3.1.2. Thorax.

a) Determine the effective mass of the dummy part. - Equation 7. The
effective mass should be determined when the impactor and dummy are at a common
velocity ie; when $V_p = V_t$. (On the first occasion if two should exist.)

$$M_e = \frac{\int M_p A_p \, dt}{\int A_t \, dt}$$

Where M_e = Effective mass of the body part (kg)
         M_p = Mass of the impactor (kg)
         A_p = Impactor deceleration (m/s^2)
         A_t = Body part lateral acceleration T1 (m/s^2)

b) Determine the thorax mass ratio - Equation 8.

$$R_m = \frac{M_s}{M_e}$$

Where R_m = Body part mass ratio
         M_s = Standard body part mass (kg)
         M_e = Effective mass of the body part (kg)

c) Determine the impactor acceleration dummy lateral acceleration and time
normalisation factors Equation 9. Equation 10. and Equation 11.

$$R_{ap} = \frac{\sqrt{R_m(M_p + M_e)}}{\sqrt{(M_p + M_s)}}$$

$$R_{at} = \frac{\sqrt{(M_p + M_e)}}{\sqrt{R_m} \sqrt{(M_p + M_s)}}$$

$$R_t = \frac{\sqrt{R_m} \sqrt{(M_p + M_e)}}{\sqrt{(M_p + M_s)}}$$

Where
R_{ap} = Impactor acceleration normalisation factor
R_{at} = Dummy T1 lateral acceleration normalisation factor
R_t = Impactor time normalisation factor
R_m = Body part mass ratio - Equation 8.
M_p = Impactor mass (23.4 kg)
M_e = Effective mass of body part (kg)
M_s = Standard body part mass (kg)

d) Determine the normalised acceleration/time responses for the dummy and impactor - Equation 12. Equation 13. and Equation 14.

$$I_n = R_{ap} * I$$

$$A_n = R_{at} * A$$

$$T_n = R_t * T$$

Where
I_n = Normalised impactor response
I = Recorded impactor response
A_n = Normalised dummy response
A = Recorded dummy response
T_n = Normalised time
T = Recorded time
R_- = Appropriate normalisation factor

2.3.1.3. Pelvis.

a) Determine the effective mass of pelvis area of the dummy. - Equation 15. The effective mass should be taken at the end of the initial impactor pulse.

$$M_e = \frac{\int F \, dt}{V_0}$$

Equation 15.
Pelvis effective mass.

Where M_e = Effective mass of the body part (kg)
　　　　F = Impactor force (kg)
　　　　V_0 = Lateral velocity (m/s)

b) Determine the body part mass ratio - Equation 16.

$$R_m = \frac{M_s}{M_e}$$

Equation 16.
Pelvis mass ratio.

Where R_m = Body part mass ratio
　　　　M_s = Standard body part mass (14.5 kg)
　　　　M_e = Effective mass of the body part (kg)

c) Determine the pelvis normalisation factor - Equation 17.

$$R_{nf} = \sqrt{R_m}$$

Equation 17.
Pelvis impactor
normalisation factor.

Where R_{nf} = Impactor force normalisation factor
　　　　R_m = Body part mass ratio

d) Determine the normalised pelvis impactor force. - Equation 18.

2.3.2. Abdomen drop test normalisation.

a) Determine the effective mass of the abdomen part - Equation 19. The effective mass should be taken at the end of the impact pulse.

$$M_e = \frac{\int F\, dt}{\int A_{T12}\, dt + (T*g)}$$

Equation 19. Abdominal effective mass.

Where
M_e = Effective mass of abdomen (kg)
A_{T12} = Lateral deceleration of T12 (m/s^2)
T = Pulse length (s)
g = gravity (m/^{2})

b) Determine the body part mass ratio. - Equation 20.

$$R_m = \frac{M_s}{M_e}$$

Equation 20. Mass ratio.

Where
R_m = Body part mass ratio
M_s = Standard body part mass (kg)
M_e = Effective mass of the body part (kg) - Equation 19.

c) Determine the normalisation factor. - Equation 21.

$$R = \sqrt{R_m}$$

Equation 21. Abdomen normalisation factor.

Where
R = Normalisation factor
R_m = Body part mass ratio

d) Determine normalised force, normalised time. - Equation 22.

$$D_{nr} = D_r * R$$

Equation 22. Abdomen normalisation.

Where
D_{nr} = Normalised response
D_r = Recorded response
R = Normalisation factor

:

2.3.3 Sled normalisation.

a) Determine the effective mass of the dummy part (thorax and pelvis). - Equation 23. The effective mass should be taken at the end of the initial wall force for the appropriate body part.

$$M_e = \frac{\int F\, dt}{V_o}$$

Equation 23.
Effective dummy mass.

Where M_e = Effective mass of the body part (kg)
       F = Compensated impact wall force (kN)
       V_0 = Initial impact velocity (m/s)

b) Determine the mass ratio - Equation 24. taking the effective mass at the end of the main pulse.

$$R_m = \frac{M_s}{M_e}$$

Equation 24.
Dummy mass ratio.

Where R_m = Body part mass ratio
       M_s = Standard body part mass (kg)
       M_e = Effective mass of the body part (kg)

c) Determine the force and time normalisation factors - Equation 25.

$$R_{nf} = \sqrt{R_m}$$

Equation 25.
Force normalisation.

Where R_{nf} = Normalisation factor
       R_m = Mass ratio

d) Determine the normalised wall force/time responses for the dummy. - Equation 26. Equation 27.

$$W_n = R_{nf} * W$$

Equation 26.
Normalised wall force.

$$T_n = R_{nf} * T$$

Equation 27.
Normalised time.

Where W_n = Normalised wall response
              W = Recorded wall response (compensated)
              T_n = Normalised time
              T = Recorded time

3.   SPECIFICATION OF IMPACT PADDING.

The sled test padded wall padding was developed by APR. The polyurethane foam blocks were 140mm x 140mm x 420mm with a density of 135 - 150 gm/l. The quasi-static force/deflection characteristics (with a loading rate of 100 mm/min) are shown in [Ref 1].

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