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Road vehicles — Injury risk curves for the evaluation of occupant protection in side impact tests

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TECHNICAL REPORT

ISO/TR 12350

Second edition
2013-10-01

Road vehicles — Injury risk curves for the evaluation of occupant protection in side impact tests

Véhicules routiers — Courbes de risques de blessures pour l'évaluation de la protection des occupants en choc latéral

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Foreword

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The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 12, *Passive safety crash protection systems.*

This second edition cancels and replaces the first edition (ISO/TR 12350:2004), which has been technically revised.

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Road vehicles — Injury risk curves for the evaluation of occupant protection in side impact tests

1 Scope

This Technical Report provides injury risk curves to assess occupant protection in side impact tests. The curves are given for the WorldSID 50th, a mid-size adult male side impact dummy. Injury risk curves for other side impact dummies could be added as soon as the necessary material is available and processed as described in this Technical Report. These dummies are used during tests carried out according to ISO 10997 or which are under investigation by regulatory bodies and consumer testing organizations.

2 Methodology

2.1 Selection of PMHS sample to be used for the construction of the injury risk curves

An in-depth review of the postmortem human subjects (PMHS) tests available in the literature and in the NHTSA database (http://www-nrd.nhtsa.dot.gov/database/aspx/biodb/querytesttable.aspx) was performed. The listed tests were analysed in order to determine if they could be accurately repeated with dummies and included in the construction of injury risk curves.

This clause summarizes the series of tests that were conducted by body region and type of loading. Reasons for including or excluding each particular test series are detailed. The PMHS characteristics are provided in the form of related electronic documents available through the ISO website and detailed in Clause 4. The detailed descriptions of the PMHS configurations allowing the reproduction of the test with a dummy are presented in Annex A to Annex F, as well as the reasons for inclusion or exclusion.

The rigid and padded head impactor tests conducted by Calspan[18] were included and are detailed in Annex A. The head impactor tests of the Highway Safety Research Institute (HSRI)[51] were excluded because the impact speeds were not known. The head impactor tests of the University of Michigan Transportation Research Institute (UMTRI) (NHTSA database) were excluded because the impactor characteristics were not known.

The whole body drop tests with head impact conducted by Wayne State University (WSU)[22], those conducted by the Association Peugeot-Renault (APR) without helmet, and the head drop tests conducted by Medical College of Wisconsin (MCW)[56] were included and are detailed in Annex A. The whole body drop tests with head impact conducted by APR with helmet were excluded because the helmet properties were unknown.

The shoulder impactor tests performed by APR[2], INRETS[14] [15] [17], and WSU[26] [30] were included. The shoulder impactor tests conducted by Ohio State University (OSU) on a rigid bench were also included[3] [4]. These configurations are detailed in Annex B. The oblique shoulder impactor tests performed by OSU on a 1996 Ford Taurus seat were excluded because the characteristics of the seat were unknown.

All, but one, of the thorax impactor tests conducted by HSRI[43] [44] [45] were included. The single-impact WSU thorax impactor test[54] [55] was also included. The UMTRI[34] [35] and OSU[49] thorax impactor tests were included when the level of load was deemed to be below the threshold of rib fracture (700 N), such that the fractures could be attributed to the final high-speed impact. These test configurations are detailed in Annex C. The 76T038 HSRI test was excluded because the data were questionable. The HSRI tests 77T079 and 77T080 were excluded because it does not seem realistic to have 18 rib fractures for 2 165 N of impact force. All the WSU and INRETS[16] multi-impact tests, as well as some UMTRI tests (83E085, 83E086, 83E106, 83E107, 83E108) and OSU tests (0505OTH25L01, 0505LTH25R01, 0506OTH25R01, 0506LTH25L01, 0601LTH25L01, 0601OTH25R01), were excluded because it was not possible to determine which impact caused each injury.

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Only one of the abdomen impactor tests performed by WSU[54] [55] (WSU063-34) was included because all the other subjects were impacted more than once in the abdomen and/or thorax. All the OSU abdomen impactor tests but two (93VRTAB08, 93VRTAB09) were included. These two tests were excluded because the abdomen deflection exceeded the target level of 16 % of the chest breadth. The test configurations are detailed in Annex D.

The Laboratory of Accidentology and Biomechanics (LAB) abdomen impactor tests[52] were excluded because a measurement system was positioned at the level of the liver and could have influenced the abdominal injuries.

Most of the reviewed pelvis impactor tests were multi-impact tests. The pelvis impactor tests performed by WSU[54] [55], UMTRI[33] [36], ONSER[11] [12], and INRETS[5] [6] were included when an increase in impactor speed was accompanied by an increase in energy for a given PMHS, as this was assumed to be an indication of no injury. The configurations are detailed in Annex E. Two UMTRI tests (83E087, 83E109) were conducted with an APR pad that is no longer available. The ONSER multi-impact tests C3, C4, D3, E2, F2, F3, H4, H5, I6, J2, J3, N7, S3, S4, X1, X2, Y2, Z1, and Z2 were excluded because there was a possible weakening of the pelvis bone.

APR conducted lateral drop tests with PMHS[2] [53]. A review of the films failed to confirm the position of the subjects' lower extremities and whether or not an impact surface was provided to catch the lower extremities. The test films revealed that some tests were conducted with the subjects' head, some were conducted without the head, and for the others, the film coverage did not reveal if the head was attached or removed. Some subjects were observed to rotate during the free fall. For these reasons, and because the APR padding cannot be reproduced, all of the whole body drop tests were excluded from the construction of injury risk curves for the thorax, abdomen, and pelvis.

Some sled tests performed by Heidelberg[25] [29], MCW/OSU[39] [40] [28] [27], and WSU[7] [8] [9] [10] [23] were included and are detailed in Annex F. Several checks were done to select the PMHS to be included in the construction of the injury risk curves. The checks are detailed in Annex G.

— The position of the PMHS at the time of impact was first checked. The Heidelberg tests (H82014, H82018, H82019, H82015) and MCW/OSU tests (SC126, SC105, SC131) were then excluded.

— The consistency between the thorax-pelvis transmissibility and the contact times of the thorax and pelvis plates were also checked. The Heidelberg tests (H82014, H82018, H82019, H82015) and MCW/OSU (SC126, SC105) were then excluded.

— The total momentum was checked. Tests for which the total momentum differed from other tests with the same impact wall configuration were excluded (MCW/OSU SC131).

— The absence of shoulder interaction with the wall was checked in the MCW/OSU configuration. Sled tests with PMHS seating height under 826 mm and shoulder interaction with the wall observed on the film were excluded from the shoulder, thorax, and abdomen injury risk curves (MCW/OSU SC137, SC138, SC119, 94LSI32P04, LSI32R08, SC30A102).

— PMHS characteristics were checked. The PMHS having sternotomy wires were excluded because the PMHS response and injuries were questionable (MCW/OSU SC122, SC132, LSI32P11, SC103, SC112, SC30A103, SC20A101).

— PMHS injuries were checked. PMHS from the MCW/OSU SC114 test with a right hemithorax, which could have resulted from secondary impact, was excluded.

— Some of the checks required the analysis of the wall plates loads. Some tests were excluded because the impact wall was not instrumented with load cells or because the data were questionable and then the checks could not be done. This was the case for the HSRI sled tests[31], the first test series conducted by WSU (NHTSA database), some Heidelberg tests (H82009, H80011, H80013, H80014, H80017, H80024, H81002, H81004, H81006, H81016, H81022, H81025, H81027, H82002, H82020, H80018, H80020, H80021, H80023, H81011, H81012, H81015, H81021, H83008, H83016, H83021, H83030, H83031), as well as some MCW/OSU sled tests (98LSI32R17, SC106, SC127, 96LSI32R07, SC123).

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— Finally, sled tests for which the impact wall padding or the airbag was no longer available were excluded (Heidelberg tests H82008, H82021, H82022, H83008, H83016, H83021, H83030, H83031, H83011, H83020, H84008, H83010, H83012, HSRI tests 76T029, 76T034, 76T039, 76T042, MCW/OSU tests SAC 101, SAC 103, SAC 104, SAC 105, WSU 2nd test series SIC-09, SIC-10, SIC-11, SIC-12, SIC-13, SIC-14, SIC-15, SIC-16, SIC-17).

— The severity of PMHS injuries were coded according to the Abbreviated Injury Scale 2005[1]. Table 1 summarizes the body regions and injury severity levels for which PMHS data are available to construct injury risk curves. There were no AIS ≥ 3 shoulder injuries from the PMHS tests. Therefore, injury risk curves for the shoulder can only be constructed for the AIS ≥ 2 level of injury. For the thorax, abdomen, and pelvis, injury risk curves were constructed at the AIS ≥ 3 injury level and either the AIS ≥ 2 or AIS ≥ 4 level if the PMHS injury/no injury results were better balanced at these AIS levels. Note that all rib fractures are coded in thoracic skeletal AIS, including those that resulted from abdominal impacts.

Table 1 — Body regions and AIS levels for which injury risk curves are constructed

Body region	AIS levels used in the injury risk curve construction
Head	AIS ≥ 3
Shoulder	AIS ≥ 2
Thorax (skeletal)	AIS ≥ 3 and AIS ≥ 4
Thorax (soft tissue)	AIS ≥ 2 and AIS ≥ 3
Abdomen	AIS ≥ 2 and AIS ≥ 3
Pelvis	AIS ≥ 2 and AIS ≥ 3

2.2 Dummy data

Once the PMHS sample to build the injury risk curves is selected, the dummy results reproducing these PMHS test configurations are collected.

The injury risk curves are proposed in this Technical Report for a 50th percentile male dummy. Only WorldSID 50th percentile results are presented in the current version of this Technical Report. It is intended to add injury risk curves for the WorldSID 5th percentile adult female dummy to a future edition of the ISO/TR 12350. There are no plans to add injury risk curves for the ES-2 or ES-2re, and it is not appropriate to use the WorldSID injury risk curves with measures from either ES-2 or ES-2re.

The dummy test results reproducing the PMHS test configurations selected for the injury risk curve construction are presented in Annex H. The build level of the production version used was not provided with the results. It is to be noted that there was no head result available. Moreover, the shoulder deflection was only available for the impactor test and not for the sled test configurations.

The test results presented in Annex H are filtered data (according to Reference[50] and according to filters indicated in Annex H) that have not been scaled and should not be used directly to construct dummy-specific injury risk curves.

The PMHS used in the biomechanical tests described in Annex A to Annex F were generally not mid-size adult males. Ideally, the test condition for the dummy tests should be scaled such that the test poses an equally severe impact as the individual PMHS test. However, many of the dummy tests used in this Technical Report were conducted at the same velocity and the same impactor mass as the PMHS tests. It is therefore necessary to scale the results of the dummy tests before they are paired with the PMHS injuries. The dummy data from impactor tests, drop tests, and sled tests were scaled using the formulae included in Annex I. The scaled dummy data are included in Annex A to Annex F.

2.3 Age adjustment

The injury risk curves are provided with age adjustment. It is out of the scope of this Technical Report to recommend an age to be used. The injury risk curves can be built for any age using the formula provided

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in Table 5. However, the quality index cannot be computed from these formulae. As it was not possible to include the quality index for all ages, only two ages were considered. As indicated in Petitjean et al. (2009), the injury risk curves were constructed for a dummy representing a 45-year-old male, as this age has been used previously to represent the average age of an adult male in the field data. The injury risk curves were also constructed for median age of the PMHS included in the samples available for the construction of the WorldSID 50th injury risk curves (67 years old). This latest age was used because it provides the values with the higher confidence because the PMHS data are mostly around that age.

2.4 Statistical analysis

Guidelines for the construction of the injury risk curves were agreed on within ISO/TC 22/SC 12 (Resolution 2, N851).

The guidelines include several steps.

2.4.1 Step 1: Collect the relevant data

The first step is to collect the relevant data, including injuries and injury criterion.

According to the methodology developed in this Technical Report, relevant data corresponded to the paired PMHS injuries and scaled dummy measurements from tests performed in similar configurations.

2.4.2 Step 2: Assign the censoring status (left, right, interval censored, exact)

Once the biomechanical data were available, the censoring status was assigned (left, right, interval censored, exact). After this step, the dataset included one column with the injury criteria values associated with the censoring status indicated in a second column.

2.4.3 Step 3: Build the injury risk curve with the Consistent Threshold Estimate (CTE)[37] and check for dual injury mechanism

The step function was visually investigated in order to detect potential change in slope corresponding to different injury mechanisms.

2.4.4 Step 4:

— If there was an evidence of dual injury mechanism, the sample was separated into samples with single injury mechanism and Step 1 was performed.

— If there was no evidence of dual injury mechanism, the injury risk curve was built with the survival analysis according to the following steps.

2.4.5 Step 5: Estimate the parameters of the Weibull, log-normal, and log-logistic distributions with the survival analysis method

2.4.6 Step 6: Identify overly influential observations using the dfbetas statistics

The overly influential observations were identified using the dfbetas statistics.

2.4.7 Step 7: Check the distribution assumption graphically using a qq-plot or the CTE method

2.4.8 Step 8: Choose the distribution with the best fit, based on the Akaike information criterion (AIC)

The distribution with the lowest AIC among the three distributions was selected.

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2.4.9 Step 9: Check the validity of the predictions against existing results (such as accidentology outcome), if available

2.4.10 Step 10:

— Step 10.1: The 95 % confidence intervals of the injury risk curve were calculated with the normal approximation of the error.

— Step 10.2: The relative sample size of the confidence interval was defined as the width of the 95 % confidence interval at a given risk relative to the value of the stimulus at this same risk. They were calculated at 5 %, 25 %, and 50 % risk.

2.4.11 Step 11: Provide the injury risk curve associated with the quality index based on the relative sample size of the 95 % confidence interval

A scale of quality indexes based on the relative sample size was defined with four categories ("good" from 0 to 0,5, "fair" from 0,5 to 1, "marginal" from 1 to 1,5, "unacceptable" over 1,5). The injury risk curves associated with the quality indexes were provided. The scale was determined using biomechanical samples in order to distribute injury risk curves in the four categories. Illustrations for one example of each class of quality index are provided in Table 2.

Table 2 — Illustrations of the width of the 95 % confidence interval for an injury risk curve for each of the quality indexes

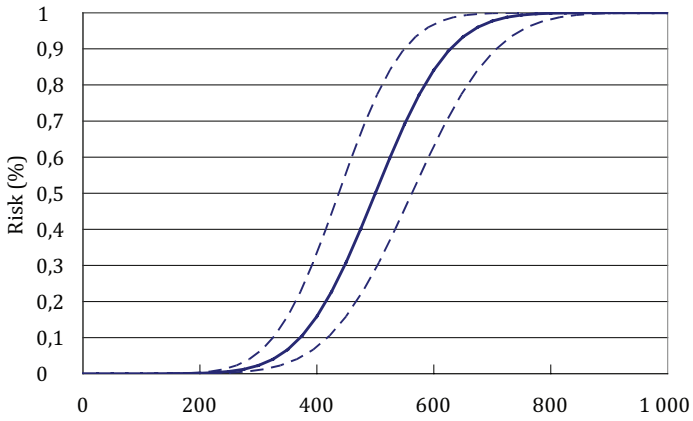
Quality index	Width of the confidence interval at that particular risk divided by the criterion value at that risk	Example (solid line: injury risk curve, dotted line: 95 % confidence intervals)
Good	0-0,5	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 0,25

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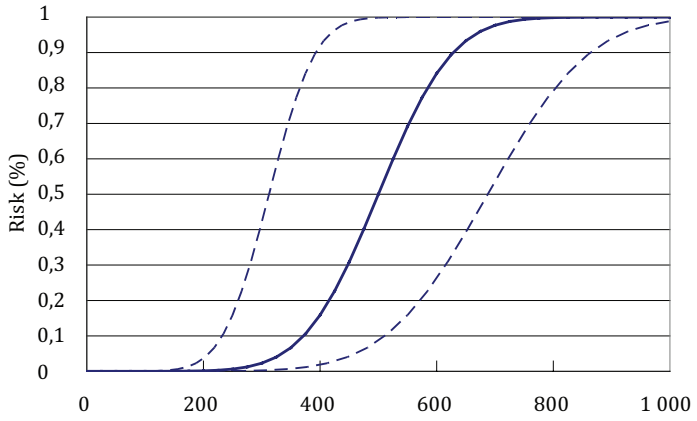
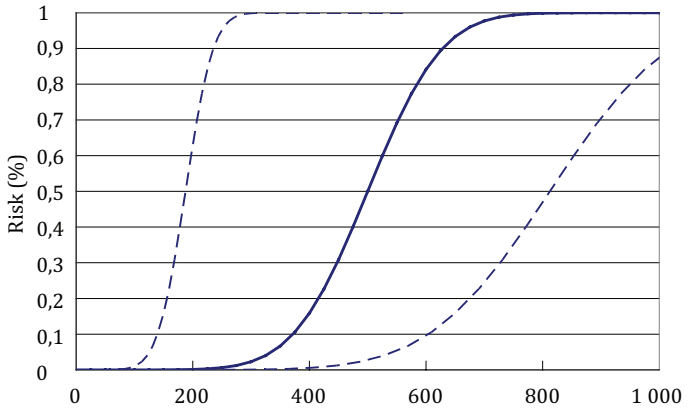
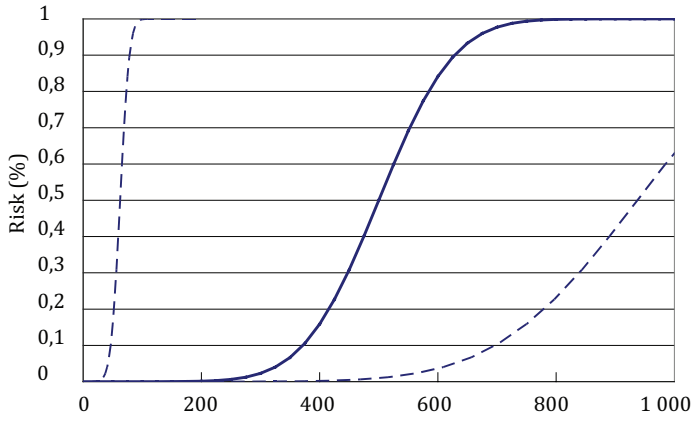
Table 2 *(continued)*

Quality index	Width of the confidence interval at that particular risk divided by the criterion value at that risk	Example (solid line: injury risk curve, dotted line: 95 % confidence intervals)
Fair	0,5-1	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 0,75
Marginal	1-1,5	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 1,25
Unacceptable	>1,5	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 1,75

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2.4.12 Step 12: Recommend one curve per body region, injury type, and injury level

— Step 12.1: If several injury risk curves could be compared with the AIC and if the difference of the AIC was greater than 2, then the curve with the lowest AIC was recommended over the others.

— Step 12.2: If an injury risk curve had an "unacceptable" quality index, it should not be recommended.

— Step 12.3: If several injury risk curves were still available for a given injury type and level, engineering judgment was used to recommend one curve over another.

The recommended injury thresholds should be provided with their associated quality indexes.

3 Injury risk curves for the WorldSID 50th

The injury risk curves were constructed by correlating the dummy responses to the PMHS injuries in the same test configurations.

The injury risk curves were built with the following steps:

Step 1: Paired PMHS injuries and dummy measurements were collected, after having selected the PMHS sample and checking the dummy data.

Step 2: The censoring status was assigned to each pair depending on if it was left, right, interval censored, or exact. The WorldSID 50th injury risk curves were computed with the R software[42]. With the R software, the right, exact, left, and interval censored data are coded 0, 1, 2, and 3 respectively.

Step 3: The injury risk curve should be built with the Consistent Threshold Estimate (CTE)[37] in order to check for dual injury mechanism.

Step 4:

— If there was an evidence of dual injury mechanism, the sample was separated into samples with single injury mechanism and Step 1 was performed.

— If there was no evidence of dual injury mechanism, the injury risk curve was built with the survival analysis according to the following steps.

However, the injury risk curves here included the age as a covariable so it would be necessary to separate the sample into different classes of age before building the CTE injury risk curves. The resulting sub-sample was too small to build reliable injury risk curves so dual injury mechanisms were not checked for the WorldSID 50th.

Step 5: The parameters of the Weibull, log-normal, and log-logistic distributions with the survival analysis method were estimated (see Table J.1).

Step 6: The overly influential observations were identified with the dfbetas test (see Table J.2 to Table J.7). These observations were checked for any specificity. As there was no evidence of difference between these observations and the others included in the sample, these observations were kept in the construction of the injury risk curve.

Step 7: The distribution assumption should be checked graphically using a qq-plot or the CTE method. However, the injury risk curves here included the age as a covariable so it would be necessary to separate the sample into age classes before building the CTE injury risk curves. The resulting sub-sample was too small to build reliable injury risk curves so distribution assumption was not checked in this Technical Report.

Step 8: The distribution with the best fit, based on the Akaike information criterion (AIC), was chosen (see Table J.1 and Table 3).

Step 9: Check the validity of the predictions against existing results (such as accidentology), if available. In the case of the WorldSID 50th, there was no prediction to be validated.

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Step 10: The 95 % confidence intervals were calculated, as well as the relative sample size of the confidence interval (width of the confidence intervals at 5 %, 25 %, and 50 % relative to the value of the stimulus at 5 %, 25 %, and 50 % of risk, respectively) (see Table J.8).

Step 11: The injury risk curves were provided with their associated quality indexes based on the relative sample size of the confidence interval (see Table 4).

Step 12: Recommend one curve per body region, injury type, and injury level.

— Step 12.1: If several injury risk curves could be compared with the AIC and if the difference of the AIC was greater than 2, then the curve with the lowest AIC was recommended over the others.

The samples that could be compared were those with the same PMHS sample and the same level and type of injury. The AIC were then compared between:

— the skeletal risk AIS3+ as a function of the maximum thoracic rib deflection and viscous criterion;

— the skeletal risk AIS4+ as a function of the maximum thoracic rib deflection and viscous criterion;

— the abdomen risk AIS2+ as a function of the maximum abdomen rib deflection and viscous criterion, as well as of the lower spine Y acceleration 3 ms;

— the abdomen risk AIS3+ as a function of the maximum abdomen rib deflection and viscous criterion.

There was no comparison possible for the shoulder and pelvis injury risk curves.

Table 3 — AIC values for the WorldSID 50th injury risk curves

Injury risk	WorldSID measurement	AIC
Skeletal thoracic AIS3+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) (mm)	24,883 7
	Maximum thoracic rib VC (measured by 1D IR-TRACC) (m/s)	29,691 1
Skeletal thoracic AIS4+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) (mm)	29,735 4
	Maximum thoracic rib VC (measured by 1D IR-TRACC) (m/s)	30,650 7
Abdomen AIS2+	Maximum abdomen rib deflection (measured by 1D IR TRACC) (mm)	14,988 9
	Maximum abdomen rib VC (measured by 1D IR-TRACC)(m/s)	14,977 7
	Lower spine Y acceleration 3 ms (m/s^2)	27,576 8
Abdomen AIS3+	Maximum abdomen rib deflection (measured by 1D IR-TRACC) (mm)	11,959 1
	Maximum abdomen rib VC (measured by 1D IR-TRACC) (m/s)	11,869 6

Based on the comparison of the AIC values (see Table 3), the skeletal thoracic risks AIS3+ and AIS4+ were recommended to be predicted as a function of the maximum thoracic rib deflection rather than as a function of the maximum thoracic rib vital capacity (VC). The abdomen risks AIS2+ and AIS3+ were recommended to be predicted as a function of the maximum abdomen rib deflection or VC rather than as a function of the lower spine Y acceleration 3 ms.

— Step 12.2: If an injury risk curve had an "unacceptable" quality index, it should not be recommended.

There was no "unacceptable" quality index for the shoulder, abdomen, and pelvis injury risk curves AIS2+ (see Table J.8). For the skeletal thoracic risk as a function of the maximum thoracic deflection, the 50 % AIS4+ risk for a 45-year-old occupant was "unacceptable". All the thoracic soft tissue injury risk curves were "unacceptable" at 5 % risk. All the abdomen injury risk curves AIS3+ were "unacceptable". This was probably due to the very limited number (only one) of AIS3+ cases. Among the pelvis injury risk curves AIS3+, the curve as a function of the pelvis Y acceleration 3 ms for a 45-year-old occupant was "unacceptable".

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— Step 12.3: If several injury risk curves were still available for a given injury type and level, engineering judgment was used to recommend one curve over another.

The shoulder injury risk AIS2+ could still be predicted by the maximum shoulder rib deflection or by the maximum shoulder **Y** force. The available sample for the construction of the injury risk curve as a function of the maximum shoulder deflection was composed of impactor tests only. On the other side, the available sample for the construction of the injury risk curve as a function of the maximum shoulder **Y** force was composed of impactor tests, as well as sled tests. The injury risk curve as a function of the maximum shoulder **Y** force was recommended because the sample was composed of impactor tests, as well as sled tests.

The abdomen soft tissue injury risk AIS2+ could be predicted by the maximum abdomen rib deflection or by the maximum abdomen rib VC. The injury risk curve as a function of the maximum abdomen rib deflection was recommended as the quality indexes associated with this curve were better.

The pelvis injury risk AIS2+ could be predicted by the maximum pubic force or by the pelvis Y acceleration 3 ms. Most of the injuries observed in the PMHS tests used to build the injury risk curves were related to ilio-ischio rami and pubic symphysis. It was then recommended to predict the risk as a function of the pubic force, as this dummy measurement was the more closely related to these injuries.

The recommended injury thresholds should be provided with their associated quality indexes.

It is out of the scope of this Technical Report to recommend a probability of risk as a limit to be respected. However, the dummy measurement values corresponding to all the probabilities cannot be provided in a table. As a consequence, the dummy measurement values are given for a few levels of risk. The values at 5 % risk are provided because the risk is close to the Injury Assessment Reference Values (IARV). It was also decided to provide the injury thresholds for the 25 % and 50 % risk because values used in regulations can reach those levels (as for example, the limit for the thorax compression criterion in the regulation ECE/R94). These injury thresholds associated with their quality indexes are provided in Table 4 for the WorldSID 50th. Other injury thresholds could be calculated using the estimated parameters of the survival analysis of the recommended injury risk curves given in Table 5.

Table 4 — WorldSID 50th recommended injury thresholds with its quality index

	5 % risk (quality index)	**25 % risk (quality index)**	**50 % risk (quality index)**
shoulder AIS ≥ 2	Maximum shoulder force **Y** adjusted to 67 year old (N)		
	1 594 (good)	2 011 (good)	2 265 (good)
	Maximum shoulder force Y adjusted to 45 year old (N)		
	1 799 (fair)	2 270 (fair)	2 556 (fair)
Skeletal thoracic AIS ≥ 3	Maximum thoracic rib deflection adjusted to 67 year old (measured by 1D IR-TRACC) (mm)		
	28,0 (fair)	35,1 (good)	40,2 (good)
	Maximum thoracic rib deflection adjusted to 45 year old (measured by 1D IR-TRACC) (mm)		
	38,5 (fair)	48,4 (good)	55,4 (good)
Abdomen AIS ≥ 2	Maximum abdomen rib deflection adjusted to 67 year old (measured by 1D IR-TRACC) (mm)		
	37,1 (fair)	45,3 (good)	50,2 (good)
	Maximum abdomen rib deflection adjusted to 45 year old (measured by 1D IR-TRACC) (mm)		
	58,9 (fair)	72,0 (fair)	79,8 (fair)

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Table 4 *(continued)*

	5 % risk (quality index)	25 % risk (quality index)	50 % risk (quality index)
Pelvis AIS ≥ 2	Maximum pubic force adjusted to 67 year old (N)		
	1 340 (fair)	1 950 (good)	2 361 (good)
	Maximum pubic force adjusted to 45 year old (N)		
	1 818 (fair)	2 645 (marginal)	3 202 (marginal)
Pelvis AIS ≥ 3	Maximum pubic force adjusted to 67 year old (N)		
	1 714 (good)	2 262 (good)	2 605 (good)
	Maximum pubic force adjusted to 45 year old (N)		
	2 214 (marginal)	2 922 (marginal)	3 365 (marginal)

The formulae of the injury risk curves are presented in Table 5.

The risk according to the Weibull distribution is

$$Risk(\%) = 1 - \exp\left[-\left(\frac{Dummy_measurement}{\exp(\text{int} + PMHS_age \times coef_age}\right)^{\frac{1}{\exp(\log_scale)}}\right] \quad (1)$$

The risk according to the log-normal distribution is

$$Risk(\%) = \log_normal_distribution\left[mean = \text{int} + age \times coef_age, std = \exp(\log_scale)\right] \quad (2)$$

The risk according to the log-logistic distribution is

$$Risk(\%) = \frac{1}{1 + \exp\left\{-\left[\ln(Dummy_measurement) - (\text{int} + age \times coef_age)\right] / \exp(\log_scale)\right\}} \quad (3)$$

where

Dummy_measurement corresponds to the dummy measurement;

PMHS_age corresponds to the PMHS age.

Table 5 — Formulae of the recommended WorldSID 50th injury risk curves built with the survival analysis

Injury risk	Dummy measurement	Distribution	int	Coef_age	Log_scale
Shoulder AIS2+	Maximum shoulder rib **Y** force (N)	Weibull	8,143 5	−0,005 5	−2,002 8
Skeletal thoracic AIS3+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) mm)	Log-logistic	4,669 9	−0,014 6	−2,094 5
Abdomen soft tissue AIS2+	Maximum abdomen rib deflection (measured by 1D IR-TRACC) (mm)	Weibull	5,367 8	−0,021 0	−2,153 1
Pelvis AIS2+	Maximum pubic force (N)	Weibull	8,774 8	−0,013 9	−1,525 9
Pelvis AIS3+	Maximum pubic force (N)	Weibull	8,704 1	−0,011 6	−1,827 4

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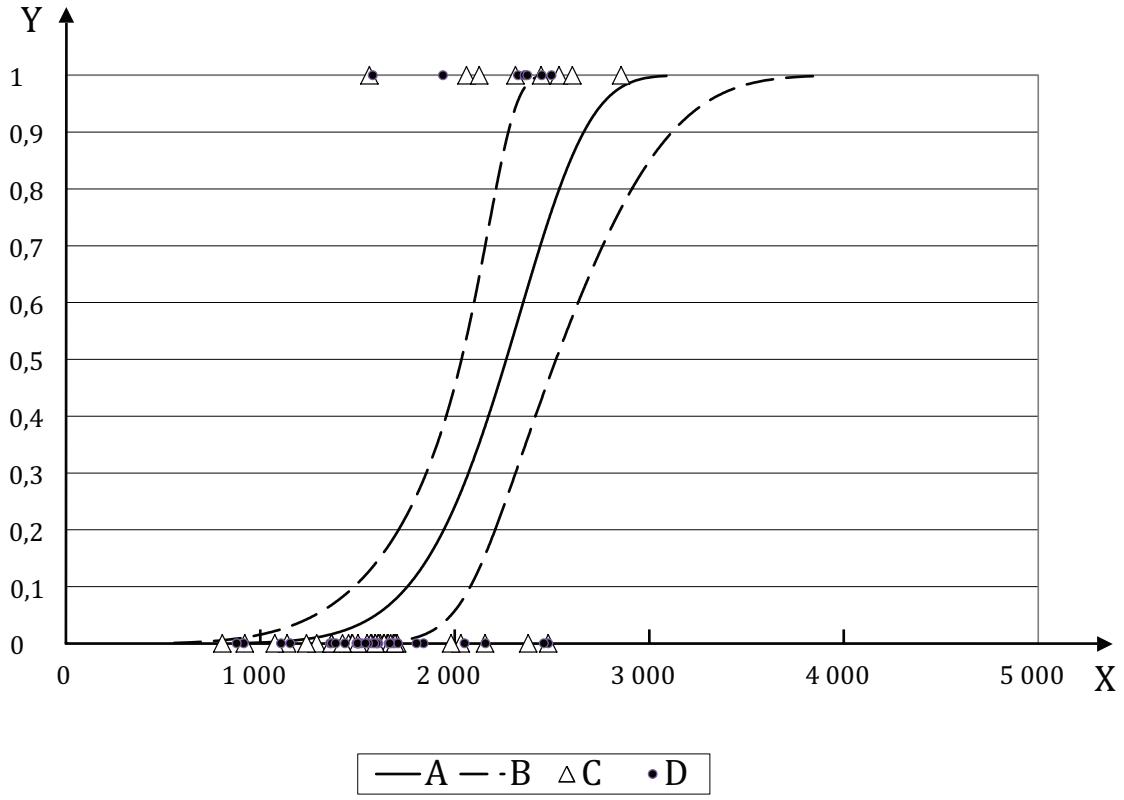
Injury risk curves for the WorldSID 50th percentile are given in Figures 1 to 10.

Figures 1 and 2 present the shoulder injury risk curves AIS ≥ 2 as a function of the maximum shoulder **Y** force for the WorldSID 50th, with adjustment to 67 year old and 45 year old.



Key

X maximum shoulder **Y** force (N)

Y shoulder injury risk AIS2+

A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 1 — Shoulder injury risk curve AIS ≥ 2 as a function of the maximum shoulder Y force adjusted to 67 year old for the WorldSID 50th

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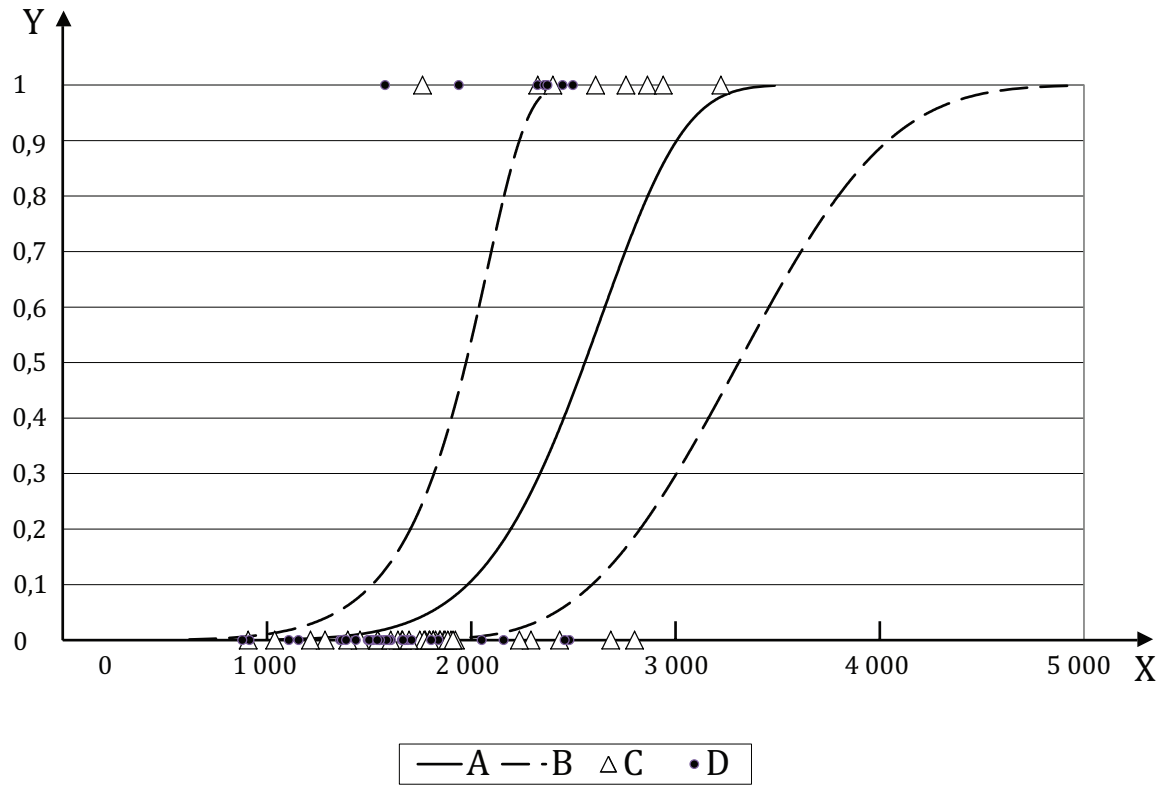

Key

X maximum shoulder **Y** force (N)

Y shoulder injury risk AIS2+

A 45 year old

B 95% confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 2 — Shoulder injury risk curve AIS ≥ 2 as a function of the maximum shoulder Y force adjusted to 45 year old for the WorldSID 50th

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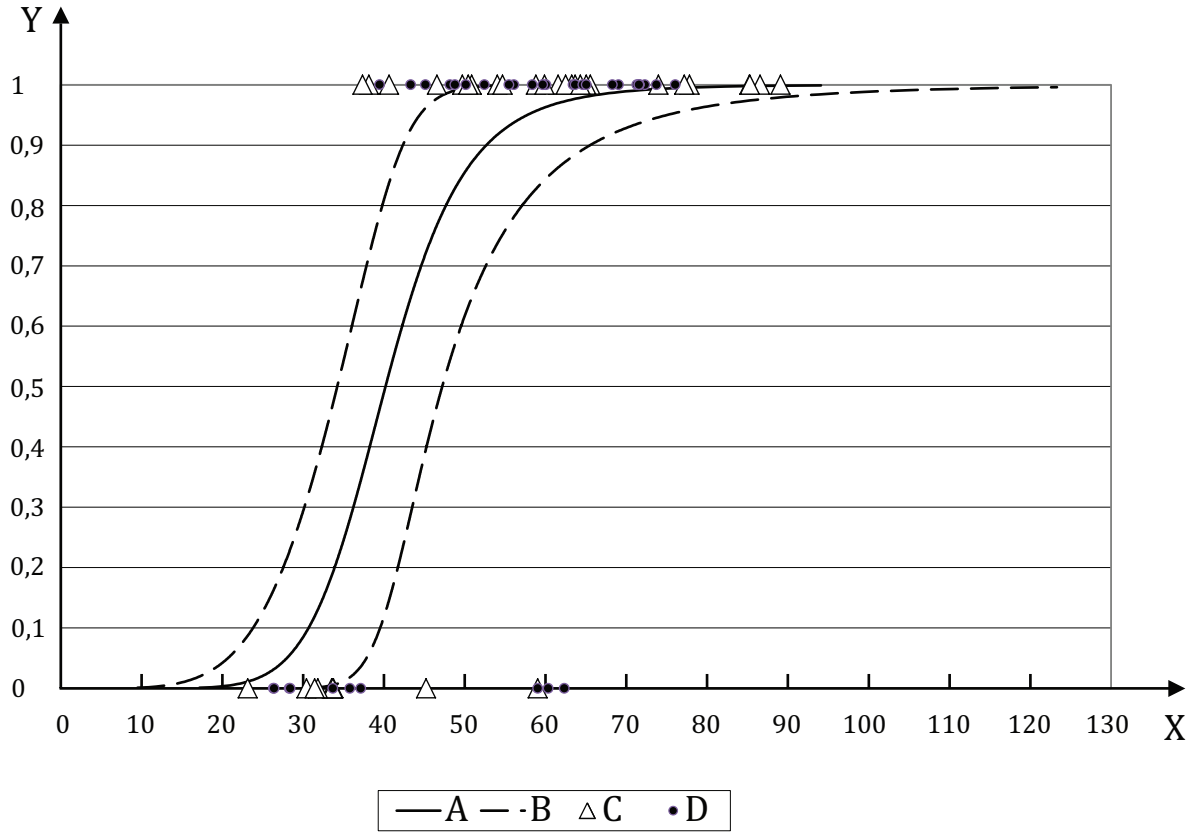
Figures 3 and 4 present the thoracic skeletal injury risk curves AIS ≥ 3 as a function of the maximum thoracic rib deflection for the WorldSID 50th, with adjustment to 67 year old and 45 year old.



Key

X maximum thoracic rib deflection (mm)

Y skeletal thoracic injury risk AIS3+

A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 3 — Thoracic skeletal injury risk curve AIS ≥ 3 as a function of the maximum thoracic rib deflection adjusted to 67 year old for the WorldSID 50th

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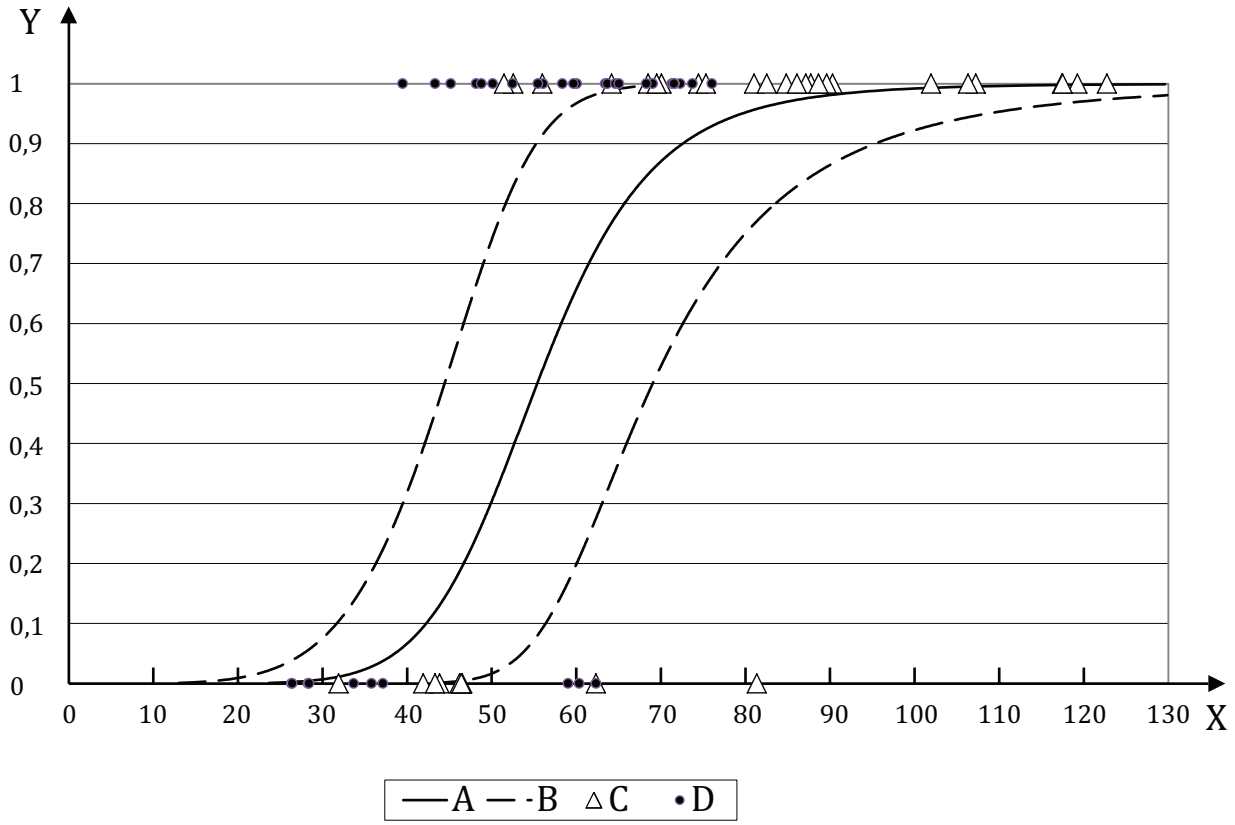

Key

X maximum thoracic rib deflection (mm)

Y skeletal thoracic injury risk AIS3+

A 45 year old

B 95 % confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 4 — Thoracic skeletal injury risk curve AIS ≥ 3 as a function of the maximum thoracic rib deflection adjusted to 45 year old for the WorldSID 50th

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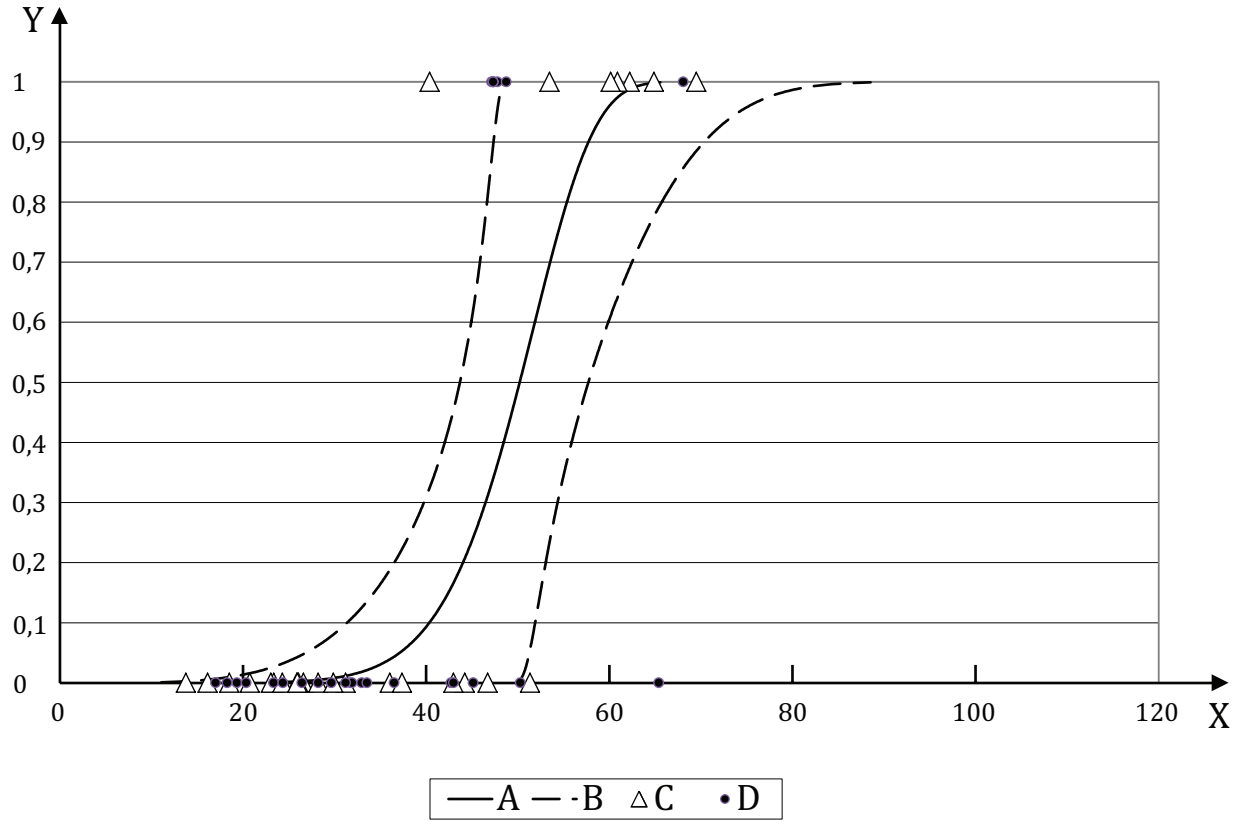
Figures 5 and 6 present the abdomen soft tissue injury risk curves AIS ≥ 2 as a function of the maximum abdomen rib deflection with adjustment to 67 year old and 45 year old.



Key

X maximum abdomen rib deflection (mm)

Y abdomen soft tissue injury risk AIS2+

A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 5 — Abdomen soft tissue injury risk curve AIS ≥ 2 as a function of the maximum abdomen rib deflection adjusted to 67 year old for the WorldSID 50th

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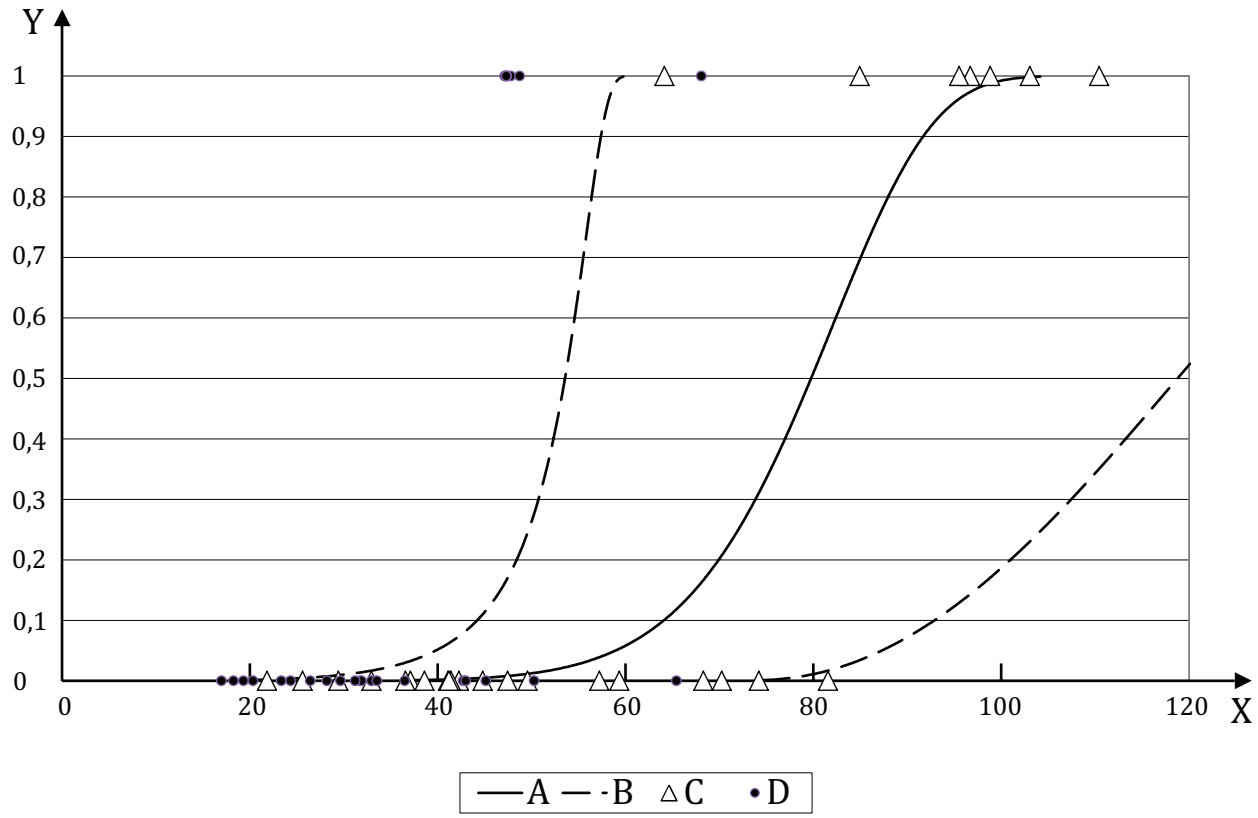

Key

X maximum abdomen rib deflection (mm)

Y abdomen soft tissue injury risk AIS2+

A 45 year old

B 95 % confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 6 — Abdomen soft tissue injury risk curve AIS ≥ 2 as a function of the maximum abdomen rib deflection adjusted to 45 year old for the WorldSID 50th

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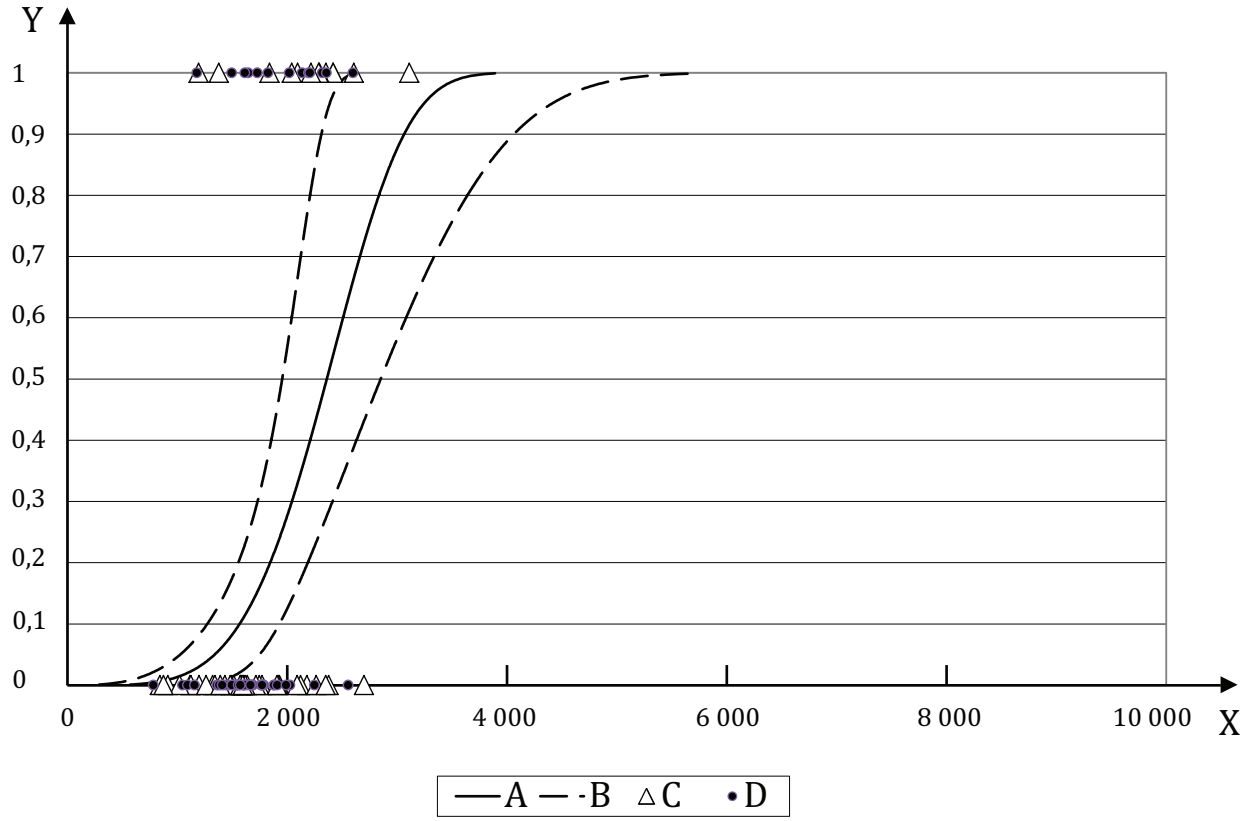
Figures 7 and 10 present the pelvis injury risk curves AIS ≥ 2 and AIS ≥ 3 as a function of the maximum pubic force for the WorldSID 50th, with adjustment to 67 year old and 45 year old.



Key

X maximum pubic force (N)

Y pelvis injury risk AIS2+

A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 7 — Pelvis injury risk curve AIS ≥ 2 as a function of the maximum pubic force adjusted to 67 year old WorldSID 50th

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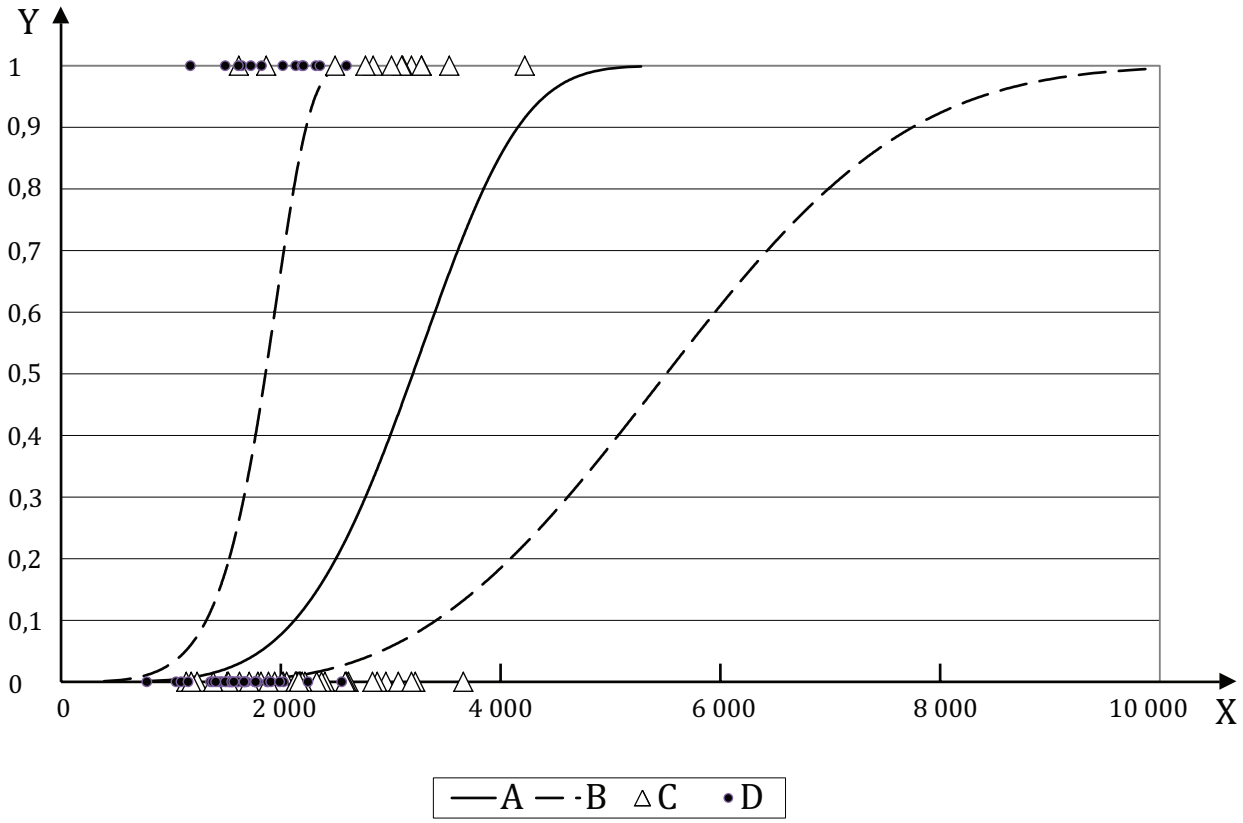

Key

X maximum pubic force (N)

Y pelvis injury risk AIS2+

A 45 year old

B 95 % confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 8 — Pelvis injury risk curve AIS ≥ 2 as a function of the maximum pubic force adjusted to 45 year old for the WorldSID 50th

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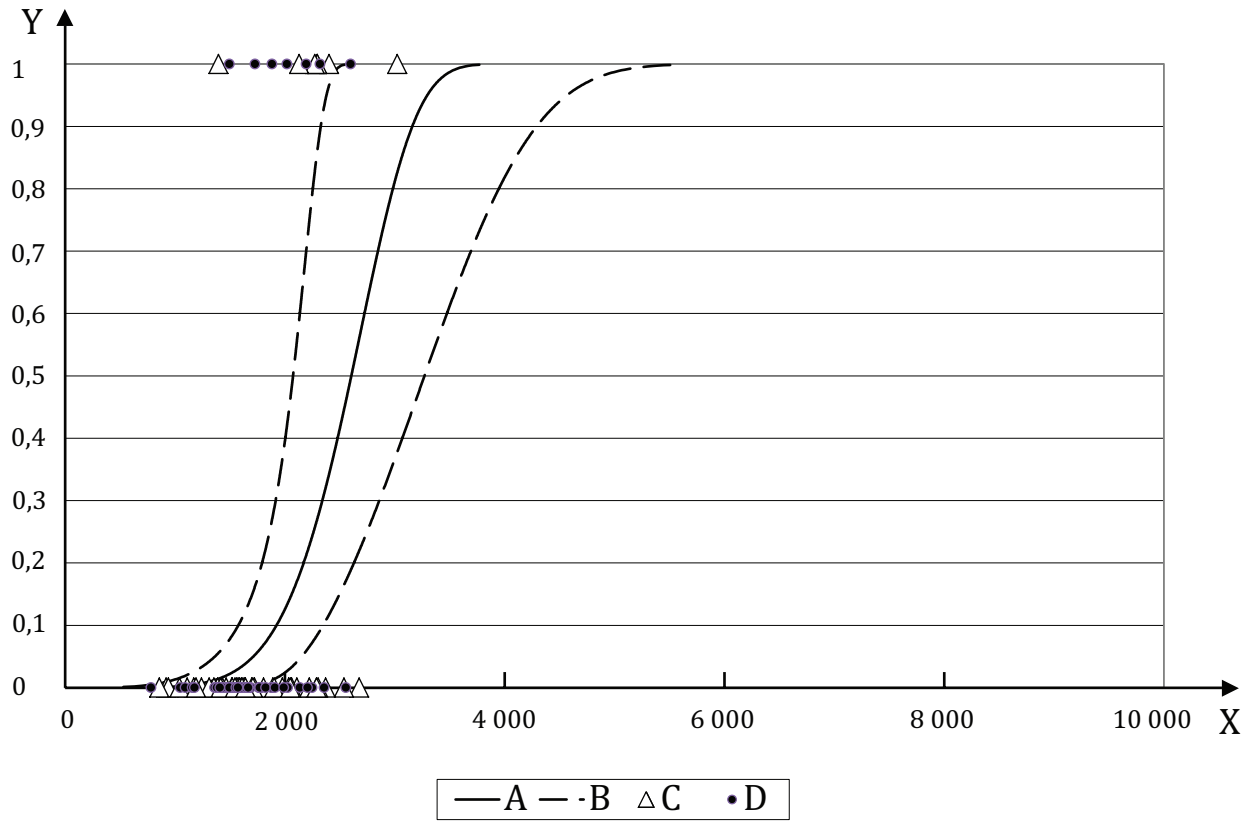

Key

X maximum pubic force (N)

Y pelvis injury risk AIS3+

A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 9 — Pelvis injury risk curve AIS ≥ 3 as a function of the maximum pubic force adjusted to 67 year old for the WorldSID 50th

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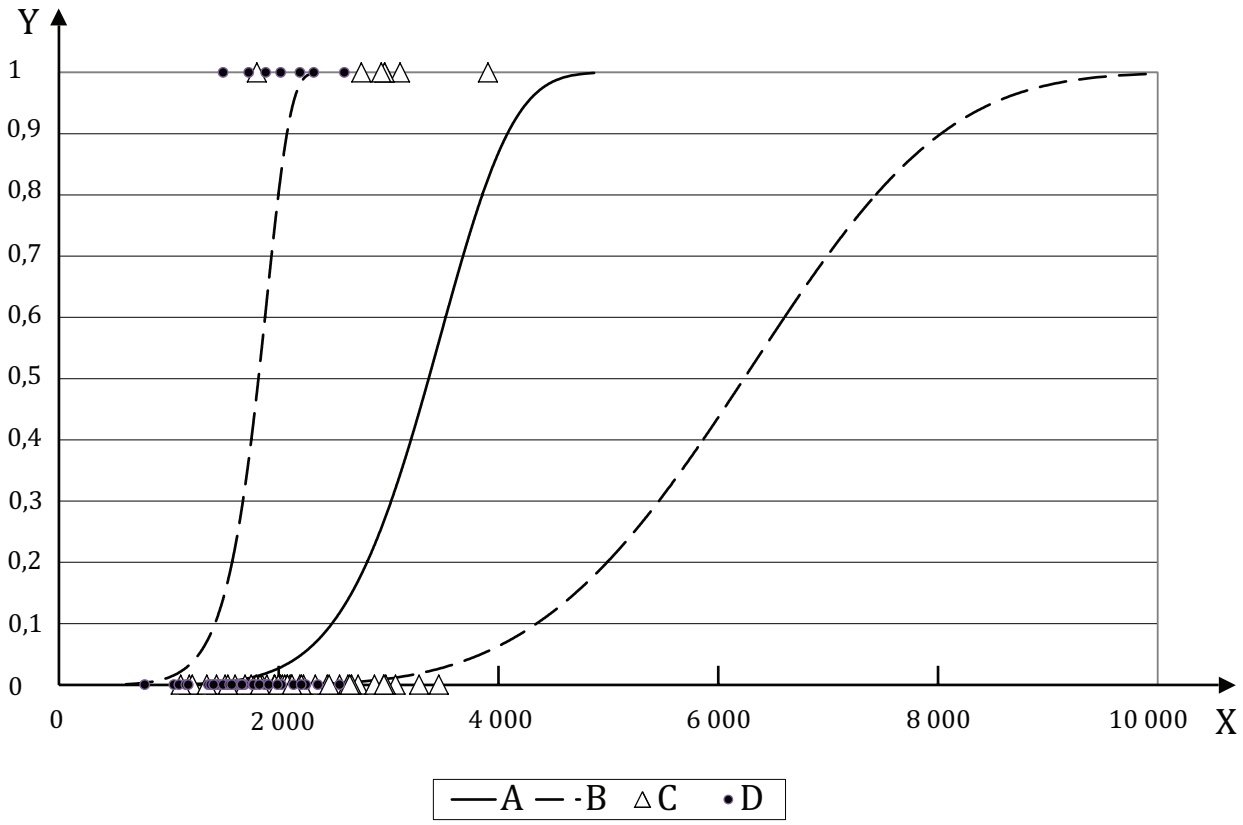

Key

X maximum pubic force (N)

Y pelvis injury risk AIS3+

A 45 year old

B 95 % confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 10 — Pelvis injury risk curve AIS ≥ 3 as a function of the maximum pubic force adjusted to 45 year old for the WorldSID 50th

4 Related electronic documents

The files providing the characteristics of the PMHS sample to be used for the construction of the injury risk curves, as well as the dummy responses, are gathered in related electronic documents posted on the ISO website at the following link: http://standards.iso.org/iso/tr/12350

— RED1: Head impactor and drop tests

— RED2: Shoulder impactor tests

— RED3: Thorax impactor tests

— RED4: Abdomen impactor tests

— RED5: Pelvis impactor tests

— RED6: Sled tests

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Annex A
(informative)

PMHS head test data

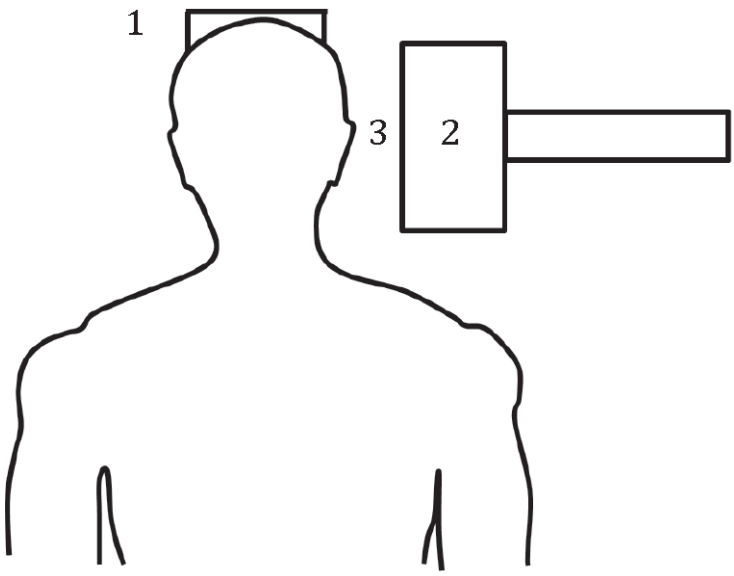
Annex A includes the description of the PMHS head impactor and drop tests used in the construction of the injury risk curves.

A.1 Head impactor tests

The Highway Safety Research Institute (HSRI) conducted a series of impactor tests to the heads of five PMHS[51]. The results of the HSRI impactor tests were excluded because the impact speeds are unknown. Therefore, the tests cannot be repeated with dummies.

The University of Michigan Transportation Research Institute (UMTRI) performed lateral impactor tests. The results of the UMTRI impactor tests were excluded because the impactor characteristics were not documented in the literature. Therefore, the tests cannot be repeated with dummies.

Calspan conducted a series of impactor tests to the heads of PMHS, as illustrated in Figure A.1 [18]. Each PMHS was seated in an upright posture, but the presence or absence of a back support was not documented. The position of the head was maintained by a chin strap that would break away upon impact. The impactor masses were 23,4 kg, 24,4 kg, and 25,3 kg. The impactor face was either rectangular (203 mm × 254 mm or 171,5 mm × 203 mm) or circular (152 mm diameter). The impactor face was either rigid or padded with a 213 foam (polyurethane) padding. The impactor face was centred on the level of the external auditory meatus.



Key

1 acceleration unit

2 impactor face

3 centreline of impactor at level of Frankfort plans and external auditory meatus

Figure A.1 — Impactor test configuration from the lateral head impacts conducted by Calspan (front view)[18]

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Table A.1 summarizes the Calspan PMHS tests that are included in constructing the injury risk curves for the head in lateral impact. The details of all the head impactor test configurations are provided in Table A.1 and in the related electronic document RED1. The padding used in dummy tests should be identical to the padding used in the original PMHS tests.

Table A.1 — PMHS impactor tests included in constructing injury risk curves for the head

Test performer	Impact angle	Test number	PMHS number	PMHS age	PMHS mass kg	Impactor surface	Impactor mass kg	Impactor face geometry	Impact speed m/s	AIS2005 skull
CALSPAN	Pure lateral	SR2-CM25	CALMAN 25	55	83,66	R	25,3	SQ80	4,0	0
CALSPAN		SR2-CM29	CALMAN 29	71	67,195	R	25,3	SQ80	4,0	2
CALSPAN		SR2-CM30	CALMAN 30	66	82,325	R	25,3	SQ80	4,0	0
CALSPAN		SR2-CM31	CALMAN 31	57	71,645	R	25,3	SQ80	4,0	0
CALSPAN		SR2-CM32	CALMAN 32	60	56,07	R	24,4	SQ54	2,2	0
CALSPAN		SR2-CM33	CALMAN 33	70	58,295	R	24,4	SQ54	3,9	0
CALSPAN		SR2-CM34	CALMAN 34	55	62,745	R	23,4	SQ28	4,0	0
CALSPAN		SR2-CM35	CALMAN 35	69	66,75	R	23,4	SQ28	4,0	2
CALSPAN		SR2-CM36	CALMAN 36			PU	24,4	SQ54	3,9	0
CALSPAN		SR2-CM37	CALMAN 37			PU	24,4	SQ54	3,9	0
CALSPAN		SR2-CM42	CALMAN 42	60	84,55	R	25,3	SQ80	3,2	0

PU Padded 2,54-cm-thick 213 foam (polyurethane)
R rigid
SQ80 515,6 cm^2 square flat plate (20,3 cm × 25,4 cm)
SQ54 347,1 cm^2 square flat plate (17,1 cm× 20,3 cm)
SQ28 180,6 cm^2 wooden face (15,2 cm circle)

No WorldSID test results were available for these test conditions at the time when this Technical Report was published. This annex is kept for future use.

A.2 Head drop tests

The Association Peugeot-Renault (APR) conducted two series of whole body drop tests that involved impact to the temporoparietal region of the PMHS head[20] [21] [13]. The first series, illustrated in Figure A.2, strapped the torso into a cradle, with the head and upper torso protruding past the edge of the cradle. A device was used to maintain head alignment until impact. The second series suspended the body from several points, without the cradle. The subject was released from a height of 0,3 m to 3,0 m. The head impact surface was at an angle of 1° to 44° relative to horizontal and either rigid or padded. Both tests on a rigid impact surface were with bare heads. The height of the mattress was chosen to avoid neck kinematics that would cause cervical injuries.

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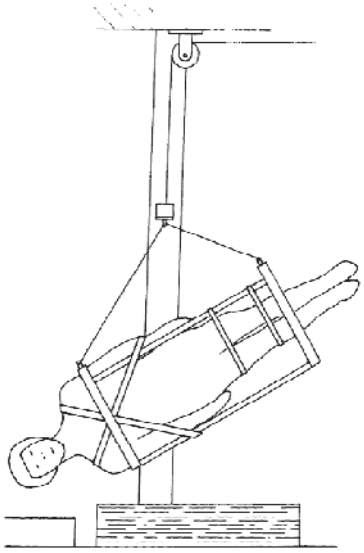

Figure A.2 — APR head lateral drop test configuration (front view)

Wayne State University (WSU) conducted whole body drop tests with head impact[22]. In this series, the torso was strapped to a pallet that was free to pivot about one end. The PMHS head and neck were extended beyond the edge of the free end of the pallet. The pallet was rotated until the subject's head was positioned 0,46 m above the head impact surface. The impact surface was a rigid cylinder with a 1 inch radius. The pallet was released to produce the desired head impact.

The Medical College of Wisconsin (MCW) conducted lateral drop tests with heads, separated at the level of the occipital condyles[56]. Each head was dropped multiple times, from increasing heights (0,3 m to 3 m), until skull fracture was detected by a decrease in force associated with an increase in velocity. The head was oriented such that the temporoparietal region impacted either a flat or cylindrical impact surface, padded with 50 mm of rubber (either 40 durometer or 90 durometer), as illustrated in Figure A.3. Some tests were conducted with the brain intact and other tests were conducted with Sylgard gel in place of the brain.

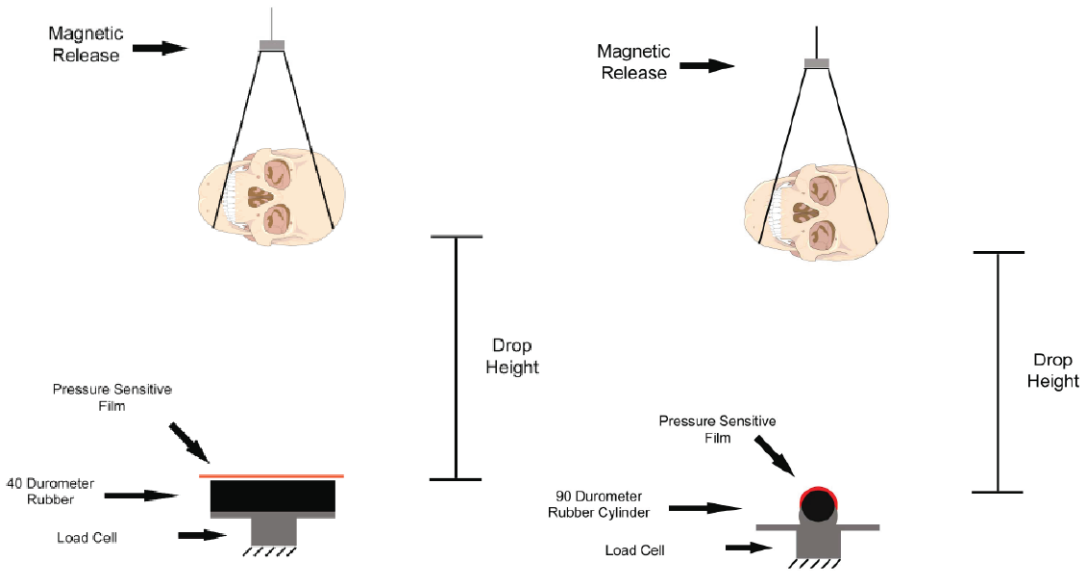

Figure A.3 — Impactor test configuration from the lateral head impacts conducted by MCW (front view)[56]

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Table A.2 summarizes the APR, WSU, and MCW PMHS tests that could be included in constructing injury risk curves for the head drop tests. The details of all the head drop test configurations are provided in Table A.2 and the related electronic document RED1.

Table A.2 — PMHS drop tests included in constructing injury risk curves for the head

Test series	Impact surface shape	Impact surface	Head impact angle	Drop height m	PMHS test number
APR	Flat	Rigid	27°	2,5	MS76
			35°	1,8	MS68
	Flat	Padded	From 1° to 44°	0,3 to 3	MS63, MS64, MS65, MS69, MS70, MS83, MS85, MS86, MS99, MS100, MS66, MS67, MS73, MS74, MS87, MS111
WSU	Flat	Rigid	Pure lateral	0,46	DOT-36-1, DOT-37-1, DOT-38-1
MCW	Flat	Padded 40 durometer rubber	Pure lateral	From 0,3 to 3	CHD1801, CHD1802, CHD1803, CHD1804, CHD1501, CHD1502, CHD1503, CHD1504, CHD1505, CHD1506, CHD1701, CHD1702, CHD1703, CHD1704, CHD1705, CHD1706, CHD901, CHD902, CHD903, CHD1101, CHD1102, CHD1103, CHD1104, CHD1301, CHD1302, CHD1303, CHD1304, CHD1305, CHD1306, CHD1307, CHD1001, CHD1002, CHD1003, CHD1004, CHD1005, CHD1006, CHD1007, CHD1008, CHD1601, CHD1602, CHD1603, CHD1604, CHD1605, CHD1606, CHD1607, CHD1401, CHD1402, CHD1403, CHD1404, CHD1405, CHD1901, CHD1902, CHD1903, CHD1904, CHD1905
			From 11° to 14°		CHD2101, CHD2102, CHD2103, CHD2104, CHD2105, CHD2106, CHD2107, CHD2108, CHD2001, CHD2002, CHD2003, CHD2004, CHD2005, CHD2006, CHD2007
		Padded 90 durometer rubber	Pure lateral		CHD601, CHD602, CHD501, CHD502, CHD503, CHD504, CHD505, CHD506, CHD507
			From 11° to 14°		CHD2501, CHD2502, CHD2503, CHD2401, CHD2402, CHD2403, CHD2404, CHD2405, CHD2406, CHD2301, CHD2302, CHD2303, CHD2304, CHD2305, CHD2201, CHD2202, CHD2203, CHD2204
	Cylinder	Padded 90 durometer rubber	From 11° to 14°		CHD2901, CHD2902, CHD2903, CHD2904, CHD2801, CHD2802, CHD2803, CHD2804, CHD2805, CHD2806, CHD2701, CHD2702, CHD2703, CHD2704, CHD2705, CHD2706, CHD2601, CHD2602, CHD2603, CHD2604

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Table A.3 — Head drop tests from the bibliography

Test number	PMHS number	PMHS age	PMHS mass kg	Test performer	Angle of impact °	Impact surface	Impact surface geometry	Drop height m	AIS2005 skull
MS68	MS68	49		APR	35	R	flat	1,83	2
MS76	MS76	75		APR	27	R	flat	2,5	4
DOT-36-1	2326	78	NA	WSU	270	R	1-inch-radius rigid cylinder	0,457 2	2
DOT-37-1	2312	71	NA	WSU	270	R	1-inch-radius rigid cylinder	0,457 2	2
DOT-38-1	2310	67	85	WSU	270	R	1-inch-radius rigid cylinder	0,457 2	2
CHD1801	HS325	44	91	MCW	0	40D	flat	0,609 6	0
CHD1802	HS325	44	91	MCW	0	40D	flat	1,219	0
CHD1803	HS325	44	91	MCW	0	40D	flat	1,524	0
CHD1804	HS325	44	91	MCW	0	40D	flat	1,829	0
CHD1501	HS543	56	95	MCW	0	40D	flat	0,609 6	0
CHD1502	HS543	56	95	MCW	0	40D	flat	0,914	0
CHD1503	HS543	56	95	MCW	0	40D	flat	1,219	0
CHD1504	HS543	56	95	MCW	0	40D	flat	1,524	0
CHD1505	HS543	56	95	MCW	0	40D	flat	1,829	0
CHD1506	HS543	56	95	MCW	0	40D	flat	2,134	2
CHD1701	HS360	71	81	MCW	0	40D	flat	0,609 6	0
CHD1702	HS360	71	81	MCW	0	40D	flat	0,914 4	0
CHD1703	HS360	71	81	MCW	0	40D	flat	1,219	0
CHD1704	HS360	71	81	MCW	0	40D	flat	1,524	0
CHD1705	HS360	71	81	MCW	0	40D	flat	1,829	0
CHD1706	HS360	71	81	MCW	0	40D	flat	2,134	0
CHD901	HS477	68	66	MCW	0	40D	flat	0,609 6	0
CHD902	HS477	68	66	MCW	0	40D	flat	1,219 2	0
CHD903	HS477	68	66	MCW	0	40D	flat	1,524	2
CHD1101	HS348	77	71	MCW	0	40D	flat	0,609 6	0
CHD1102	HS348	77	71	MCW	0	40D	flat	1,219 2	0
CHD1103	HS348	77	71	MCW	0	40D	flat	1,524	0
CHD1104	HS348	77	71	MCW	0	40D	flat	1,828 8	0
CHD1301	HS329	65	75	MCW	0	40D	flat	0,61	0
CHD1302	HS329	65	75	MCW	0	40D	flat	1,219	0
CHD1304	HS329	65	75	MCW	0	40D	flat	1,524	0
CHD1305	HS329	65	75	MCW	0	40D	flat	1,83	0

R rigid

40D 50-mm-thick 40-durometer padding

90D 50-mm-thick 90-durometer padding

Angle A Resulting specimen orientation was such that the sagittal plane was rotated between −11° to −14° from horizontal about the X-axis and −1° to −4° from horizontal about the Z-axis

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Table A.3 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	Test performer	Angle of impact °	Impact surface	Impact surface geometry	Drop height m	AIS2005 skull
CHD1306	HS329	65	75	MCW	0	40D	flat	2,134	0
CHD1307	HS329	65	75	MCW	0	40D	flat	2,438	2
CHD1001	HS209	87	48	MCW	0	40D	flat	0,609 6	0
CHD1002	HS209	87	48	MCW	0	40D	flat	1,219 2	0
CHD1003	HS209	87	48	MCW	0	40D	flat	1,524	0
CHD1004	HS209	87	48	MCW	0	40D	flat	1,828 8	0
CHD1005	HS209	87	48	MCW	0	40D	flat	2,133 6	0
CHD1006	HS209	87	48	MCW	0	40D	flat	2,438 4	0
CHD1007	HS209	87	48	MCW	0	40D	flat	2,743 2	0
CHD1008	HS209	87	48	MCW	0	40D	flat	3,048	0
CHD1601	HS491	30	41	MCW	0	40D	flat	0,609 6	0
CHD1602	HS491	30	41	MCW	0	40D	flat	0,914 4	0
CHD1603	HS491	30	41	MCW	0	40D	flat	1,219	0
CHD1604	HS491	30	41	MCW	0	40D	flat	1,524	0
CHD1605	HS491	30	41	MCW	0	40D	flat	1,829	0
CHD1606	HS491	30	41	MCW	0	40D	flat	2,314	0
CHD1607	HS491	30	41	MCW	0	40D	flat	2,438	2
CHD1401	HS378	70	80	MCW	0	40D	flat	0,609 6	0
CHD1402	HS378	70	80	MCW	0	40D	flat	1,219	0
CHD1403	HS378	70	80	MCW	0	40D	flat	1,524	0
CHD1404	HS378	70	80	MCW	0	40D	flat	1,829	0
CHD1405	HS378	70	80	MCW	0	40D	flat	2,134	0
CHD1901	HS337	59	100	MCW	0	40D	flat	0,914 4	0
CHD1902	HS337	59	100	MCW	0	40D	flat	0,914 4	0
CHD1903	HS337	59	100	MCW	0	40D	flat	1,219	0
CHD1904	HS337	59	100	MCW	0	40D	flat	1,524	0
CHD1905	HS337	59	100	MCW	0	40D	flat	1,829	0
CHD2901	HS532	71	80	MCW	Angle A	90D	cylinder	0,304 8	0
CHD2902	HS532	71	80	MCW	Angle A	90D	cylinder	0,609 6	0
CHD2903	HS532	71	80	MCW	Angle A	90D	cylinder	0,914 4	0
CHD2904	HS532	71	80	MCW	Angle A	90D	cylinder	1,219 2	3
CHD2801	HS542	61	65	MCW	Angle A	90D	cylinder	0,304 8	0
CHD2802	HS542	61	65	MCW	Angle A	90D	cylinder	0,609 6	0
CHD2803	HS542	61	65	MCW	Angle A	90D	cylinder	0,914 4	0
CHD2804	HS542	61	65	MCW	Angle A	90D	cylinder	1,219 2	0

R rigid

40D 50-mm-thick 40-durometer padding

90D 50-mm-thick 90-durometer padding

Angle A Resulting specimen orientation was such that the sagittal plane was rotated between −11° to −14° from horizontal about the X-axis and −1° to −4° from horizontal about the Z-axis

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Table A.3 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	Test performer	Angle of impact °	Impact surface	Impact surface geometry	Drop height m	AIS2005 skull
CHD2805	HS542	61	65	MCW	Angle A	90D	cylinder	1,524	0
CHD2806	HS542	61	65	MCW	Angle A	90D	cylinder	1,828 8	3
CHD2701	HS518	60	102	MCW	Angle A	90D	cylinder	0,304 8	0
CHD2702	HS518	60	102	MCW	Angle A	90D	cylinder	0,609 6	0
CHD2703	HS518	60	102	MCW	Angle A	90D	cylinder	0,914 4	0
CHD2704	HS518	60	102	MCW	Angle A	90D	cylinder	1,219 2	0
CHD2705	HS518	60	102	MCW	Angle A	90D	cylinder	1,524	0
CHD2706	HS518	60	102	MCW	Angle A	90D	cylinder	1,828 8	2
CHD2601	HS544	68	81	MCW	Angle A	90D	cylinder	0,304 8	0
CHD2602	HS544	68	81	MCW	Angle A	90D	cylinder	0,609 6	0
CHD2603	HS544	68	81	MCW	Angle A	90D	cylinder	0,914 4	0
CHD2604	HS544	68	81	MCW	Angle A	90D	cylinder	1,219 2	3
CHD2501	HS354	76	58	MCW	Angle A	90D	flat	0,304 8	0
CHD2502	HS354	76	58	MCW	Angle A	90D	flat	0,609 6	0
CHD2503	HS354	76	58	MCW	Angle A	90D	flat	0,914 4	2
CHD2401	HS501	67	87	MCW	Angle A	90D	flat	0,304 8	0
CHD2402	HS501	67	87	MCW	Angle A	90D	flat	0,609 6	0
CHD2403	HS501	67	87	MCW	Angle A	90D	flat	0,914 4	0
CHD2404	HS501	67	87	MCW	Angle A	90D	flat	1,219 2	0
CHD2405	HS501	67	87	MCW	Angle A	90D	flat	1,524	0
CHD2406	HS501	67	87	MCW	Angle A	90D	flat	1,828 8	3
CHD2301	HS351	81	60	MCW	Angle A	90D	flat	0,304 8	0
CHD2302	HS351	81	60	MCW	Angle A	90D	flat	0,609 6	0
CHD2303	HS351	81	60	MCW	Angle A	90D	flat	0,914 4	0
CHD2304	HS351	81	60	MCW	Angle A	90D	flat	1,219 2	0
CHD2305	HS351	81	60	MCW	Angle A	90D	flat	1,524	3
CHD2201	HS473	74	51	MCW	Angle A	90D	flat	0,609 6	0
CHD2202	HS473	74	51	MCW	Angle A	90D	flat	0,914 4	0
CHD2203	HS473	74	51	MCW	Angle A	90D	flat	1,219 2	0
CHD2204	HS473	74	51	MCW	Angle A	90D	flat	1,524	2
CHD2101	HS516	48	75	MCW	Angle A	40D	flat	0,914 4	0
CHD2102	HS516	48	75	MCW	Angle A	40D	flat	1,219 2	0
CHD2103	HS516	48	75	MCW	Angle A	40D	flat	1,524	0
CHD2104	HS516	48	75	MCW	Angle A	40D	flat	1,828 8	0
CHD2105	HS516	48	75	MCW	Angle A	40D	flat	2,133 6	0

R rigid

40D 50-mm-thick 40-durometer padding

90D 50-mm-thick 90-durometer padding

Angle A Resulting specimen orientation was such that the sagittal plane was rotated between −11° to −14° from horizontal about the X-axis and −1° to −4° from horizontal about the Z-axis

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Table A.3 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	Test performer	Angle of impact °	Impact surface	Impact surface geometry	Drop height m	AIS2005 skull
CHD2106	HS516	48	75	MCW	Angle A	40D	flat	2,438 4	0
CHD2107	HS516	48	75	MCW	Angle A	40D	flat	3,022 6	0
CHD2108	HS516	48	75	MCW	Angle A	40D	flat	3,327 4	0
CHD2001	HS373	68	84	MCW	Angle A	40D	flat	0,609 6	0
CHD2002	HS373	68	84	MCW	Angle A	40D	flat	0,914 4	0
CHD2003	HS373	68	84	MCW	Angle A	40D	flat	0,914 4	0
CHD2004	HS373	68	84	MCW	Angle A	40D	flat	1,219 2	0
CHD2005	HS373	68	84	MCW	Angle A	40D	flat	1,524	0
CHD2006	HS373	68	84	MCW	Angle A	40D	flat	1,828 8	0
CHD2007	HS373	68	84	MCW	Angle A	40D	flat	2,133 6	3
CHD601	HS439	68	34	MCW	0	90D	flat	0,609 6	0
CHD602	HS439	68	34	MCW	0	90D	flat	0,914 4	3
CHD501	HS271	67	50	MCW	0	90D	flat	0,304 8	0
CHD502	HS271	67	50	MCW	0	90D	flat	0,609 6	0
CHD503	HS271	67	50	MCW	0	90D	flat	0,914 4	0
CHD504	HS271	67	50	MCW	0	90D	flat	1,219 2	0
CHD505	HS271	67	50	MCW	0	90D	flat	1,524	0
CHD506	HS271	67	50	MCW	0	90D	flat	1,828 8	0
CHD507	HS271	67	50	MCW	0	90D	flat	2,133 6	3

R rigid

40D 50-mm-thick 40-durometer padding

90D 50-mm-thick 90-durometer padding

Angle A Resulting specimen orientation was such that the sagittal plane was rotated between −11° to −14° from horizontal about the X-axis and −1° to −4° from horizontal about the Z-axis

No WorldSID test results were available for these test conditions at the time when this Technical Report was published. This annex is kept for future use.

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Annex B
(informative)

PMHS shoulder test data (shoulder impactor tests)

Annex B includes the description of the PMHS shoulder impactor tests used in the construction of the injury risk curves.

APR conducted a series of impactor tests to the shoulders of four PMHS[2]. Each PMHS was seated on a horizontal hardwood surface. The position of the head was maintained by taping it to a stick located behind the subject's back. The impactor mass was 23 kg and its flat circular impact face had a diameter of 150 mm. The impact face was centred at the shoulder level of each subject. Three subjects (MS202, MS203, and MS204) were impacted in a pure lateral direction and the fourth (MS201) was impacted at an angle of 15° forward of pure lateral. Each subject was impacted once.

INRETS conducted a series of shoulder impactor tests, as illustrated in Figure B.1 [14] [15] [17]. Each PMHS was seated upright, without back support. The 23,4 kg rigid impactor had a rectangular impact face (150 mm wide and 80 mm high) with rounded edges. The impactor face was centred on the glenohumeral joint. Each subject was impacted three times on the right shoulder (pure lateral, 15° rearward of lateral, and 15° forward of lateral) and once, at higher speed, on the left shoulder in the pure lateral direction.

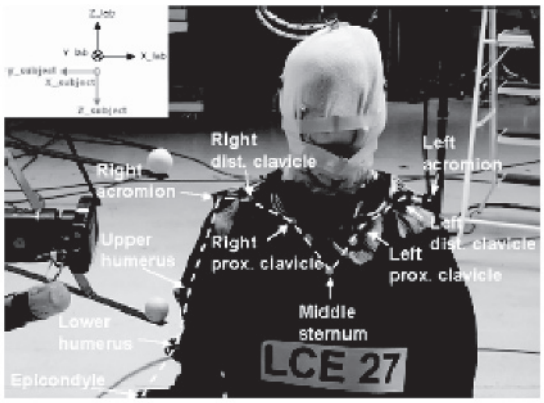

Figure B.1 — Impactor test configuration from the lateral and oblique-lateral shoulder impacts conducted by INRETS (front view)[14] [15] [17]

Ohio State University (OSU) conducted a series of shoulder impact tests[3] [4]. In the first test series, each PMHS was seated on a Teflon sheet on a rigid bench with backrest, as shown in Figure B.2. The 23 kg impactor had a rectangular impact face (203,2 mm wide and 152,4 mm high). The impactor face was padded with a 58-mm-thick piece of Arcel 310 foam (26,4 kg/m^3 density). The characteristics of the padding are presented in Figure B.3.

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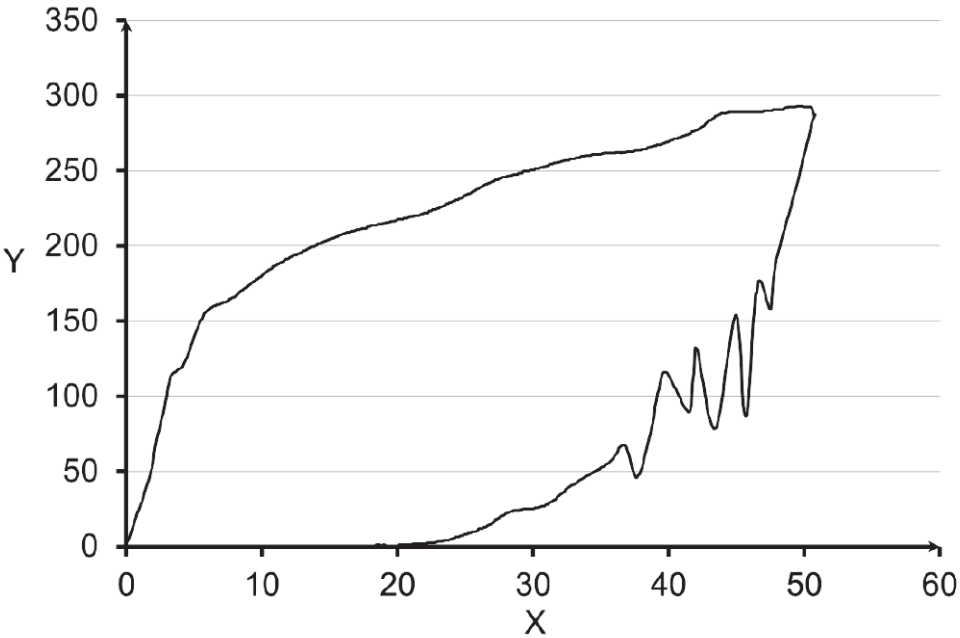
Figure B.2 — Impactor test configuration from the lateral shoulder impacts conducted by OSU (front view)[3],[4]



Key

X compression in %

Y pressure in kPa

Figure B.3 — Characteristic pressure versus compression curve for Arcel 310 padding tested at 6,0 m/s

The impactor face was centred on the glenohumeral joint. After the first impact, the shoulder was palpated for fractures. If a fracture was detected, the impact velocity for the opposite shoulder was reduced by 10 %. If no fracture was detected, then the impact velocity was increased by 10 %. Each subject was impacted once on each shoulder.

In the second test series of OSU tests (see Figure B.4), four subjects were tested on a rigid bench, in the pure lateral direction, with the same impactor configuration as the first series[4]. Supports were placed under the subject's elbows to position the acromion 25 mm above the spinous process of T1. The impactor face was centred 25 mm below the glenohumeral joint. Each subject was impacted once.

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