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Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side-impact dummy —

Part 1:
Vocabulary and rationale

Véhicules routiers — Conception et spécifications de performance pour le mannequin mondial (WorldSID), 50e percentile homme, de choc latéral —

Partie 1: Vocabulaire et raisonnement

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 36, *Safety and impact testing*.

This third edition cancels and replaces the second edition (ISO 15830-1:2013), which has been technically revised.

The main changes are as follows:

— in B.3.3.3 and Table B.4, corrected biofidelity rating of neck test 2;

— in B.3.6.3 and Table B.7, corrected biofidelity rating of abdomen test 3;

— in Table B.9, corrected biofidelity ratings;

— in Table B.10, replaced "rotation accelerometer" with "angular accelerometer or ARS";

— in Table B.10, replaced "IR-TRACC" with "deflection sensors";

— in Table B.10, removed ankle rotation sensors;

— replaced "WorldSID production dummy" with "WorldSID (May 2005 version)";

— in Figure C.15, corrected zero offset;

— in Table C.3, corrected biofidelity rating of neck test 2;

— in Table C.13, corrected biofidelity ratings of abdomen test 3;

— in Table C.20, corrected biofidelity ratings.

A list of all parts in the ISO 15830 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of the ISO 15830 series is to document the design and specifications of this side-impact dummy in a form suitable and intended for worldwide use.

In 1997, the WorldSID 50th percentile adult male dummy development was initiated, with the aims of defining a global-consensus side-impact dummy, with more human-like anthropometry, improved biofidelity, and increased injury-monitoring capabilities, suitable, for example, for regulatory use. Participating in the development were research institutes, dummy and instrumentation manufacturers, governments, and vehicle manufacturers from around the world.

This document is intended to document information and design changes which have become available since the publication of the second edition of the ISO 15830 series (2013-05-15).

In order to apply the ISO 15830 series properly, it is important that all four parts be used together.

Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side-impact dummy —

Part 1:
Vocabulary and rationale

1 Scope

This document provides the vocabulary, symbols, and rationale used in all parts of the ISO 15830 series for the WorldSID 50th percentile side-impact dummy, a standardized anthropomorphic dummy for near-side-impact tests of road vehicles.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
1-to-2-g-setting
joint friction setting which will support the weight of a horizontally extended limb segment but will not support twice the limb segment weight

3.2
abdomen rib
lowest two ribs of the six mechanical ribs in the WorldSID dummy

3.3
aluminium honeycomb
manufactured material comprising multi-layered bonded sheets of aluminium bent or corrugated in a rib pattern, in which there is an internal pattern of hexagonal cylindrical spaces

3.4
angular rate sensor
ARS
sensor which records angular velocity

3.5
arm
assembly of the WorldSID dummy comprising dedicated upper arm components which are different from the components of the *full arm* (3.12)

Note 1 to entry: Unless otherwise specified, arm refers to the half arm for the ISO 15830 series.

3.6
C7
location corresponding to the seventh cervical vertebra in a human

3.7
capacity
maximum designed range for force or moment measurements

3.8
cheese screw
slotted button head screw

Note 1 to entry: This concept is also referred to as a slotted cheese head screw as defined by ISO 1207.

3.9
data acquisition system
DAS
system that includes sensors, recorders, cables and other associated hardware

3.10
docking station
data recorder connection point inside the dummy which allows the recorder to be conveniently disconnected from the sensors

3.11
frontal
forward-facing or anterior surfaces of the dummy, when it is in a standing posture

3.12
full arm
optional assembly of the WorldSID dummy comprising the articulated upper arm and forearm, including the hand

3.13
H-point
point on the outer surface of the dummy on an imaginary line which passes through the left and right hip ball centres

3.14
H-point tool
device which can be inserted into index holes in the dummy pelvis to provide an external surface for indicating the orientation of the pelvis and an imaginary line connecting the left and right hip ball joint centres

3.15
head form
mechanical device with the same mass and I_{xx} inertia as the WorldSID head, used for lateral neck *validation* (3.33) tests

3.16
infrared telescoping rod for assessment of chest compression
IR-TRACC
sensor for deflection measurements

3.17
L1
location corresponding to the first lumbar vertebra in a human

3.18
L5
location corresponding to the fifth lumbar vertebra in a human

3.19
lower leg
portion of the lower extremity between the knee and the ankle

3.20
mass replacement
non-electronic component which is substituted for a given dummy electronic component, which has the same mass as the given electronic component, and which does not act as a structural component of the dummy (e.g. an accelerometer)

3.21
rib deflection
change in distance between the accelerometer mount on the rib and the spine box

3.22
S1
location corresponding to the first sacral vertebra in a human

3.23
shoulder rib
upper-most rib of the six mechanical ribs in the WorldSID dummy

3.24
side impact dummy
dummy used to evaluate performance of impacts lateral to the dummy

3.25
structural replacement
non-electronic component which is substituted for a given dummy electronic component (e.g. a load cell), which has the same mass as the given component, and which also acts as a structural component of the dummy

3.26
thorax rib
second, third, and fourth upper-most ribs of the six mechanical ribs in the WorldSID dummy

3.27
T1
location corresponding to the first thoracic vertebra in a human

3.28
T4
location corresponding to the fourth thoracic vertebra in a human

3.29
T12
location corresponding to the twelfth thoracic vertebra in a human

3.30
tilt sensor
sensor that measures angle relative to gravity

3.31
universal
capable of being mounted at several different locations on the dummy

3.32
upper leg
portion of the lower extremity between the knee and the hip ball

3.33
validation
process by which the relevant dummy component or whole dummy is verified and documented to meet the specifications

3.34
validation bench
specialized seat with defined seat bottom and seat back angles used to position the dummy for *validation* (3.33) tests

3.35
W50-
prefix denoting WorldSID 50th percentile adult male dummy part or drawing number

4   Symbols, subscripts and abbreviated terms

4.1   Symbols

See Table 1.

Table 1 — Symbols and their meanings

Symbol	Meaning
a	Linear acceleration
B	Biofidelity rating for a body region
F	Force
g	Acceleration due to gravity (9,81 m/s^2)
M	Moment
R	Biofidelity rating for how well an individual response meets its requirement
V	Biofidelity weighting factor for a test condition of a body region
W	Biofidelity weighting factor for an individual response measurement
x	Coordinate in accordance with SAE J1733
y	Coordinate in accordance with SAE J1733
z	Coordinate in accordance with SAE J1733
α	Angular acceleration
β	Maximum angular displacement of the head form relative to the neck pendulum
δ	Deflection
θ	Tilt angle
φ	Angular displacement
ω	Angular rate

4.2 Subscripts

See Table 2.

Table 2 — Subscripts and their meanings

Symbol	Meaning
F	Forward pendulum-to-head form sliding rod
H	Head form
R	Rearward pendulum-to-head form sliding rod
i, j, k	Biofidelity rating: i: body region j: test condition for a given body region k: response measurement for a given test condition j and body region i
x, y, z	Coordinate system: In the x, y, or z direction; about the x, y, or z axis where x, y, or z are in accordance SAE J1733

4.3 Abbreviated terms

See Table 3.

Table 3 — Abbreviated terms

Abbreviation	Meaning
AMVO	Anthropometry for Motor Vehicle Occupants data set (established by UMTRI)
APR	Association Peugeot-Renault
A-P	Anterior-posterior
ASIS	Anterior superior iliac spine

Table 3 *(continued)*

Abbrevia-tion	Meaning
ATD	Anthropomorphic test device
BHCS	Button head cap screw, also referred to as a hexagon socket button head screw as defined by the ISO 7380 series
CG	Centre of gravity
CFC	Channel frequency class
CPSS	Cone point set screw, also referred to as a hexagon socket set screw with cone point as defined by ISO 4027
CPSSS	Cone point socket set screw as defined by ISO 4027
CPNT	Cone point nylon tip
DAS	Data acquisition system
FHCS	Flat head cap screw, also referred to as a hexagon socket countersunk head screw as defined by ISO 10642
IARV	Injury assessment reference value
ISO	International Organization for Standardization
LHSHCS	Low head socket head cap screw
MDB	Movable deformable barrier
NHTSA	National Highway Traffic Administration
NM	Not measured
OC	Occipital condyle
PTFE	Polytetrafluoroethylene
R-L	Right-left
ROM	Range of motion
SHCS	Socket head cap screw, also referred to as a hexagon socket head cap screw as defined by ISO 4762
SHSS	Socket head shoulder screw, also referred to as a hexagon socket head shoulder screw as defined by ISO 7379
SI	Sacroiliac
SSCP	Set screw with cup point, also referred to as a hexagon socket set screw with cup point as defined by ISO 4029
SSFP	Set screw with flat point, also referred to as a hexagon socket set crew with flat point as defined by ISO 4026
SSHDP	Set screw with half dog point, as defined by ISO 4026
SSNT	Set screw with nylon tip
UMTRI	University of Michigan Transportation Research Institute
WSU	Wayne State University

5   Technical targets and performance of WorldSID

Technical targets and brief background for WorldSID are given in Annex A.

WorldSID performance relative to the technical targets is given in Annex B.

Data from WorldSID biofidelity tests is given in Annex C.

Data from WorldSID repeatability and reproducibility tests is given in Annex D.

Annex A
(informative)

Rationale regarding background and goals for WorldSID

A.1 Historical background

A.1.1 General

In November 1997, the WorldSID task group was formed to develop a technologically advanced side-impact dummy with better biofidelity and to replace the variety of side-impact dummies used in regulatory and other tests.

The resulting WorldSID 50th percentile adult male side-impact dummy has an overall biofidelity classification of 8,0 ("good") using the ISO/TR 9790 biofidelity rating scale. The WorldSID 50th percentile adult male has a mass of 74,35 kg, a theoretical standing height of 1 753 mm, and a seated height of 911 mm. It can accommodate over 200 permissible sensor channels (including six tilt sensors) and associated cabling, and up to 192 recording channels with an optional in-dummy data acquisition system (DAS).

A.1.2 Need for an International Standard side-impact dummy

As of December 2008, six other mid-sized male side-impact dummies were available for regulatory, consumer information and development use. These were the USDOT-SID dummy, which was utilized in the United States side-impact protection regulation[42]; the EuroSID-1 dummy, which was regulated in a European standard[24]; the ES-2 dummy; the ES-2re; the SID/Hybrid III dummy, which was utilized in the United States side-impact protection regulation FMVSS-201; and the BioSID dummy, which was available for developmental purposes. None of these dummies had "good" biofidelity (i.e. they all had a less than "6,5" rating using the ISO/TR 9790 biofidelity rating scale). The six dummies are structurally different and have different instrumentation capabilities and associated injury assessment criteria. Because of these differences, as well as the differences in the associated test procedures, these dummies typically provided different design directions in the vehicle development process. This could result in substantially different vehicle designs with regard to side-impact protection in the different world regions, despite the similarity in occupant protection needs among the regions.

A.1.3 Biofidelity comparisons with previous side-impact dummies

The six mid-sized male side-impact dummies, as well as some variations thereto, available for use in December 2008 have different levels of biofidelity. The USDOT-SID, EuroSID-1, ES-2, ES-2re, BioSID dummies have each been rated using the ISO/TR 9790 biofidelity scale that provides classifications, as shown in Table A.1. These classifications quantify how closely the dummy dynamic response matches those of a sample of human subjects. The USDOT-SID has an ISO biofidelity classification of "unacceptable", the EuroSID-1 and ES-2re have a classification of "marginal," and the BioSID and ES-2 have a classification of "fair".

Table A.1 — ISO biofidelity rating scale

Excellent	> 8,6 to 10
Good	> 6,5 to 8,6
Fair	> 4,4 to 6,5
Marginal	> 2,6 to 4,4
Unacceptable	0 to 2,6

The ISO/TR 9790 biofidelity ratings of the WorldSID, USDOT-SID, EuroSID-1, ES-2, and BioSID are reported in Reference [39] as shown in Table A.2. WorldSID achieved the best overall dummy rating and the best single body region ratings for the head, shoulder, thorax, and abdomen.

Table A.2 — Biofidelity comparison of side-impact dummies

	Biofidelity rating						
	Head	Neck	Shoulder	Thorax	Abdomen	Pelvis	Overall
WorldSID (2005 version)	10,0	5,3	10,0	8,2	9,3	5,1	8,0
BioSID	6,7	6,7	7,3	6,3	3,8	4,0	5,7
ES-2	5,0	4,4	5,3	5,2	2,6	5,3	4,6
EuroSID-1	5,0	7,8	7,3	5,4	0,9	1,5	4,4
ES-2re	5,0	4,2	4,5	4,0	4,1	3,2	4,2
USDOT-SID	0,0	2,5	0,0	3,1	4,4	2,5	2,3

Independently, the US/NHTSA (National Highway Traffic Safety Administration) evaluated the WorldSID prototype with the ES-2 and the SID/Hybrid III, to Bio Rank, a more recently developed biofidelity ranking system, as reported by Reference [36].

The Bio Rank system quantifies the ability of a dummy to load a sled wall as a cadaver does (external biofidelity) and the ability of a dummy to replicate those cadaver responses that best predict injury potential (internal biofidelity). The ranking is based on the ratio of the cumulative variance of the dummy response relative to the mean cadaver response and the cumulative variance of the mean cadaver response relative to the mean plus one standard deviation. That ratio expresses how well a dummy duplicates a cadaver response. Contrary to the ISO/TR 9790 rating system, the lower the rating value, the better the biofidelity.

Although still under development and not in use by the international community, the data presented by Reference [36] indicate that this assessment system also showed the WorldSID prototype to have the best biofidelity out of the three tested dummies.

In summary, compared with other contemporary mid-sized adult male side-impact dummies, the WorldSID overall ratings are better than all others using either biofidelity rating system.

A.2 Technical targets for the WorldSID prototype

A.2.1 General

The WorldSID task group developed a comprehensive set of technical targets in the following categories:

— functional description;

— loading conditions and interactions;

— anthropometry;

— biofidelity;

— instrumentation;

— repeatability and reproducibility;

— durability;

— robustness;

— handling;

— validation;

— miscellaneous.

Detailed targets in each of these areas were identified for the overall dummy and for each of the following body regions:

— head;

— neck;

— shoulder-thorax-abdomen;

— full arms;

— half arms;

— lumbar spine;

— pelvis;

— upper legs;

— lower legs;

— clothing.

In addition, targets for internal electronic measurement components were identified, including those for the following:

— accelerometers;

— load cells;

— displacement transducers;

— tilt sensors, to facilitate dummy positioning;

— in-dummy data acquisition system.

During the development, the highest priority among these targets was given to the goal of matching the biofidelity (i.e. human dynamic response) targets specified in ISO/TR 9790. The target performance was that a rating of "good" to "excellent" be achieved on the biofidelity rating scale contained in ISO/TR 9790, for all segments of the dummy, and for the overall dummy.

The WorldSID task group reviewed all of the currently existing side-impact dummies to determine what functions and features to incorporate into the WorldSID. Various proposals and ideas from dummy and instrumentation manufacturers and research organizations were reviewed. The majority of the WorldSID consists of new design concepts, with the exception of the neck, which is mainly from the ES-2 dummy (all parts except for the neck buffers).

The WorldSID dummy shall be capable of:

— left-right symmetrical design instrumented on both sides simultaneously;

— off-axis loading for ±30° in the horizontal plane and ±10° in the vertical plane without binding or producing unreasonable data;

— optional in-dummy DAS to enable properly positioning the highly-instrumented dummy without a large bundle of cables.

A.2.2   Functional description

WorldSID was designed to have improved dynamic behaviour, improved measurement capabilities and be easier to handle in the following types of tests:

— standardized tests to assess occupant protection in full vehicle side impacts.

— development tests conducted by vehicle manufacturers and their suppliers to assess and improve performance of restraint systems, vehicle interiors, vehicle structures, etc.

— research tests to enhance the knowledge base of side-impact vehicle and occupant behaviour, through accident reconstructions, component tests, biomechanical tests, etc.

To accommodate the different test conditions, the WorldSID components were designed to meet the following functional targets:

— head, exhibiting multidirectional biofidelity considering its large variety of contact and non-contact loading conditions;

— neck, assuring proper head kinematics;

— shoulders/thorax/abdomen assembly, exhibiting improved biofidelity over existing dummies, and capable of handling off-axis loading without compromising durability, repeatability, and reproducibility;

— full arms, to assess airbag interaction;

— half arms, to enhance test-to-test repeatability for full vehicle tests;

— lumbar spine, representing the coupling between upper and lower torso and allowing various pre-test postures according to seat and vehicle design;

— pelvis, exhibiting improved biofidelity over existing dummies, and capable of handling off-axis loading without compromising durability, repeatability, and reproducibility;

— upper legs, including integrated instrumentation;

— lower legs, including integrated instrumentation;

— clothing, extending over the complete torso and parts of the extremities to simulate clothing, but also some human skin/flesh;

— in-dummy data acquisition system, accommodating at least 64 channels with integrated wiring throughout the dummy;

— accelerometers, including linear and angular accelerometers throughout the dummy;

— tilt sensors dedicated in the head, thorax and pelvis for pre-test positioning;

— load cells and their structural replacements, throughout the dummy and designed as structural components.

A.2.3   Loading conditions and interactions

One requirement for WorldSID was that it functions properly within the loading conditions specified by existing and future harmonized test procedures. This was not to be restricted to the test procedures themselves, but also includes tests to enable development of vehicles, vehicle components, and restraints.

A.2.4 Anthropometry

A.2.4.1 General

The WorldSID represents a mid-sized adult male vehicle occupant. After comparing several anthropometry data sources the AMVO data set for a 50th percentile male[36] was accepted. Included are a 3D surface description, almost 150 anatomical reference points (including joint centres), definitions of segments (head, neck, etc.), and derivation of inertial properties of these segments. The automotive posture as represented by the AMVO data set is defined as the design reference posture for the dummy.

Corrections to the H-point definition in the AMVO were necessary. The data set was corrected and a 3D stickman diagram (lines connecting the joint centres) within the outer shell definition and anatomical landmarks were created. A detailed description of the anthropometry is given in Reference [32].

A.2.4.2 Overall landmarks

The anthropometric landmark targets for WorldSID are specified in Table A.3.

Table A.3 — Landmarks

Landmark	Description	x mm	y mm	z mm
	vertebral column			
7	C7	−264	0	499,4
8	T4	−291	0	390,4
10	T12	−244	0	156,4
12	L5	−172	0	23,4
	pelvis			
27	iliocristale	−78	±161	103,4
28	anterior superior iliac spine (l,r)	−23	±116	93,4
29	pubic symphysis	53	0	51,4
31	trochanterion (skeletal reconstruction) (l,r)	22	±203	−9,6
32	H-point	0	±83,5	0
	shoulder			
35	greater tubercle humerus (l,r)	Not specified	±218	Not specified
	joint centres			
54	head/neck	−194	0	598,4
55	C7/T1	−191	0	479,4
58	T12/L1	−175	0	175,4
60	L5/S1	−89	0	39
61	sternoclavicular	−143	±43	443,4
62	claviscapular	−228	±168	437,4
63	glenohumeral	−184	±173	403,4
64	elbow	38	±208	211,4
65	wrist	230	±158	403,4
66	hip (H-point)	0	±83,5	0

Table A.3 *(continued)*

Landmark	Description	x mm	y mm	z mm
67	knee	408	±138	146,4
68	ankle	686	±94	−158,6
	estimated segment centres of gravity			
79	head	−177	0	656,4

A.2.4.3 Ranges of motion

The ranges of motion are based on several sources. Shoulder flexion, extension, abduction, and adduction ranges are based upon estimates of initial positioning of the arm and motion without binding. Shoulder lateral and medial angular displacement ranges are from the SAE Arm-Airbag Interaction Task Group. The elbow flexion and extension ranges match those of the SAE 5th percentile female instrumented arm. The flexion range is the maximum practical mechanical range. The wrist range of motion was provided by the University of Virginia Auto Safety Laboratory:

— shoulder flexion: 180° to soft stop;

— shoulder extension: 45° to soft stop;

— shoulder abduction: 100° to soft stop;

— shoulder adduction: 0° to soft stop;

— shoulder lateral angular displacement: 31° to soft stop;

— shoulder medial angular displacement: 91° to soft stop;

— elbow flexion: 135° to soft stop;

— elbow extension: −5° to soft stop;

— wrist pronation/supination: 80° to soft stop;

— wrist flexion/extension: 75° to soft stop;

— wrist abduction: 15° to soft stop;

— wrist adduction: 25° to soft stop.

A.2.4.4 Head

The reference for the head anthropometry was the AMVO data set. The target data are specified in Table A.4. The target for the outer geometry of the head was based on the more detailed Hybrid-III geometry,[27] excluding the facial features from the Hybrid-III (nose, lips, etc.).

Table A.4 — General head anthropometry reference data (Source: AMVO data set)

Parameter	Target	Reference	Remark
Mass	4,14 kg ± 0,1 kg	AMVO	
Circumference	570,6 mm ± 5 mm	AMVO 1983 Study	
Length	197,4 mm ± 2 mm	AMVO	
Width	158 mm ± 2 mm	AMVO	Hybrid-III: (155 ± 5) mm

Table A.4 *(continued)*

Parameter	Target	Reference	Remark
CG location	177 mm, 0 mm, 656,4 mm (with respect to mid H-point)	Corrected AMVO	WorldSID-α anthropometry

The location of the head's centre of gravity was indicated on the left and right exterior of the head. The tolerance of the indications was ±2,0 mm.

The coordinates with respect to the H-point for the head CG and OC-joint were (−177, 0, 656,4)[1] and (−194, 0, 598,4) respectively.

For packaging reasons, an adjustment to change the orientation of the head depending on the dummy's posture inside a vehicle was incorporated into the neck-thorax bracket instead of the head-neck junction. An adjustable lower neck bracket allowed proper orientation of the head. The head reference plane marked on the head served as a reference to level the head. Note that the head reference plane in the reference posture of the occupant as defined by the AMVO data set is at an angle of 3,7° with the horizontal plane.

A.2.4.5   Neck

The neck has similar mass and mass distribution to that of the human, as available from the reference AMVO data set. The target data specifies the mass as 0,965 ± 0,2 kg. Targets for coordinates of the OC-joint and C7/T1-joint were (−194, 0, 598,4) and (−191, 0, 479,4). A neck shroud prevented unrealistic airbag interactions.

At the end of the ranges of motion, progressive stiffness was built in to prevent overloading.

To allow the head to be oriented over a sufficient range of motion (angular displacement around the y-axis) with the dummy in an automotive position, the neck bracket exhibits an adjustability of at least 10° forward (flexion) and 20° rearward (extension) with respect to the reference posture.

A.2.4.6   Shoulder/thorax/abdomen

The anthropometry landmarks are based on the AMVO and derivative studies. Major design targets are given in Table A.5. The three-dimensional surface of the AMVO model was used as the design target for the outside contours of the dummy.

Table A.5 — Segment masses

Segment masses	Target
Shoulder and thorax	23,763 kg
Abdomen	2,365 kg

A.2.4.7   Optional full arms

The optional full arm was designed with reference to the AMVO anthropometry data set. This included approximate outside flesh contours, pivot-to-pivot lengths, component masses, and approximate centre of gravity locations.

— Pivot lengths:

— shoulder pivot to elbow pivot length: 295,5 mm;

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1)   Coordinates are expressed as x, y, z in mm with respect to the dummy reference position in an orthogonal reference axis system at the H-point (0, 0, 0), unless specifically specified otherwise. The designation "±" refers to left and right side.

— elbow pivot to wrist pivot length: 276,1 mm.

— Assembly masses: the assembly masses were made to match the AMVO data set target of 3,79 kg (1,77 kg upper arm and 2,02 kg forearm). Precise segmentations were established during the design phase.

— Flesh contours:

— hand flesh contour was new since it is a gripping hand. Basic contour was from the AMVO data surface model with simplified geometry with the fingers curved into a gripping position. Left and right hands were mirror images of each other;

— forearm flesh contour was based on the AMVO data surface model with simplified geometry;

— upper arm flesh contour was based on the AMVO data surface model with simplified geometry;

— the shoulder was covered with flesh by extending the upper arm flesh up over the shoulder structure. The specific method for covering the shoulder with flesh was addressed during the design stage.

A.2.4.8 Half arms

The half arm was designed to meet the WorldSID anthropometry specifications, with reference to the source anthropometry data defined by the AMVO data set. The flesh contour was derived from the AMVO shell surface model and approximated to a rectangular section to improve the arm stability during loading.

The half arm-shoulder joint coincides with that of the full arm and at or very close to the position of the gleno-humeral joint of the anthropometry data set (point 63: −184, ± 173, 403,4).

The mass property target of the half arm is identical for the left and right half arm and specified as 1,769 kg.

A.2.4.9 Lumbar spine

The WorldSID lumbar spine component is defined as the connection between the upper and lower torso and does not specifically simulate the human skeletal lumbar spine. The WorldSID lumbar spine length was targeted to occupy the space between T12/L1 and L5/S1 according to the WorldSID anthropometry specifications in Table A.3.

A.2.4.10 Pelvis

A.2.4.10.1 General

The reference for the pelvis anthropometry is the AMVO data set. In order to define the internal geometry of the pelvis, additional data are used from Reference [35].

A.2.4.10.2 Overall external dimensions

The external shape of the pelvis is based on the AMVO data set ("shell") but adjusted to obtain a non-compressed buttock flesh. AMVO defined the pelvis coordinate system at the H-point with the directions of the axes along the vehicle coordinate system. Target data are given in Table A.6.

Table A.6 — Target data for pelvis external dimensions

Parameter	Target
Mass (only pelvis)	11 kg ± 0,2 kg
Mass (pelvis + femur heads)	14,5 kg ± 0,3 kg

Table A.6 *(continued)*

| Parameter	Target
Hip breadth	385 mm ± 8 mm

A.2.4.10.3 Detailed internal dimensions

The internal design of the pelvis was primarily based on Reference [35]. The internal body shape (dummy skeleton) only represents some important anatomical points as well as the overall pelvic girdle configuration. Whereas the human pelvis skeleton mass is approximately 1 kg, the dummy uses material with higher density than human bone and has to be instrumented, and hence, has a larger mass than the human pelvis. This also results in variation of the pelvic inertia.

Based on data in Reference [35], several bone points were defined with respect to the (corrected) AMVO H-point definition. To achieve this, the coordinate system in Reference [35] was rotated over 54° and the origin was moved to the H-point.

Differences were noted between the Reynolds bone markers and the AMVO surface markers and other data were used to further confirm the pelvic bone geometry. The European Project HUMOS[2] produced a 3D model of a 50th percentile male (175 cm and 80 kg) in the AMVO seated posture. The 3D reconstruction was based on several cross sections obtained from the frozen cadaver subject. The dimensions of the HUMOS male cannot be considered statistically representative of the population but the HUMOS and Reynolds bone dimensions, were similar.

The iliac crest points (for example, point number 336 as shown in Figure A.1 and Table A.7) are the highest points in the seated position and their coordinates are important for defining potential interaction with the abdominal ribs.
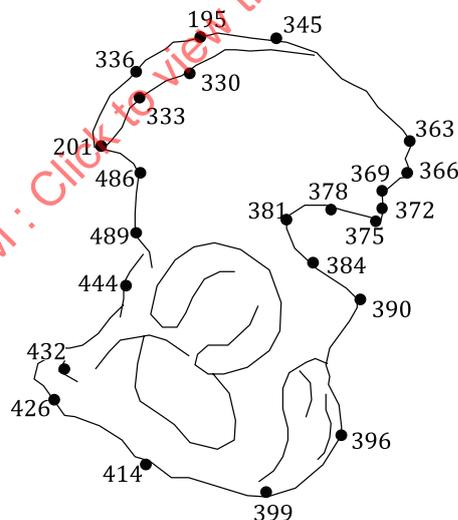
SOURCE: Reference [35]

Figure A.1 — Location of Reynolds' pelvis landmarks

Table A.7 — Coordinates of Reynolds' pelvis bony landmarks with origin at AMVO H-point

Points on left side contour	X	Y	Z
330	−86	133	65
333	−61	132	79
336	−63	123	83

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2)   Human Model for Safety — Project Programme BE 97-4169.

Table A.7 *(continued)*

Points on left side contour	X	Y	Z
342	−130	100	59
345	−126	95	63
363	−127	37	−14
366	−111	35	−22
369	−102	44	−22
372	−89	45	−28
378	−71	58	−9
381	−58	66	−4
384	−41	60	−21
390	−33	54	−28
414	49	25	−27
444	5	64	29
486	−24	104	58
489	−8	95	45
492	−4	87	31
189-H point	0	0	0
195-ilocristale summum	−102	119	74
201-ASIS	−25	117	78
204-pubis	38	0	32
375-post-inf iliac spine	−77	52	−22
396-medial tuberosity point	7	48	−68
399-inf. tuberosity point	37	39	−61
426-ant. symphysis pole	44	9	13
432-pubotubercule	33	25	29
Trochanter	22	165	−9,6

A.2.4.10.4 Detailed pelvis shape

The ischium shape and position have to be human-like to have a proper pressure mapping on the seat cushion and seat back. The WorldSID-α pressure map was similar to that shown in Figure A.2. No pressure values were specified.
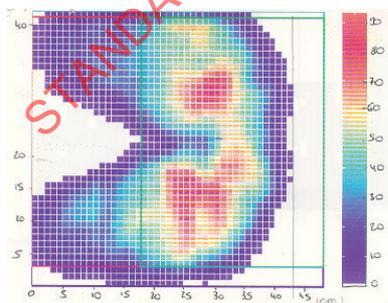
a) Pressure mapping of buttock
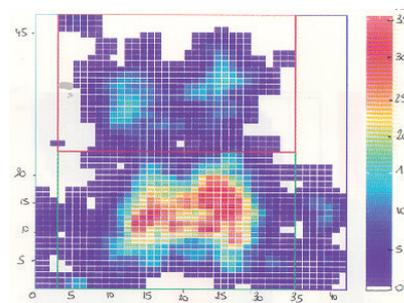
b) Pressure mapping of back

Figure A.2 — An example of a mean seat pressure distribution obtained from five different subjects seated in a truck seat (Seat angle: 4°, back seat angle: 18°)[3]

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3)   Personal communication — RENAULT-RVI.

The average horizontal flesh thicknesses found in the HUMOS subject are as follows:

— at iliocristale: 40 to 45 mm (each side, in lateral direction);

— at ASIS: 40 mm (each side, in lateral direction);

— at trochanter level: 40 to 45 mm (each side, in lateral direction);

— at pubis: 60 mm (in front of the pubic bone).

In conclusion:

— the pelvic bone dimension in Reference [35] was considered for the main bony points of the dummy pelvis;

— the AMVO shape gave exterior dimensions of the pelvis;

— the flesh thickness was derived from the AMVO and markers distance (40 mm on the iliocristale and 30 mm at the trochanter)[34].

A.2.4.10.5 Pelvis ranges of motion

Hip ranges of motion depend on knee position. The WorldSID was a seated dummy; therefore, the focus was on the range of motion in seated position.

The flesh should not reduce the femur joint range of motion by more than 5°. The hip joint can be tuned by friction setting.

A.2.4.10.6 Posture

The dummy should be able to be seated in the rear of a small car. Hip ranges of motion and flesh design have to allow 53° of flexion in the upward direction. The position of the dummy pelvis (H-point location) should be measurable with an H-point tool. The measurement should be precise at ±2,5 mm. The design of the WorldSID pelvis included a tilt sensor to measure pelvis angle ±1°.

A.2.4.11 Upper leg

The AMVO data set was taken as reference for the anthropometry specifications. The knee pivot position and orientation were maintained at the AMVO coordinates of (408 mm, 138 mm, 146,4 mm) and (408 mm, –138 mm, 146,4 mm) relative to the H-point. The segmentation locations were defined during the design stage. Once the segmentation was defined, the mass target was defined based upon the AMVO data, correcting for the segmentation. The basic flesh shape was based upon a simplification of the AMVO flesh surface shell adjusted to an uncompressed state. The knee range of motion design target was 144° forced, based on Reference [46].

A.2.4.12 Lower leg

The lower leg was designed to represent the mid-sized male as represented by the AMVO data set. Major anthropometry specifications that were considered in the design of the lower leg were:

— the knee joint centres (points 67: 408 mm, ± 138 mm, 146,4 mm), and

— the ankle joint centres (points 68: 686 mm, ± 94 mm, –158,6 mm).

The flesh system has a continuous outer surface when the lower leg is at or close to its reference position (according to the AMVO data set). Continuous surfaces cannot be guaranteed over the full range of motion of the ankle and knee joints.

A.2.4.13 Clothing

The suit was tailored to be snug fitting, with additional material added around joints to allow full range of motion. A soft shoulder pad improved the shape of the jacket, without affecting the response of the dummy.

A.2.5 Biofidelity

A.2.5.1 General

ISO/TR 9790:1999 describes laboratory test procedures and impact response requirements suitable for assessing the lateral impact biofidelity of the head, neck, shoulder, thorax, abdomen, and pelvis of crash test dummies, subcomponent test devices, and math models that are used to represent a 50th percentile adult male.

A.2.5.2 Head

Two lateral head impact tests are defined in ISO/TR 9790. Head test 1 is based on the rigid surface cadaver impacts in Reference [26]. Head test 2 is based on the padded surface cadaver impacts of the Association Peugeot-Renault (APR). Note that test 2 was not conducted since the padding specified for the test is no longer available.

A.2.5.3 Neck

Three sled tests are defined to assess lateral neck bending. Neck test 1 is based on the human volunteer data in Reference [25], and the requirements are based on further analysis in Reference [47]. Neck test 2 is also based on the human volunteer data in Reference [34]. Neck test 3 is based on the cadaver tests of the APR. All three sled tests were conducted.

A.2.5.4 Shoulder

Four lateral impact test conditions are defined for the shoulder. Shoulder test 1 is based on impactor tests conducted by the APR using unembalmed cadavers in Reference [17]. Shoulder test 2 is based on volunteer sled tests in Reference [25]. Shoulder test 3 is based on cadaver sled tests. Shoulder test 4 is based on the cadaver sled tests of WSU[28] [29]. Note that shoulder test 4 was not conducted since the exact padding is no longer available.

A.2.5.5 Thorax

Six lateral thoracic impact test conditions are defined. Thorax tests 1 and 2 are based on cadaver impactor tests conducted by the Highway Safety Research Institute (HSRI)[23] and WSU [43]. Thorax tests 3 and 4 are based on the cadaver drop tests of the APR [40] [44] [45]. Thorax test 5 is based on cadaver sled tests of the University of Heidelberg[30]. Thorax test 6 is based on cadaver sled tests of WSU [28] [29]. Note that thorax test 4 and test 6 were not conducted because the padding is no longer available.

A.2.5.6 Abdomen

Five lateral abdominal impact test conditions are defined. Abdomen tests 1 and 2 are based on the lateral cadaver drop tests conducted by the APR [17] [39]. Abdomen tests 3 to 5 are based on cadaver sled tests of WSU [29]. Three abdomen tests were not included in the biofidelity rating. Abdomen test 2, a 2-m drop, and test 4, a high-speed rigid-wall sled test, were not included because it was deemed that the test energies were excessive. In addition, test 5 was excluded because the padding is not available.

A.2.5.7 Pelvis

Thirteen lateral pelvic impact test conditions are defined. Pelvis tests 1 and 2 are based on impactor tests of ONSER [19] [20] [21]. Pelvis tests 3 to 6 are based on free fall cadaver tests of the APR [41]. Pelvis tests 7 to 9 are based on cadaver sled tests of the University of Heidelberg [30]. Pelvis tests 11 to 13 are

based on cadaver sled tests of WSU [30]. Note that pelvis tests 5, 6, 9, 12, and 13 were not conducted because the padding is no longer available. In addition, tests 8 and 11 were not conducted due to their excessive energy levels.

A.2.6 Instrumentation

Overall design targets for measurement capability of the WorldSID were:

— support the assessment of injury risk using existing criteria as described in standard side-impact test procedures;

— support the assessment and optimization of vehicle components and restraint systems;

— support assessment of occupant behaviour in reconstructed accidents;

— designed as integral parts of the dummy;

— conform to ISO 6487 or SAE J211-1, whichever reference is the most up to date;

— designed such that an in-dummy data acquisition system can be used;

— support ease of use with sensor identification incorporated with or without an in-dummy data acquisition system.

Specific component instrumentation targets are shown in Table A.8.

Table A.8 — Target WorldSID instrumentation listing

Component	Instrumentation	Channels	Subtotal
Head	Head CG linear acceleration ($a_{x,y,z}$)	3	8
	Rotational acceleration ($\alpha_{x,y,z}$)	3	
	Head tilt ($\theta_{x,y}$)	2	
Neck	OC joint (upper neck) loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	12
	C7/T1 (lower neck) loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	
Shoulders (each side)	Shoulder rib linear acceleration ($a_{x,y,z}$)	3	7 each side 14 total
	Shoulder rib deflection (δ_y)	1	
	Shoulder joint forces ($F_{x,y,z}$)	3	
Full arm (each side)	Upper arm loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	21 each side 42 total
	Lower arm loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	
	Elbow moments ($M_{x,y}$)	2	
	Elbow angular displacement (φ_y)	1	
	Elbow linear acceleration ($a_{x,y,z}$)	3	
	Wrist linear acceleration ($a_{x,y,z}$)	3	
Half arm (each side)	None		0
Thorax (each side)	Upper thorax rib linear acceleration ($a_{x,y,z}$)	3	12 each side 24 total
	Upper thorax rib deflection (δ_y)	1	
	Middle thorax rib linear acceleration ($a_{x,y,z}$)	3	
	Middle thorax rib deflection (δ_y)	1	
	Lower thorax rib linear acceleration ($a_{x,y,z}$)	3	
	Lower thorax rib deflection (δ_y)	1	

Table A.8 *(continued)*

Component	Instrumentation	Channels	Subtotal
Spine	T1 acceleration ($a_{x,y,z}$)	3	13
	T4 (centre spine box) linear acceleration ($a_{x,y,z}$)	3	
	T12 (lower spine box) linear acceleration ($a_{x,y,z}$)	3	
	Thorax (spine box) rotational acceleration ($\alpha_{x,z}$)	2	
	Thorax tilt ($\theta_{x,y}$)	2	
Abdomen (each side)	Upper abdomen rib linear acceleration ($a_{x,y,z}$)	3	8 each side
	Upper abdomen rib deflection (δ_y)	1	16 total
	Lower abdomen rib linear acceleration ($a_{x,y,z}$)	3	
	Lower abdomen rib deflection (δ_y)	1	
Lumbar spine	Lower lumbar spine loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	6
Pelvis	Pelvis CG linear acceleration ($a_{x,y,z}$)	3	18
	Pubic symphysis loads (F_y)	1	
	Sacroiliac loads (left and right) ($F_{x,y,z}$, $M_{x,y,z}$)	12	
	Pelvis tilt ($\theta_{x,y}$)	2	
Upper leg (each side)	Femur neck forces ($F_{x,y,z}$)	3	12 each side
	Mid-femur loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	24 total
	Outboard knee force (F_y)	1	
	Inboard knee force (F_y)	1	
	Knee angular displacement (φ_y)	1	
Lower leg (each side)	Upper tibia loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	15 each side
	Lower tibia loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	30 total
	Ankle angular displacement ($\varphi_{x,y,z}$)	3	

The targets for the WorldSID total channel count differed with the various configurations of the dummy.

— Total number of channels for WorldSID with two full arms and instrumented on struck and non-struck side (shoulder-thorax-abdomen ribs not instrumented on non-struck side) was 180.

— Total number of channels for WorldSID with full arms and instrumented on the struck side only (for extremities) was 132.

— Total number of channels for WorldSID with half arms and instrumented on struck side only (for extremities) was 111.

The WorldSID was designed with an optional in-dummy data acquisition system, capable of recording a minimum of 64 channels on-board (power and set-up external).

All sensors were orientated in accordance with ISO 6487 or SAE J211-1 and local coordinate systems were defined for all components listed in Table A.8.

A high level of integration of the instrumentation with WorldSID parts was achieved through an integrated wiring concept (i.e. the mass of cables internal to the dummy were designated as part of the dummy). In addition, for all sensors, structural or mass replacements were provided and the mass characteristics of the sensors were accounted for at body part level. All load sensors were structural components of the dummy.

A.2.7 Repeatability and reproducibility

Repeatability of the WorldSID could only be assessed once the actual design was completed and built. Assessment of reproducibility requires multiple dummies. At the design level, low mass tolerances, low dimensional tolerances, selection of strong materials, and good symmetry (where applicable) helped

ensure that the dummy met overall repeatability requirements. In addition, validation procedures considered body part responses relevant to the expected test conditions.

General repeatability requirements for the WorldSID were cumulative variance (CV) less than or equal to 7 % on injury assessment and calibration signals in both validation and in general use.

A.2.8 Durability

The durability target was that components remain functional for at least 10 tests provided the loads on components remain below 150 % of the injury assessment reference values (IARV). Since injury tolerance levels (e.g. probability of AIS ≥ 3) for each body region of WorldSID did not yet exist at the time when WorldSID performance targets were established, Reference [31] was used in the subsequent WorldSID durability evaluation phase.

A.2.9 Robustness

The robustness targets included:

— continuous surfaces;

— integrated shoes;

— clothing;

— targetable surfaces;

— non-binding design for oblique impacts up to ±30° from lateral and ±10° from horizontal;

— compatible with a temperature range of 16 °C to 26 °C.

A.2.10 Handling

Targets for ease of handling included:

— high level of integration with required and desired instrumentation;

— integrated dummy storage and positioning features;

— detailed user's manual.

A.2.11 Verification, calibration, and validation

As much as possible, existing dummy validation fixtures and procedures were used for WorldSID. Validation specifications for the extremities, which did not exist for other side-impact dummies, were targeted for WorldSID.

A.2.12 Other

A drawing and part coding system consisting of an eight-digit character code was established. The first three digits represent the dummy type: "W50" for the 50th percentile male WorldSID. The following five digits represent the body region (one digit), body sub-region (one digit), and the part ID (three digits). Fasteners are the exception to this rule and are coded upward of W50-6000000. Table A.9 gives the designated codes for WorldSID assembly, subassemblies, and components for reference.

Table A.9 — WorldSID part coding system

Dummy ID	Component number	Body region/other
W50	0	Top level assembly
W50	10000	Head
W50	20000	Neck

Table A.9 *(continued)*

Dummy ID	Component number	Body region/other
W50	30000	Torso — shoulders/thorax/abdomen
W50	40000	Pelvis/lumbar
	41000	Lumbar spine
	42000	Pelvis
W50	50000	Legs
	51000	Femur
	52000	Knee
	53000	Tibia
	54000	Ankle
	55000	Foot
W50	60000	Arms — full/half
	61000	Full arm
	62000	Half arm
W50	70000	Data acquisition system and instrumentation
	71000	Load cells
	72000	Accelerometers
	73000	Deflection sensors
	74000	Data acquisition system and signal conditioning
W50	80000	Clothing, test equipment, miscellaneous
W50	6000000	Fasteners

Annex B
(informative)

Rationale regarding performance of the WorldSID (May 2005)

B.1 Performance basis of the WorldSID

NOTE   Unless otherwise noted, the performance of the WorldSID is described subsequently, based on the test data, design drawings, and CAD files available up through May 2005.

B.2 Anthropometry performance

B.2.1 Overall dummy landmarks

Table B.1 — Measured dummy versus design target landmarks

Landmark	Description	Design target			Measured[a]		
		x	y	z	x	y	z
		mm	mm	mm	mm	mm	mm
	vertebral column						
7	C7	−264	0	499,4	−264	0	499,4
8	T4	−291	0	390,4	−291	0	390,4
10	T12	−244	0	156,4	−244	0	156,4
12	L5	−172	0	23,4	−172	0	23,4
	pelvis						
27	iliocristale	−78	±161	103,4	−78	±161	103,4
28	anterior superior iliac spine (l,r)[b]	−23	±116	93,4	Not available	Not available	Not available
29	pubic symphysis[c]	53	0	51,4	Not available	Not available	Not available
31	trochanterion (skeletal reconstruction) (l,r)	22	±203	−9,6	Not available	Not available	Not available
32	H-point	0	±83,5	0	0	±83,5	0
	shoulder						
35	greater tubercle humerus (l,r) (half arm)		±218			±218	
35	greater tubercle humerus (l,r) (full arm)		±218			±222,6	

[a]   Some of the landmarks listed are very difficult or impossible to measure directly, and therefore, the computer-aided design (CAD) values for all points are listed as measured and are believed to be accurate.

[b]   The dummy pelvis was designed with a single curvature shape to avoid a structural buckling mode that would occur with a more human-like shape.

[c]   Packaging of the pubic load cell required a deviation from the target location.

[d]   The actual shoulder joint had to be 15 mm forward of the target to accommodate the shoulder rib design.

Table B.1 *(continued)*

Landmark	Description	Design target			Measured[a]		
		x	*y*	*z*	*x*	*y*	*z*
		mm	mm	mm	mm	mm	mm
	joint centres						
54	head/neck	−194	0	598,4	−194	0	598,4
55	C7/T1	−191	0	479,4	−191	0	479,4
58	T12/L1	−175	0	175,4	−175	0	175,4
60	L5/S1	−89	0	39	−89	0	39
61	sternoclavicular	−143	±43	443,4	−143	±43	443,4
62	claviscapular	−228	±168	437,4	−228	±168	437,4
63	glenohumeral[d]	−184	±173	403,4	−169	±173	404,4
64	elbow[d]	38	±208	211,4	53,4	±211,6	212,2
65	wrist[d]	230	±158	403,4	244,2	±162,5	403,3
66	hip (H-point)	0	±83,5	0	0	±83,5	0
67	knee	408	±138	146,4	408	±138	146,3
68	ankle	686	±94	−158,6	680	±94	−158,6
	estimated segment centre of gravity						
79	head	−177	0	656,4	−177	0	656,4

[a] Some of the landmarks listed are very difficult or impossible to measure directly, and therefore, the computer-aided design (CAD) values for all points are listed as measured and are believed to be accurate.

[b] The dummy pelvis was designed with a single curvature shape to avoid a structural buckling mode that would occur with a more human-like shape.

[c] Packaging of the pubic load cell required a deviation from the target location.

[d] The actual shoulder joint had to be 15 mm forward of the target to accommodate the shoulder rib design.

B.2.2 Range of motion

Table B.2 — Measured dummy range of motion vs. design target

Motion	Design target	Measured
Shoulder flexion	180° to soft stop	172° to contact, 190° forced
Shoulder extension	45° to soft stop	40° contact, 50° forced
Shoulder abduction	100° to soft stop	101,5°
Shoulder adduction	0° to soft stop	−1°
Shoulder lateral angular displacement	31° to soft stop	31°
Shoulder medial angular displacement	91° to soft stop	91,8°
Elbow flexion	135° to soft stop	137,1°
Elbow extension	−5° to soft stop	−3,9°
Wrist pronation	80° to soft stop	81,7°
Wrist supination	80° to soft stop	82°
Wrist flexion	75° to soft stop	75°
Wrist extension	75° to soft stop	55° to flesh contact, 77° forced
Wrist abduction	15° to soft stop	15°
Wrist adduction	25° to soft stop	28,5°
Ankle plantar flexion	40° to soft stop	

Table B.2 *(continued)*

Motion	Design target	Measured
Ankle dorsiflexion	55° to soft stop	
Ankle inversion/eversion	30° to soft stop	

B.2.3 Head

The measured WorldSID head anthropometry is given in Table B.3 and is compared with the original design target.

Table B.3 — Measured dummy head anthropometry vs. design target

Parameter	Target	Measured
Mass	4,14 kg ± 0,1 kg	4,29 kg [a]
Circumference	570,6 mm ± 5 mm	568 mm
Height	230,9 mm	231 mm
Length	197,4 mm ± 2 mm	199 mm
Width	158 mm ± 2 mm	159 mm
CG location	−177 mm, 0 mm, 656,4 mm (with respect to mid H-point)	−177 mm, 0 mm, 656 mm
[a] Head mass is the mean of head measurements from May 2015 dummies.		

B.2.4 Neck anthropometry

The neck is designed according to AMVO corrected anthropometry. The length of the neck design complies with the AMVO requirement; however, to meet the biofidelity performance requirement, the diameter of the neck itself is reduced. A neck shroud assembly is designed to simulate the skin contour of the AMVO shell. Due to the limit of the mechanical design packaging, the dummy design cannot have the same split location as defined in the AMVO for a 50th percentile human. Therefore, the mass of the neck design is 1,038 kg, which is within the AMVO requirement of 0,966 kg ± 0,200 kg.

B.2.5 Shoulder/thorax/abdomen anthropometry

The shoulder is designed with an outer and an inner rib for each side. The inner rib has damping material attached to the metal rib. The shoulder rib is tilted 10° upward at the front to simulate arm joint motion during an impact test. The arm-to-shoulder joint is designed to provide range of motion for the arm.

Three thorax ribs are designed to represent the human thorax. The ribs are horizontal in reference to the AMVO sitting posture except for the first thorax rib, which is tilted 5° upward at the front to cover the space between the shoulder rib and the first thorax rib.

The abdomen is represented by two abdomen ribs. The mechanical design is similar to the thorax except for the damping material, which is thicker to meet the performance requirements.

Since the mechanical interface between the upper torso and the lower torso differs from the AMVO body segment locations, the total mass of 22,74 kg for the shoulder/thorax/abdomen, including the lower neck bracket assembly, is different from the specifications in AMVO. The total mass without the neck bracket is 20,56 kg.

B.2.6 Full arms

The pivot lengths were first priority. The target for shoulder pivot to elbow pivot was 295,5 mm, whereas the design measured 295,0 mm in CAD. The target for elbow-to-wrist pivot was 276,1 mm, and the design measured 276,1 mm in CAD. The second priority for the arm design was measurement capability and strength. The strength of the arm bone was designed to exceed the capacities of the load

cells. The third priority was range of motion (ROM). The measured ROMs on one arm are shown in Table B.2.

The fourth priority was the external shape of the arm flesh. The upper arm flesh shape was derived by taking slices of the AMVO surface shell and drawing ellipses through the sections to approximate the area of the section. The resulting surface was smoothed and simplified somewhat, and the left and right upper arm fleshes were made as mirror images. The forearm flesh shape was derived in a similar fashion by taking slices of the AMVO surface shell and drawing ellipses through the sections to approximate the area of the section. This surface was smoothed, simplified, and made symmetrical so that one arm flesh part could be used for the left and right arms. The hand shape was derived in a slightly different fashion. The hand was made by taking one of the Hybrid III 50th male hand shapes, bending the fingers, and mirroring it for the other side. This gave a more reasonable shape for a dummy hand than trying to use the AMVO surface data directly.

Matching the mass distributions of the arm could only be an approximation. The AMVO anthropometry data set splits body segments by defining planes through the joint centres. In a dummy, these planes pass through multiple parts. The arm was designed by grouping parts that would be cut by the split planes into one of the body segments. Then, the mass targets of the flesh components were adjusted to have the dummy segments match the AMVO body segment mass targets. The final check of this process was to measure the entire arm mass of one of the arms and compare it to the full arm mass target from the AMVO data set. The measured full arm mass was 3,72 kg as compared to the target mass from the AMVO study of 3,79 kg.

Due to the many other requirements for the arm, there was no possibility to adjust the centre of gravity locations of the arm segments.

B.2.7   Half arms

The half arm was designed to match the AMVO upper arm weight and geometry. The measured weight is 1,76 kg.

B.2.8   Lumbar spine

The lumbar design was limited by space constraints and was designed to fit within 50 mm between the thorax and the pelvis. The lumbar flexibility provides shear flexibility between the upper and lower torso to simulate human response. The lumbar is approximately aligned with L5/S1 but not with T12/L1.

B.2.9   Pelvis

The measured pelvis breadth is 384,6 mm. The actual dummy pelvis mass is difficult to compare to the target mass because the dummy mechanical split lines are different than those used for determining the target masses; however, the overall dummy mass and mass distributions match the general mass targets.

B.2.10 Upper leg

The AMVO data set was taken as reference for the anthropometry specifications for the upper leg segment. The hip and knee joint centres were matched to the locations specified in the AMVO data (see Table B.1). The flesh shape was split from the pelvis and is a smoothed simplified shape derived from an approximation of what the un-deformed surface shell would be. In the knee area, the outer flesh shape was made with spherical radii on both sides and the front to give uniform surfaces to transfer load to the knee contact load cells and the front of the knee. The front knee surface radius approximated the forward location of the surface shell.

The mass segmentation between the AMVO data set and the upper leg was an approximation. The split planes in the AMVO data set pass through the hip socket and the knee centre. In the dummy, the pelvis flesh is split in a plane perpendicular to the femur bone well below the hip ball. The bone from the hip ball to the split above the upper tibia load cell is part of the upper leg assembly in the dummy. Due to

these major differences in the splits in the dummy versus the AMVO study, the masses were adjusted by taking a portion of the mass from the AMVO study and transferring it from the upper leg to the pelvis. This made the dummy upper leg mass several kilograms light. The human mass of bone structure and flesh from the knee pivot to the top of the upper tibia load cell should be part of the lower leg but is included in the upper leg in the dummy. This adds to the dummy upper leg mass. As a result of such mass distributions, the average measured upper leg mass of the dummies was 6,7 kg while the target mass was 8,6 kg. Updated segmentation in 2015 changed the upper leg mass to 5,86 kg.

B.2.11 Lower leg

The AMVO data set was taken as reference for the anthropometry specifications for the lower leg segment. The knee joint centre location is shown in Table B.1. The AMVO data set specifies one joint centre for the ankle, but the dummy was designed with a split distance between the inversion/eversion and dorsiflexion/plantar flexion pivots. The dorsiflexion/plantar flexion pivot was located at the AMVO pivot shown in Table B.1.

The external flesh shape was designed based on the surface shell by taking vertical slices through surface shell. At each slice, an ellipse was drawn approximating the area of the cross section. These ellipses were made symmetric about the centre of the bone so that one flesh could be used on both the left and right legs. The resulting surface was smoothed. At the knee end, a spherical cut was made to mate to the upper leg flesh.

The mass segmentation between the AMVO data set and the lower leg was an approximation. The split planes in the AMVO data set pass through the knee and ankle joint centres. The dummy segmentation is very different. The split between the upper and lower legs is at the top of the upper tibia load cell. The split between the lower leg and ankle/foot is at the bottom of the lower tibia load cell for the bone structure, which is well above the ankle pivot. In addition, the foot and shoe are combined in the dummy into one moulded component.

These major segmentation differences make a comparison of dummy and AMVO mass targets difficult. For the dummy, the average lower leg mass was measured at 2,8 kg, whereas the AMVO target was 3,6 kg. For the dummy ankle/foot assembly, the average measured mass was 2,3 kg versus a target of 1,0 kg. These differences are partly due to the segmentation differences, partly due to the inclusion of the shoe in the dummy, and partly due to the dummy ankle assembly being somewhat heavier than the AMVO mass target. In 2015 the mass specification for the leg/ankle/foot segment was updated to 5,06 kg.

B.2.12 Clothing

The clothing is fabricated from 5 mm thick polychloroprene and is tailored to fit the dummy according to the AMVO shell. The clothing provides smooth external contours for the dummy skin surface and does not adversely affect the joint motions. Two shoulder pads, which are not an integral part of the suit, provide human-like shoulder contours.

B.3 Biofidelity performance

B.3.1 ISO/TR 9790 ratings procedures

As found in ISO/TR 9790, the biofidelity rating for the six body regions is defined as follows:

$$B_i = \frac{\sum j\left(V_{i,j}\left(\sum W_{i,j,k}R_{i,j,k}\right)\right)/\sum W_k}{\sum j V_{i,j}} \tag{1}$$

where

B_i is the body region biofidelity rating;

$V_{i,j}$ is the weighting factor for each test condition for a given body region;

$W_{i,j,k}$ is the weighting factor for each response measurement for which a requirement is given;

$R_{i,j,k}$ is the rating of how well a given response meets its requirement ($R_{i,j,k}$ is equal to 10 if the response meets the requirement, 5 if the response is outside but lies within one corridor width of the requirement, and 0 if neither of the previous is met). Note that when a rating was determined by the WorldSID task group, particular emphasis was placed on the loading phase and peak of the data being considered. This is common practice that has been used in the determination of ratings for other dummies;

i represents the body region;

j represents the test condition for a given body region i;

k represents the response measurement for a given test condition j and a body region i.

Values for the weighting factors for the various test conditions, $V_{i,j}$, and response measurements, $W_{i,j,k}$, are given in ISO/TR 9790:1999, Tables S.2 to S.7.

The values of $R_{i,j,k}$ were assigned as follows:

$R_{i,j,k}$ = 10 if response meets requirement;

$R_{i,j,k}$ = 5 if response is outside requirement but lies within one corridor width of the requirement;

$R_{i,j,k}$ = 0 if neither of the above is met.

Using this method, the overall biofidelity rating, B, was to have a design target value between 0 and 10. Five classifications indicating the degree of biofidelity were established for the overall biofidelity rating. These are,

— Excellent biofidelity: $8,6 < B \le 10,0$

— Good biofidelity: $6,5 < B \le 8,6$

— Fair biofidelity: $4,4 < B \le 6,5$

— Marginal biofidelity: $2,6 < B \le 4,4$

— Unacceptable biofidelity: $0,0 \le B \le 2,6$

The overall biofidelity value, B, of a side-impact dummy (or math model) has to be greater than 2,6 to be acceptable for assessing side-impact occupant protection.

The objective for the WorldSID was "good" to "excellent" biofidelity.

B.3.2   Head

Two head tests are specified in ISO/TR 9790. Head test 1 was carried out with the WorldSID for lateral assessment. Head test 2 was not conducted because the required padding for the test is no longer available.

Head test 1, defined in ISO/TR 9790 is a 200-mm drop onto a rigid surface with the head only. Targets are given for head resultant accelerations. As only test 1 could be carried out, the overall head biofidelity rating is the same as that of test 1. Head test 1 data are given in Annex C.

The biofidelity rating of the head, B_1, is 10,0.

B.3.3 Neck

B.3.3.1 General

Three different sled tests were conducted to determine the lateral biofidelity of the dummy neck assembly. Neck test 2 data are from the WorldSID revised prototype. Neck tests 1 and 3 were performed with the arm at 45° with respect to the ground. Neck test 2 was performed with the arm at 45° with respect to the torso. All neck tests were conducted without the neck shroud assembly since it was previously determined that the neck shroud assembly had no influence on the neck biofidelity performance[22]. Neck tests 1 through 3 data are given in Annex C.

B.3.3.2 Neck test 1

Neck test 1, defined in ISO/TR 9790, is a sled test with a mean sled velocity of 6,9 m/s and average sled deceleration of 7,2g. Boundaries were given for lateral acceleration and displacement at T1, lateral and vertical head CG displacement relative to T1, the time of peak head excursion, lateral and vertical peak head acceleration, the peak lateral flexion angle, and the peak twist angle.

The biofidelity rating for neck test 1 is 7,4.

B.3.3.3 Neck test 2

Neck test 2, defined in ISO/TR 9790, is a sled test with a velocity of 5,8 m/s and the constant deceleration level of 6,7g. From this test, boundaries for peak flexion angle, peak forces and moments at the occipital condyles, and peak head resultant acceleration were given.

The biofidelity rating for neck test 2 is 2,1.

B.3.3.4 Neck test 3

Neck test 3, defined in ISO/TR 9790, is a sled test with an initial velocity of 6 m/s and sled deceleration of 12,2g. Boundaries are given for peak lateral T1 acceleration, peak lateral head CG acceleration, peak horizontal displacement of the head CG relative to the sled, peak flexion angle, and peak twist angle.

The biofidelity rating for neck test 3 is 7,2.

B.3.3.5 Overall neck biofidelity rating

The overall neck biofidelity ratings are given in Table B.4.

Table B.4 — Overall neck biofidelity

	j	$V_{2,j}$	$R_{2,j}$
Neck test 1	1	7	7,4
Neck test 2	2	6	2,1
Neck test 3	3	3	7,2
Neck biofidelity rating, B_2			5,4

B.3.4 Shoulder

B.3.4.1 General

Three of four ISO/TR 9790 shoulder tests were conducted on the WorldSID. Shoulder test 4 was excluded because the padding is not available. Tests conducted included one pendulum impact and two sled tests. As recommended by the WorldSID task group, shoulder tests 2 and 3 were performed with the arm at 45° with respect to the ground. The shoulder tests 1 through 3 data are given in Annex C.

B.3.4.2 Shoulder test 1

Shoulder test 1, defined in ISO/TR 9790, involves pendulum impacts using a 23,4-kg cylindrical pendulum with a 150-mm circular impact face at 4,5 m/s. Targets are given for the impactor force/time history and the maximum shoulder deflection.

The biofidelity rating for shoulder test 1 is 10,0.

B.3.4.3 Shoulder test 2

Shoulder test 2, defined in ISO/TR 9790, is the 7,2g sled test configuration described under neck test 1. targets are given for peak horizontal T1 acceleration and peak horizontal T1 displacement.

The biofidelity rating for shoulder test 2 is 10,0.

B.3.4.4 Shoulder test 3

Shoulder test 3, defined in ISO/TR 9790, is the 12,2g sled test configuration described under neck test 3. Targets are given for T1 accelerations.

The biofidelity rating for shoulder test 3 is 10,0.

B.3.4.5 Overall shoulder biofidelity rating

The overall biofidelity ratings of the WorldSID shoulder are given in Table B.5.

Table B.5 — Overall shoulder biofidelity

	j	$V_{3,j}$	$R_{3,j}$
Shoulder test 1	1	6	10,0
Shoulder test 2	2	5	10,0
Shoulder test 3	3	3	10,0
Shoulder biofidelity rating B_3		10,0	

B.3.5 Thorax

B.3.5.1 General

Four different tests were performed on the WorldSID thorax to determine the thorax biofidelity rating. These tests included two pendulum tests, a drop test, and one sled test. Thorax tests 4 and 6 were not conducted because the required padding is no longer available. As recommended by the WorldSID task group, 10 of the 13 tests of thorax test 5 were performed with the arm at 45° with respect to the ground while the remaining three runs were inadvertently performed with the arm at 45° with respect to the torso. The data are given in Annex C.

B.3.5.2 Thorax test 1

Thorax test 1, defined in ISO/TR 9790, is a pendulum test in which a 23,4 kg, rigid impactor with a diameter of 150 mm impacts the thoracic ribs at 4,3 m/s, with the arms in a horizontal position. Targets are given for the pendulum force and upper spine lateral acceleration.

The biofidelity rating for thorax test 1 is 7,8.

B.3.5.3 Thorax test 2

Thorax test 2 is the same configuration as thorax test 1 except that the impact speed is 6,7 m/s. Targets are only given for the pendulum impact force.

The biofidelity rating for thorax test 2 is 10,0.

B.3.5.4 Thorax test 3

Thorax test 3, defined in ISO/TR 9790, consists of dropping the dummy laterally from a height of 1 m onto a continuous, rigid plate which spans the shoulder, thorax, and abdomen regions, with a separate plate for the pelvis region. The arm is rotated 20° forward of the dummy's thoracic spine. Targets are given for the thoracic plate force and peak rib deflection.

The biofidelity rating for thorax test 3 is 8,3.

B.3.5.5 Thorax test 5

Thorax test 5, defined in ISO/TR 9790, requires a Heidelberg-type sled impact that creates a differential velocity of 6,8 m/s between the dummy and a rigid wall. Targets are given for the thorax plate force, peak lateral upper spine acceleration, peak lateral lower spine acceleration, and peak lateral acceleration of the impacted rib.

The biofidelity rating for thorax test 5 is 6,4.

B.3.5.6 Overall thorax biofidelity rating

The overall biofidelity ratings of the WorldSID thorax are given in Table B.6.

Table B.6 — Summary of thorax biofidelity ratings

	j	$V_{4,j}$	$R_{4,j}$
Thorax test 1	1	9	7,8
Thorax test 2	2	9	10,0
Thorax test 3	3	6	8,3
Thorax test 5	5	7	6,4
Thorax biofidelity rating B_4		8,2	

B.3.6 Abdomen

B.3.6.1 General

To determine the overall abdomen biofidelity of the WorldSID, two different abdominal tests were performed. These tests consist of one drop test and one sled test. Abdomen tests 2 and 4 were not conducted due to the severity of the tests which caused the dummy's ribs to bottom out and invalidate the required data. Abdomen test 5 was not conducted because the padding is not available. As recommended by the WorldSID task group, six of the nine abdomen test 3 runs were performed with the arm at 45° with respect to the ground while the remaining three runs were inadvertently performed with the arm at 45° with respect to the torso. The data are given in Annex C.

B.3.6.2 Abdomen test 1

Abdomen test 1, defined in ISO/TR 9790, is a lateral drop test from a height of 1 m onto a simulated armrest, which protrudes 41 mm above a continuous, rigid plate. One plate spans the shoulder and thorax regions, with a separate plate for the pelvis region. Targets are given for the armrest force, peak lower spine acceleration, peak impacted rib acceleration, and peak abdominal penetration.

The biofidelity rating for abdomen test 1 is 9,0.

B.3.6.3   Abdomen test 3

Abdomen test 3, defined in ISO/TR 9790, is a WSU-type sled impact that creates a differential velocity of 6,8 m/s between the dummy and a rigid wall. The dummy is seated on the sled with its arm at 45° forward from the vertical. A target is given for the abdominal plate force.

The biofidelity rating for abdomen test 3 is 8,9.

B.3.6.4   Overall abdomen biofidelity rating

The overall biofidelity ratings of the WorldSID abdomen are given in Table B.7.

Table B.7 — Summary of abdomen biofidelity ratings

	j	$V_{5,j}$	$R_{3,j}$
Abdomen test 1	1	7	9,0
Abdomen test 3	3	3	8,9
Abdomen biofidelity rating B_5			9,0

B.3.7   Pelvis

B.3.7.1   General

Six out of 13 ISO/TR 9790 pelvis tests were conducted with the WorldSID. Pelvis tests 5, 6, 9, 12, and 13 were not conducted, as the padding was unavailable. Pelvis tests 8 and 11 were not conducted due to the severity of the tests. For pelvis test 7, 10 of the 13 tests were performed with the arm at 45° with respect to the ground while the remaining runs were inadvertently performed with the arm at 45° with respect to the torso. For pelvis test 10, 6 of the 10 tests were performed with the arm at 45° with respect to the ground while the remaining runs were inadvertently performed with the arm at 45° with respect to the torso. The data are given in Annex C.

B.3.7.2   Pelvis test 1

Pelvis test 1, defined in ISO/TR 9790, involves a rigid pendulum impact at 6 m/s. The impactor is defined as a 17,3 kg rigid impactor with a 600 mm radius of curvature and an outer diameter of 127 mm. A target is given for the pendulum force.

The biofidelity rating for pelvis test 1 is 10,0.

B.3.7.3   Pelvis test 2

Pelvis test 2 configuration is equivalent to pelvis test 1, but with an impact speed of 10 m/s. A target is given for the pendulum force.

The biofidelity rating for pelvis test 2 is 5,0.

B.3.7.4   Pelvis test 3

Pelvis test 3, defined in ISO/TR 9790, consists of dropping the dummy laterally from a height of 0,5 m onto a continuous, rigid plate which spans the shoulder, thorax, and abdomen regions, with a separate plate for the pelvis region. The arm is rotated 20° forward of the dummy's thoracic spine. A target is given for the peak pelvic acceleration.

The biofidelity rating for pelvis test 3 is 5,0.

B.3.7.5 Pelvis test 4

Pelvis test 4 is the same as pelvis test 3, but with a drop height of 1 m. A target is given for the peak pelvis acceleration.

The biofidelity rating for pelvis test 4 is 0,0.

B.3.7.6 Pelvis test 7

Pelvis test 7, defined in ISO/TR 9790, requires a Heidelberg-type sled impact that creates a differential velocity of 6,8 m/s between the dummy and a rigid wall. Targets are given for the peak pelvic force and the peak pelvic acceleration.

The biofidelity rating for pelvis test 7 is 3,9.

B.3.7.7 Pelvis test 10

Pelvis test 10, defined in ISO/TR 9790, requires a WSU-type sled impact that creates a differential velocity of 6,8 m/s between the dummy and a rigid wall. Targets are given for the pelvic plate force and the peak lateral pelvic acceleration.

The biofidelity rating for pelvis test 10 is 3,1.

B.3.7.8 Overall pelvis biofidelity rating

The overall biofidelity ratings of the WorldSID pelvis are given in Table B.8.

Table B.8 — Overall pelvis biofidelity

	j	$V_{6,j}$	$R_{6,j}$
Pelvis test 1	1	8	10,0
Pelvis test 2	2	9	5,0
Pelvis test 3	3	4	5,0
Pelvis test 4	4	4	0,0
Pelvis test 7	7	8	3,9
Pelvis test 10	10	3	3,1
Pelvis biofidelity rating B_6			5,1

B.3.8 Overall dummy

The overall biofidelity rating of the WorldSID is given in Table B.9.

Table B.9 — Overall WorldSID biofidelity ratings

Region	Weighting	Rating
Head	7	10,0
Neck	6	5,4
Shoulder	5	10,0
Thorax	10	8,2
Abdomen	8	9,0
Pelvis	8	5,1
Overall		7,9

B.4 Available instrumentation

B.4.1 General

The instrumentation that is compatible with the WorldSID and that was available at the time of its launch in 2004 is described in Reference [38] and Reference [33]. All sensors were specified as being "permissible" in order to allow for variations as may be required by different regulatory, consumer information, test facility, laboratory, and research applications. The permissible and compatible sensors are described subsequently by body region. Normative mechanical specifications for permissible sensors are given in ISO 15830-3.

A summary of permissible instrumentation units by body region for the May 2015 version of WorldSID is given in Table B.10.

In addition, a permissible, modular data acquisition system comprising up to five 32-channel digital recording units (i.e. up to 160 recorder channels) was available and can be housed at various specified locations in the dummy.

Since all WorldSID sensors and the DAS are "permissible" (i.e. optional), the baseline configuration of the WorldSID is specified with either a "mass replacement" or a "structural replacement" for each of these units, the latter being provided for load bearing sensors. This was done so that the specified mass and structural continuity of the overall dummy and all dummy subassemblies are maintained regardless of which sensors are selected for a given application.

Table B.10 — Summary of permissible instrumentation units for May 2015 version of WorldSID

Body region	Number	Instrumentation units
Head	2	Tilt sensors
	1	Tri-axial linear accelerometer at CG
	3	Angular accelerometers or ARS
	1	Upper neck load cell
Neck	1	Lower neck load cell
	1	T1 tri-axial accelerometer
Upper torso	6	Deflection sensors
	6	Tri-axial rib accelerometers
	1	Shoulder load cell
	2	Angular accelerometers or ARS
	1	T4 tri-axial linear accelerometer
	1	T12 tri-axial linear accelerometer
	1	Temperature sensor
	2	Tilt sensors
	3	DAS modules
Full arm (per full arm)	1	Arm load cell
	1	Forearm load cell
	1	Tri-axial elbow linear accelerometer
	1	Tri-axial wrist accelerometer
	1	Elbow rotation sensor
	1	Elbow load cell

Table B.10 *(continued)*

Body region	Number	Instrumentation units
Lower torso	1	Lower lumbar spine load cell
	1	Sacroiliac load cell module
	1	Pubic symphysis load cell
	1	Tri-axial linear accelerometer
	2	Tilt sensors
	3	Angular accelerometers or ARS
Lower extremities	1	Femur load cell
(per lower extremity)	1	Femur neck load cell
	2	Knee load cells
	1	Knee rotation sensor
	2	DAS modules
	1	Upper tibia load cell
	1	Lower tibia load cell

B.4.2   Head

The head instrumentation core inserts from the base of the head and is secured by a bolt that is inserted through the top of the head. This method of instrumentation mounting and access avoids a vertical seam in the skull element, which could confound interactions with vehicle interior surfaces and airbags. The head instrumentation, mounted on the core, consists of a tri-axial accelerometer located at the head centre of gravity, three angular accelerometers or ARS, also located at the head centre of gravity, and two tilt sensors. The tilt sensors are static devices and are intended to be used for proper positioning of the head prior to testing. A six-axis load cell mounts between the base of the head and the upper neck.

B.4.3   Neck

The neck instrumentation consists of one six-axis load cell and a tri-axial accelerometer at T1. The lower neck load cell mounts to the neck adjustment bracket.

B.4.4   Upper torso

B.4.4.1   Shoulder

The shoulder rib is instrumented with a sensor to measure deflection and a tri-axial accelerometer. A shoulder load cell is located on the impacted side of the dummy where it can measure loads along three axes: F_x, F_y, and F_z.

B.4.4.2   Ribs

Each thoracic and abdominal rib is instrumented with tri-axial accelerometers on the inside of the rib at its most lateral point. Each rib can also be equipped with a sensor to measure deflection.

B.4.4.3   Thoracic spine

Tri-axial accelerometers are located in the proximity of the T4 and T12 locations along the spine box. Two angular accelerometers or ARS are mounted on the spine box, measuring about the x and z axes. Two tilt sensors are mounted to the spine box to measure pre-test orientations of the spine box about the x and y axes. In addition, three DAS unit replacements are mounted in the spine box of the WorldSID upper torso.

B.4.5 Full arm

The full arm has six-axis upper and lower arm load cells, a two-axis elbow load cell (M_x, M_y), an elbow rotary potentiometer, and tri-axial accelerometers adjacent to the elbow and wrist joints.

B.4.6 Lower torso

B.4.6.1 Lumbar spine

In order to meet packaging constraints, the six-channel lumbar load cell nests inside the 12-channel sacroiliac load cell.

B.4.6.2 Pelvis

The pelvis has a tri-axial accelerometer mounted at its centre of gravity. A single-channel pubic symphysis load cell connects both sides of the pubic bone. The pelvis also contains a 12-channel sacroiliac load cell (6 left side and 6 right side channels) and left and right femoral neck load cells (3 left side and 3 right side channels). The pelvis also includes two tilt sensors that are to be used for pre-test pelvis positioning.

B.4.7 Lower extremities

Each leg is instrumented with "universal" six-axis leg load cells. "Universal" denotes that each load cell was designed to be mounted at various locations within the leg assembly. These load cells can be located in the femur, upper tibia, and lower tibia. The knees have rotary potentiometers and single-axis load cells located at the inboard and outboard side of each knee measuring lateral loads. In addition, one 32-channel DAS system can be included in each upper leg.

B.5 Repeatability and reproducibility performance

B.5.1 General

A series of tests was performed for the purpose of assessing the repeatability of the WorldSID (May 2005 version). Analysis was performed using the coefficient of variation (CV) as a figure of merit. The CV is defined as the standard deviation of the samples divided by the sample mean and is expressed as a percentage. Responses which have a CV of 3 % or less, are commonly considered as having an excellent level of repeatability, while a value of 10 % and above is considered to have a poor level of repeatability.

Production dummy test results which follow include a combination of repeat tests performed on the same part (repeatability) and tests performed on different parts (reproducibility). The CV values from these tests should be considered as general indications of the WorldSID repeatability and reproducibility.

B.5.2 Head

The validation tests performed on WorldSID (May 2005 version) heads are described in ISO 15830-2:2013, 5.1. The data from these tests are given Annex D. The results are given in Table B.11.

Table B.11 — Head test results

Response measurements	CV (%)
Lateral drop peak resultant CG acceleration	5,6
Frontal drop peak resultant CG acceleration	4,3

B.5.3   Neck

The validation tests performed on WorldSID (May 2005 version) necks are described in ISO 15830-2:2013, 5.2. The data from these tests are given in Annex D. The results are given in Table B.12.

Table B.12 — Neck test results

Response measurements	CV (%)
Peak flexion angle	4,1
Peak M_x	4,7

B.5.4   Shoulder

The validation tests performed on the WorldSID (May 2005 version) shoulder are described in ISO 15830-2:2013, 5.3.2. The data from these tests are given in Annex D. The results are given in Table B.13.

Table B.13 — Shoulder test results

Response measurements	CV (%)
Pendulum force	4,2
Peak shoulder deflection	4,9

B.5.5   Thorax

B.5.5.1   General

The validation tests performed on the WorldSID (May 2005 version) thorax are described in ISO 15830-2:2013, 5.3.3 and 5.3.4. The data from these tests are given in Annex D. The results are given in Table B.14 and Table B.15.

B.5.5.2   Thorax with arm

The thorax with arm test described in ISO 15830-2:2013, 5.3.3 is no longer specified. These data given in Table B.14 are provided for historical purposes.

Table B.14 — Thorax with arm test results

Response measurements	CV (%)
Pendulum force	4,1
Upper spine T4 lateral acceleration	6,7
Lower spine T12 lateral acceleration	5,6
Thorax rib 1 deflection	7,0
Thorax rib 2 deflection	4,3
Thorax rib 3 deflection	4,0

B.5.5.3   Thorax without arm

Table B.15 — Thorax without arm test results

Response measurements	CV (%)
Pendulum force	4,7
Upper spine T4 lateral acceleration	8,1
Lower spine T12 lateral acceleration	10,7

Table B.15 *(continued)*

Response measurements	CV (%)
Thorax rib 1 deflection	6,4
Thorax rib 2 deflection	4,6
Thorax rib 3 deflection	5,5

B.5.6   Abdomen

The validation tests performed on the WorldSID (May 2005 version) abdomen are described in ISO 15830-2:2013, 5.3.5. The data from these tests are given in Annex D. The results are given in Table B.16.

Table B.16 — Abdomen test results

Response measurements	CV (%)
Pendulum force	3,9
Peak acceleration of the lower spine T12	6,3
Abdomen rib 1 deflection	3,9
Abdomen rib 2 deflection	4,4

B.5.7   Pelvis

The validation tests performed on the WorldSID (May 2005 version) pelvis are described in ISO 15830-2:2013, 5.3.6. The data from these tests are given in Annex D. The results are given in Table B.17.

Table B.17 — Pelvis test results

Response measurements	CV (%)
Pendulum force	5,5
Pelvis acceleration	6,5

B.6   Durability performance

The WorldSID durability was evaluated by means of detailed inspections of components following prescribed biofidelity and verification tests. The head, neck, thorax, and pelvis were each subjected to a minimum of 10 tests over the full range of severity not exceeding 150 % of the IARVs (i.e. as given in Reference [31]). No damage was observed to any of the components or the associated instrumentation.

Permanent deformation of the shoulder rib and accompanying IR-TRACC damage was observed as a result of the 8,9 m/s rigid wall sled test and the 2-m body drop test. These test conditions are extremely severe and caused excessive stroking of several ribs and bottoming out the IR-TRACCs. While these conditions were considered to be in excess of 150 % of the IARVs, structural reinforcement in the form of a rib doubler was added to the outer shoulder rib to further improve durability.

Numerous full-scale pole and MDB tests were carried out with WorldSID in the driver and/or rear passenger struck-side position. Dummy responses ranged from below the IARVs to three times the IARVs or the maximum measurement range. No damage was observed during visual inspections of the head, neck, thorax, pelvis, or legs, indicating excellent durability.

Some rib damping material cracks and debonding were reported in 2007. Analysis linked the problems to a particular batch of damping material. This problem prompted the task group to locate a new supplier of damping material and review the overall design. The new damping material and rib design have good durability.

B.7 Robustness performance

As required, the WorldSID production design consists of continuous surfaces, including a neck shroud, integrated shoes, and clothing. No targeting problems were reported by any test laboratories.

The WorldSID was subjected to a wide variety of test types including oblique sled impacts up to 30° from lateral and no binding of ribs or other flexible dummy components was observed. In addition, overall good repeatability in sled testing was observed indicating that the dummy is not overly sensitive to the small changes in impact angles which are a part of test-to-test setup variability. Overall, the dummy is not overly sensitive to small changes in impact angles but the responses do change in response to gradually increasing changes in impact angles.

A temperature sensitivity study was conducted to assess the influence of temperature variations on the performance of the shoulder, thorax, abdomen, and pelvis. The results indicated that the rib deflection measurements were insensitive to temperature in the temperature range from 20,6 °C to 22,2 °C. Thus, the use of the WorldSID in a temperature range from 20,6 °C to 22,2 °C is recommended.

B.8 Handling performance

WorldSID was designed with ease of handling being a key requirement. WorldSID was designed to have a high level of integration with the permissible instrumentation, which enhances its overall handling. It is also provided with user manuals, which provide detailed instructions for disassembling and assembling the dummy. A lifting bar which is used for dummy transfer, positioning, and storage is included in the dummy design. This feature provides further enhancement of dummy handling.

B.9 Verification, calibration, and validation performance

Validation requirements and test procedures for the head, neck, shoulder, thorax, abdomen and pelvis are described in ISO 15830-2. The procedures were developed to harmonize to the extent possible with existing dummy validation procedures.

Test fixtures required for the validation procedures are predominantly universal and common to other ATDs. Equipment unique to WorldSID is listed in ISO 15830-2. The validation bench, which was originally unique to WorldSID, was designed to facilitate and improve the repeatability of dummy positioning. The bench has since been adopted for use in validation testing of the SID-IIs 5th percentile adult female side impact dummy.

Annex C
(informative)

Biofidelity test data (May 2005 version)

C.1 General

The biofidelity response is based on the WorldSID (May 2005 version). Corrections from the prior editions are noted.

C.2 Head

The biofidelity rating for head test 1 resultant acceleration is 10 for both sides of the head. See Figure C.1 for the right side impact and Figure C.2 for the left side impact.
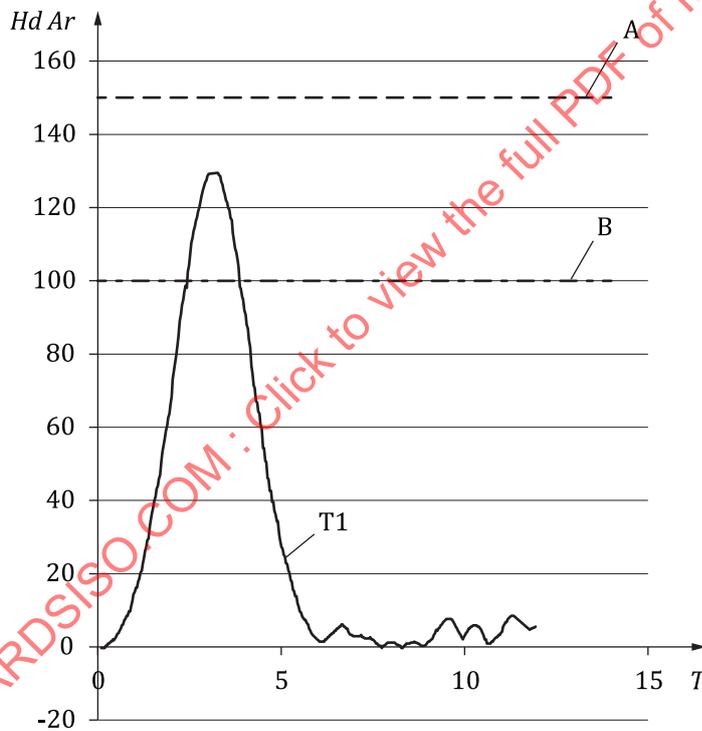
Key

T time (ms)

Hd Ar   acceleration of non-impact side of head (g)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   test number W009-PRSH-2

Figure C.1 — Head test 1 - 200 mm lateral head drop (right side) - resultant acceleration
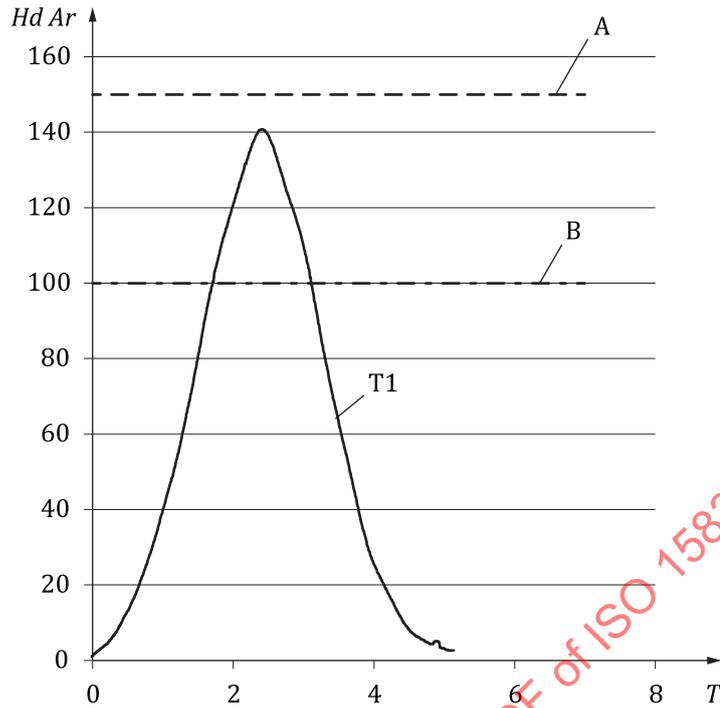
Key

T   time (ms)

Hd Ar   acceleration of non-impact side of head (*g*)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   left side impact

Figure C.2 — Head test 1 - 200 mm lateral head drop (left side) - resultant acceleration

The biofidelity rating for head is summarized in Table C.1.

Table C.1 — Head test 1 - 200 mm rigid lateral test results

Measure	Lower bound	Upper bound	Run #1	Weight factor	Rating
Peak resultant acceleration at a point on the non-impacted side of the head, left impact (*g*)	100	150	141	9	10,0
Rating			10		
Peak resultant acceleration at a point on the non-impacted side of the head, right impact (*g*)	100	150	129	9	
Rating			10		

C.3   Neck

C.3.1   Neck test 1 – 7,2*g* sled test

The biofidelity rating for neck test 1, peak lateral T1 acceleration was 10 for all tests. See Figure C.3.

Key

T	time (ms)
T1 *A*y	T1 lateral acceleration (*g*)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure C.3 — Neck test 1 - 7,2*g* sled - peak lateral T1 acceleration

The biofidelity rating for neck test 1, peak lateral T1 displacement relative to sled was 10 for all tests. See Figure C.4.
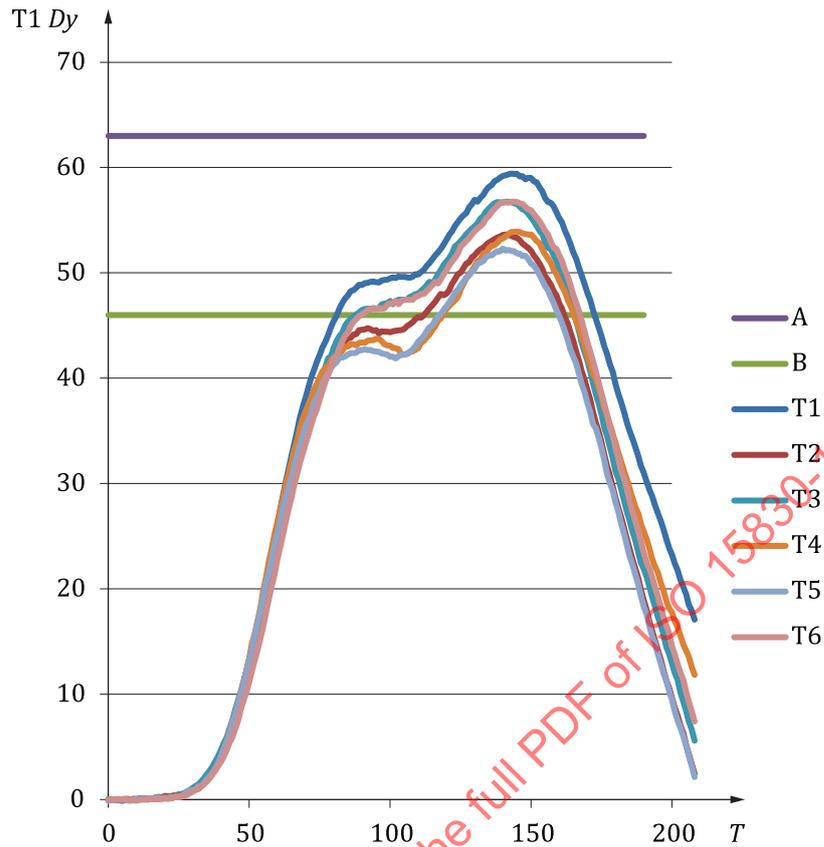
Key

T	time (ms)
T1 Dy	T1 lateral displacement with respect to sled (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

**Figure C.4 — Neck test 1 – 7,2*g* sled – peak lateral T1 displacement relative to sled**

The biofidelity rating for neck test 1, peak lateral head CG displacement relative to T1 was 5 for four tests and 10 for two tests. See Figure C.5.
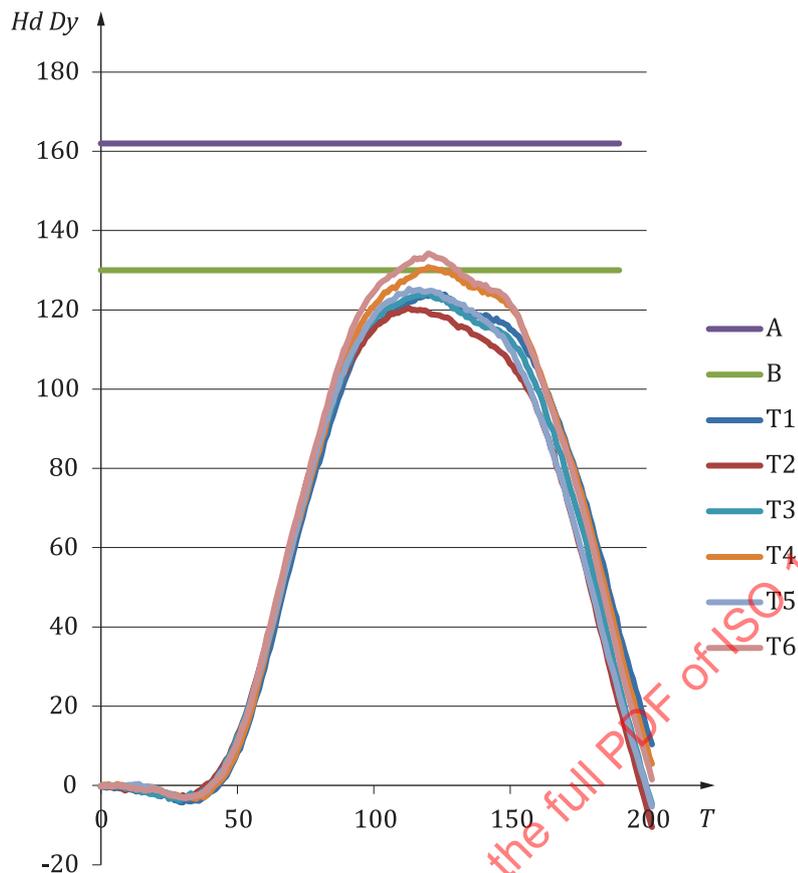
Key

T	time (ms)
$Hd\ Dy$	head lateral displacement with respect to T1 (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

**Figure C.5 — Neck test 1 - 7,2*g* sled - peak lateral head CG displacement relative to T1**

The biofidelity rating for neck test 1, peak vertical head CG displacement relative to T1 was 5 for four tests and 10 for two tests. See Figure C.6.
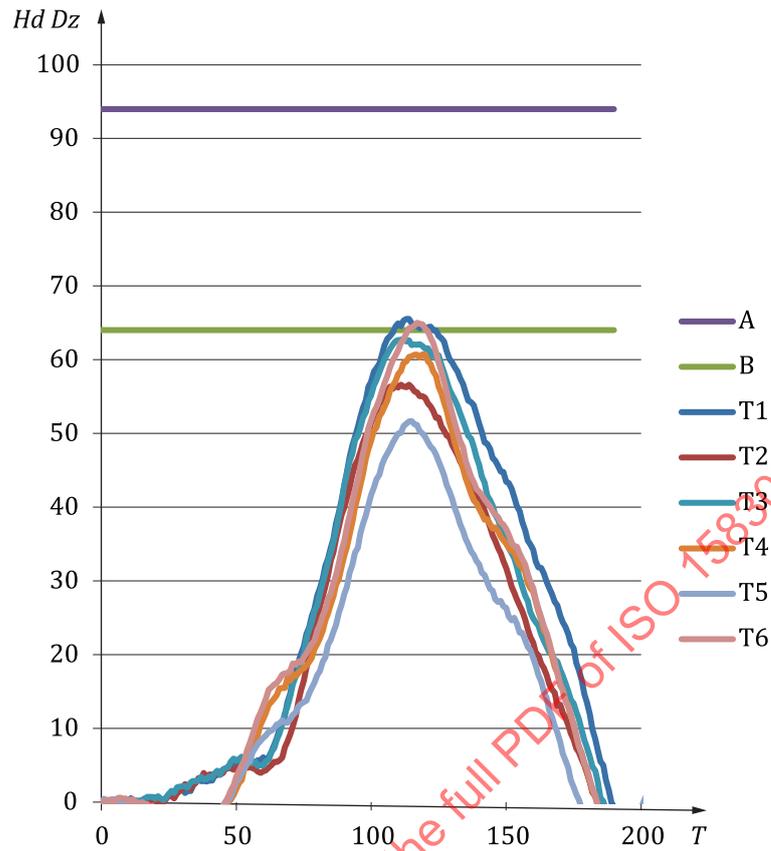
Key

T	time (ms)
Hd Dz	head vertical displacement with respect to T1 (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure C.6 — Neck test 1 - 7,2*g* sled - peak vertical head CG displacement relative to T1

The biofidelity rating for neck test 1, peak head lateral acceleration was 5 for three tests and 10 for three tests. See Figure C.7.
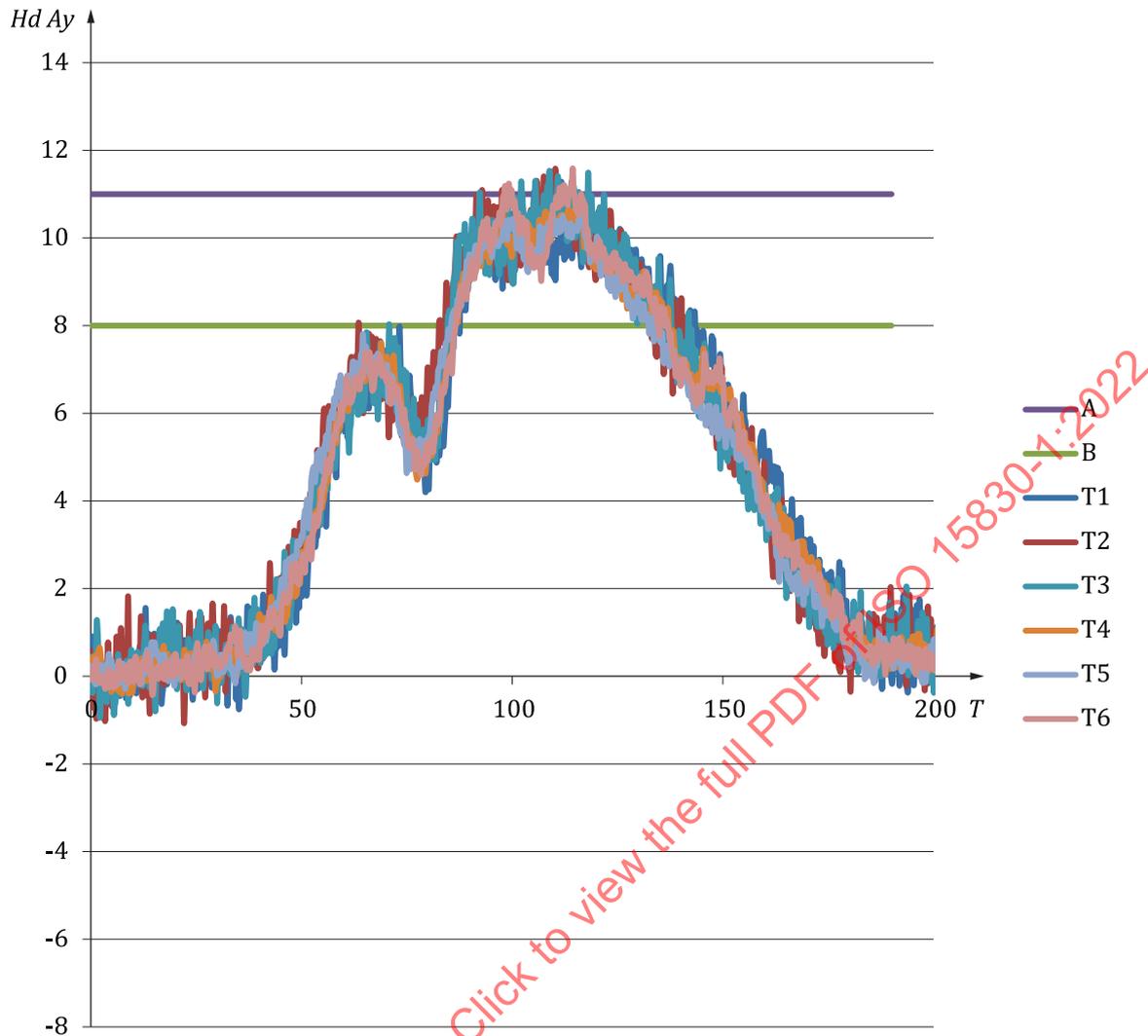
Key

T	time (ms)
Hd Ay	head lateral acceleration (*g*)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure C.7 — Neck test 1 - 7,2*g* sled - peak head lateral acceleration

The biofidelity rating for neck test 1, peak head vertical acceleration was 10 for all tests. See Figure C.8.
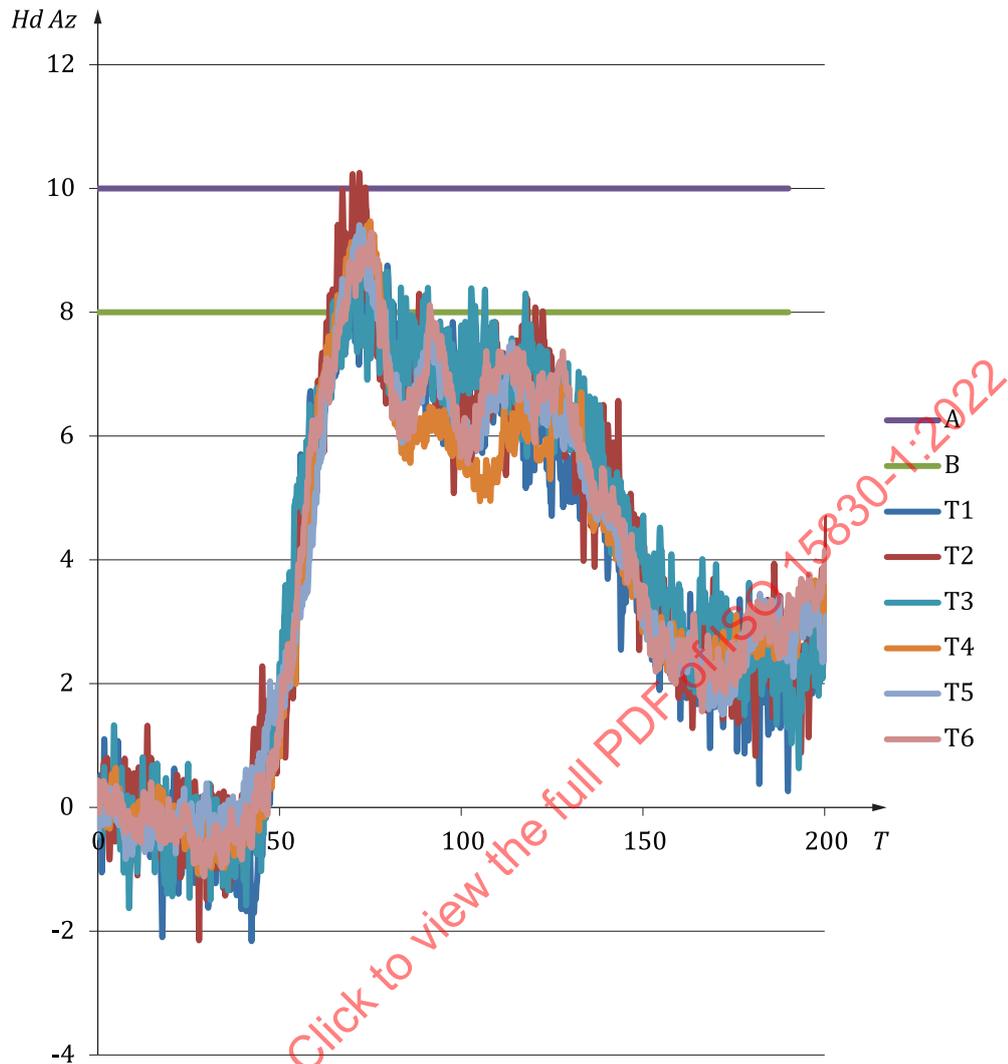
Key

T	time (ms)
Hd Az	head vertical acceleration (*g*)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure C.8 — Neck test 1 - 7,2*g* sled - peak head vertical acceleration

The biofidelity rating for neck test 1, peak flexion angle was 10 for all tests. See Figure C.9.
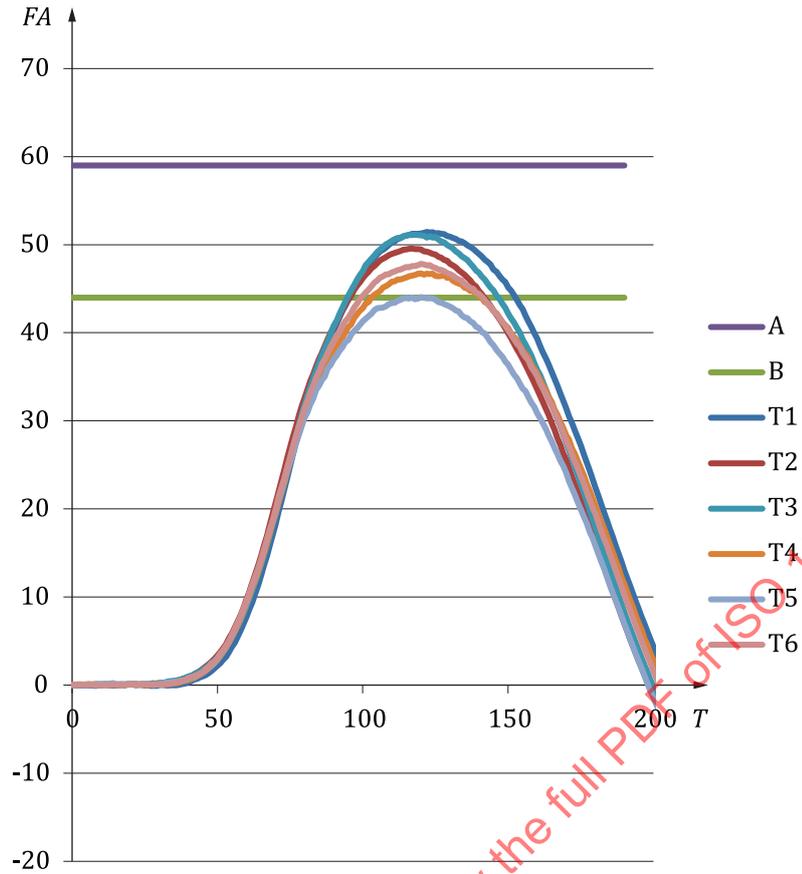
Key

T — time (ms)

FA — flexion angle (°)

A — ISO/TR 9790 upper corridor

B — ISO/TR 9790 lower corridor

T1 — test number WSID1-70423-1

T2 — test number WSID1-70424-1

T3 — test number WSID1-70424-2

T4 — test number WSID2-70423-1

T5 — test number WSID2-70424-1

T6 — test number WSID2-70424-2

Figure C.9 — Neck test 1 - 7,2*g* sled - peak flexion angle

The biofidelity rating for neck test 1, peak twist angle was 5 for all tests. See Figure C.10.
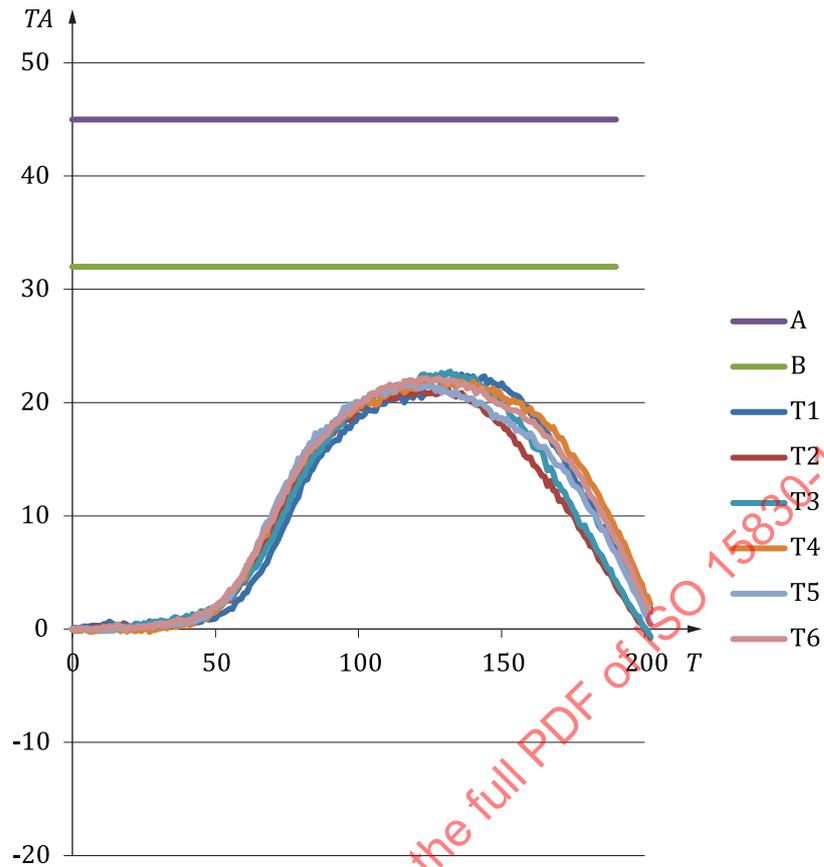
Key

T	time (ms)
TA	twist angle (°)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure C.10 — Neck test 1 - 7,2*g* sled - peak twist angle

The biofidelity rating for neck test 1 is summarized in Table C.2.

Table C.2 — Neck test 1 - 7,2*g* sled test results

Measure	Lower bound	Upper bound	Run						Avg. rating	Weight factor	Rating
			#1	#2	#3	#4	#5	#6			
Horizontal acceleration of T1 (*g*) CFC180	12	18	16	13	13	12	12	12		5	
Rating			10	10	10	10	10	10	10,0		
NOTE All test results, except time of peak head excursion, were rounded to the nearest whole number.											

Table C.2 *(continued)*

Measure	Lower bound	Upper bound	Run						Avg. rating	Weight factor	Rating
			#1	#2	#3	#4	#5	#6			
Horizontal displacement of T1 relative to sled (mm)	46	63	59	54	57	54	52	57		5	
Rating			10	10	10	10	10	10	10,0		
Horizontal displacement of head CG relative to T1 (mm)	130	162	124	121	124	131	125	134		8	
Rating			5	5	5	10	5	10	6,7		
Vertical displacement of head CG relative to T1 (mm)	64	94	66	57	63	61	52	65		6	
Rating			10	5	5	5	5	10	6,7		7,4
Time of peak head excursion (sec)	0,159	0,175	0,122	0,113	0,120	0,120	0,113	0,120		5	
Rating			0	0	0	0	0	0	0,0		
Lateral acceleration of head CG (*g*) CFC1000	8	11	11	12	12	11	11	12		5	
Rating			10	5	5	10	10	5	7,5		
Vertical acceleration of head CG (*g*) CFC1000	8	10	9	10	9	9	9	9		5	
Rating			10	10	10	10	10	10	10,0		
Head flexion angle (°)	44	59	51	50	51	47	44	48		7	
Rating			10	10	10	10	10	10	10,0		
Head twist angle (°)	32	45	22	21	23	22	22	22		4	
Rating			5	5	5	5	5	5	5,0		

NOTE   All test results, except time of peak head excursion, were rounded to the nearest whole number.

C.3.2   Neck test 2 – 6,7*g* sled test

The biofidelity rating for neck test 2, peak A-P bending moment at the occipital condyles was 0 for all tests. See Figure C.11.
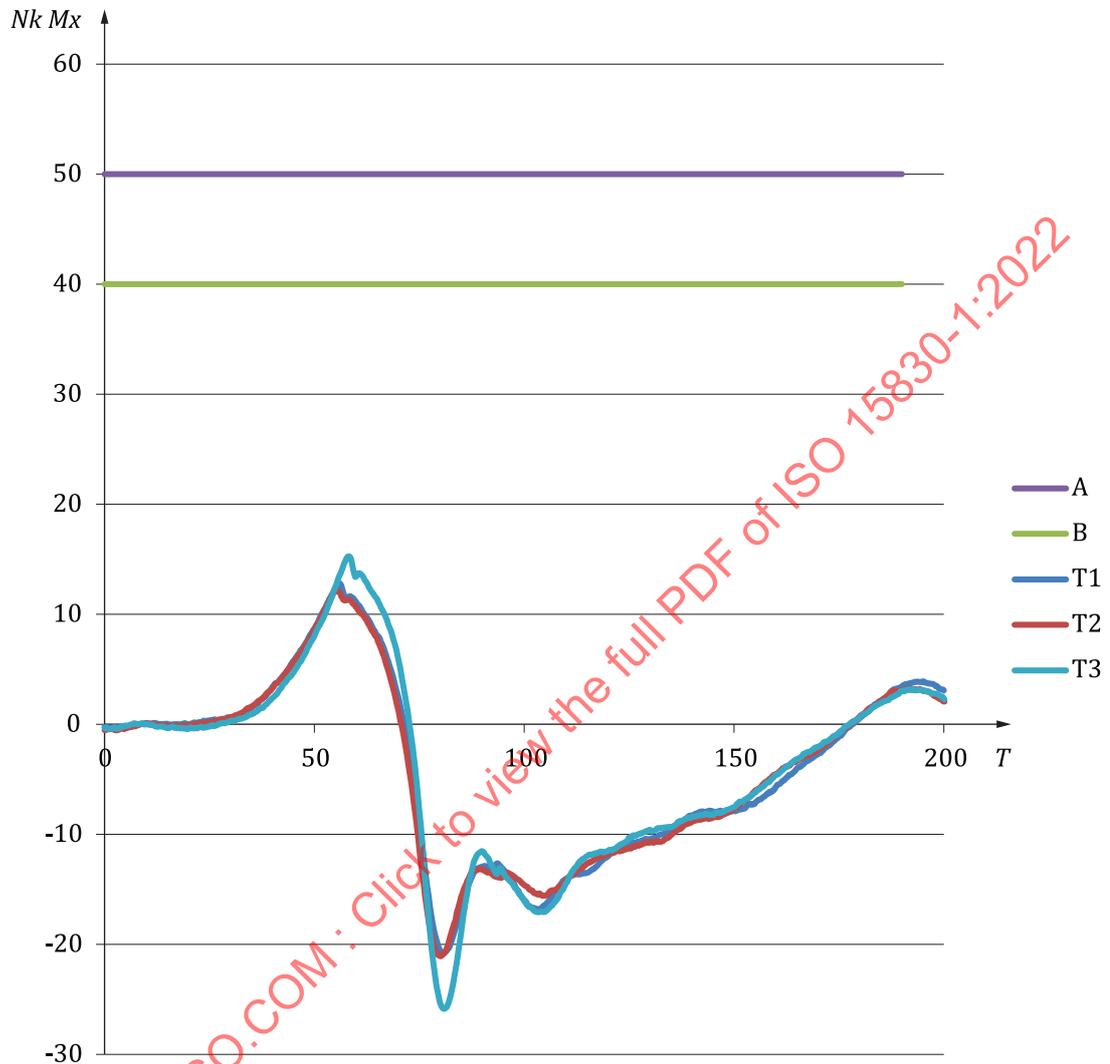
Key

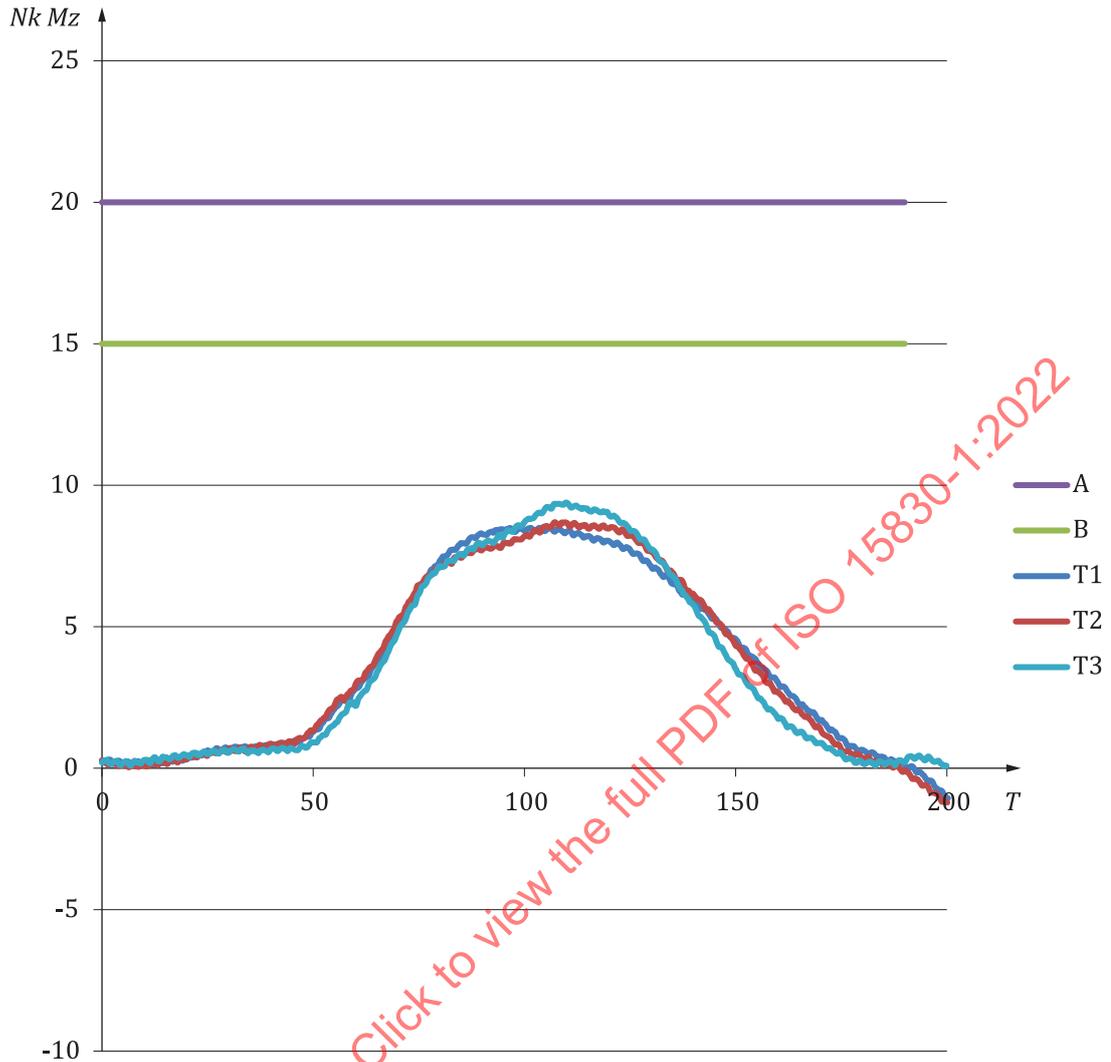|	
T	time (ms)
$Nk\ Mx$	neck OC M_x (Nm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure C.11 — Neck test 2 - 6,7*g* sled - peak bending moment about A-P (M_x) at occipital condyles

The biofidelity rating for neck test 2, peak R-L bending moment at the occipital condyles was 0 for all tests. See Figure C.12.
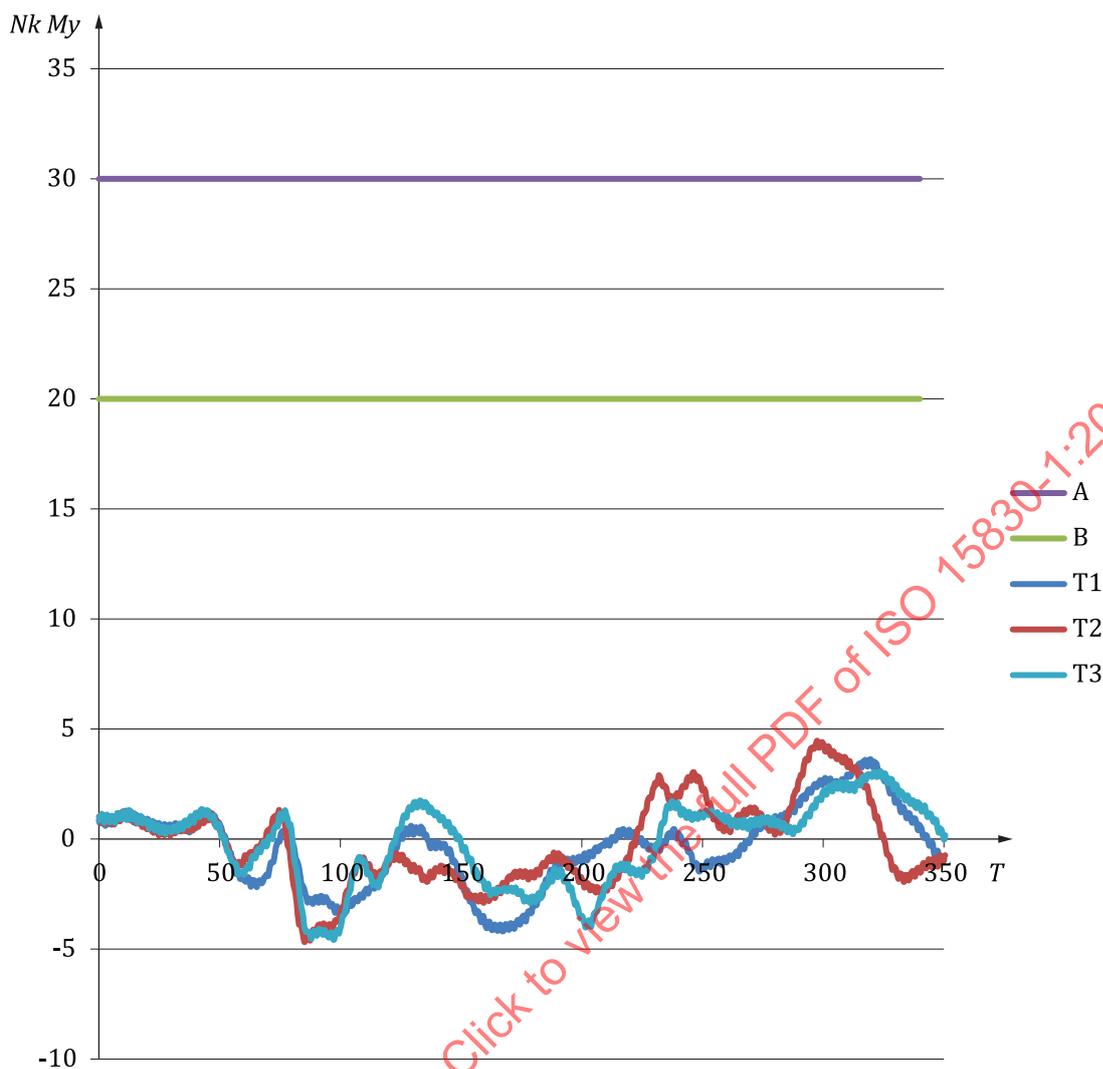
Key

T	time (ms)
$Nk\,My$	neck OC My (Nm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure C.12 — Neck test 2 - 6,7g sled - peak bending moment about R-L (M_y) at occipital condyles

The biofidelity rating for neck test 2, peak neck twist moment was 0 for all tests. See Figure C.13.

Key

T	time (ms)
Nk Mz	upper neck *Mz* (Nm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure C.13 — Neck test 2 - 6,7*g* sled - peak twist moment (M_z)

The biofidelity rating for neck test 2, peak F_y shear force was 0 for all tests. See Figure C.14.
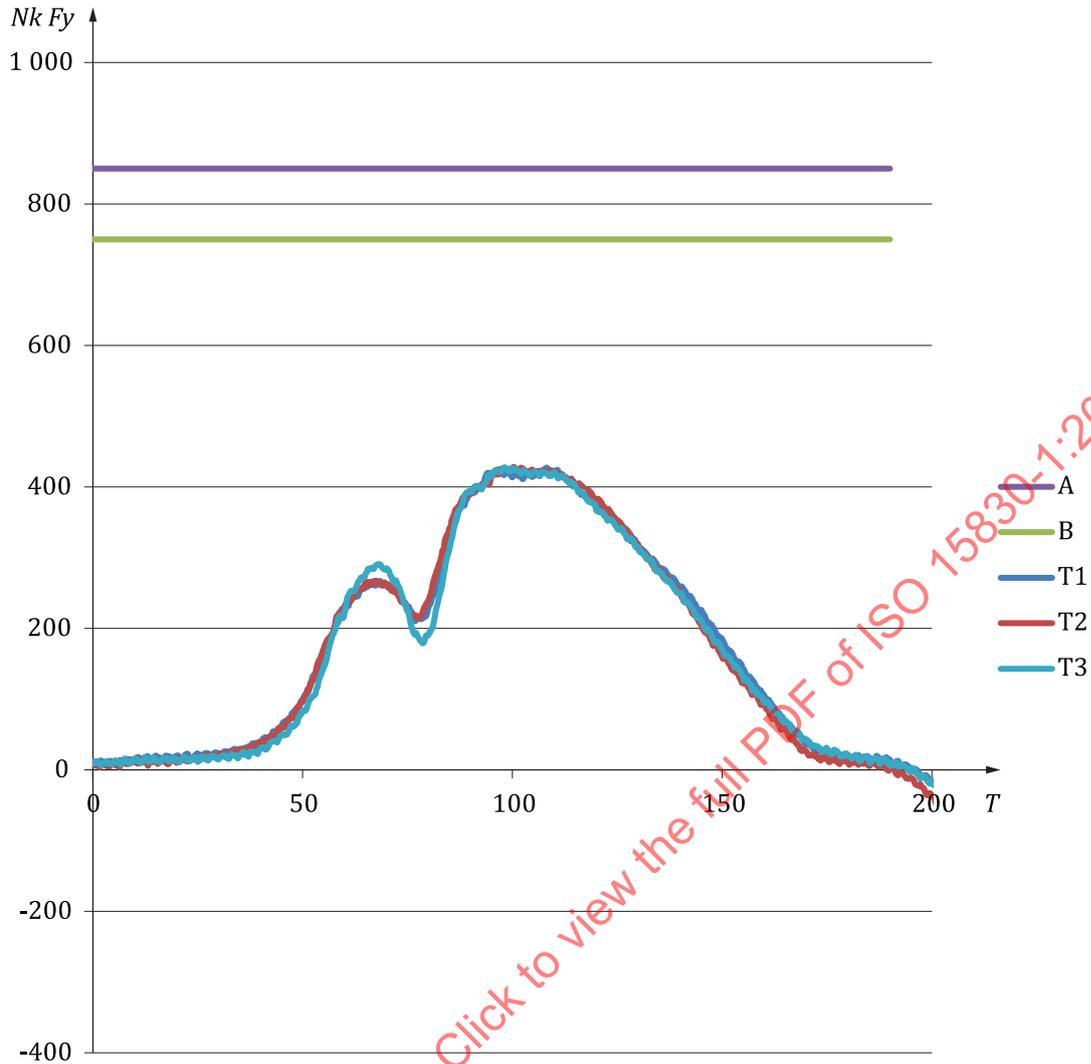
Key

T	time (ms)
$Nk\,Fy$	upper neck Fy (N)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure C.14 — Neck test 2 - 6,7g sled - peak F_y shear force

The neck tension force of all tests had a zero offset that was corrected in Figure C.15. The biofidelity ratings of tests T1 and T3 are unchanged. The biofidelity rating of test T2 changed from 10 to 5. The biofidelity rating for neck test 2, peak F_z tension force was 5 for one test and 10 for two tests. See Figure C.15.
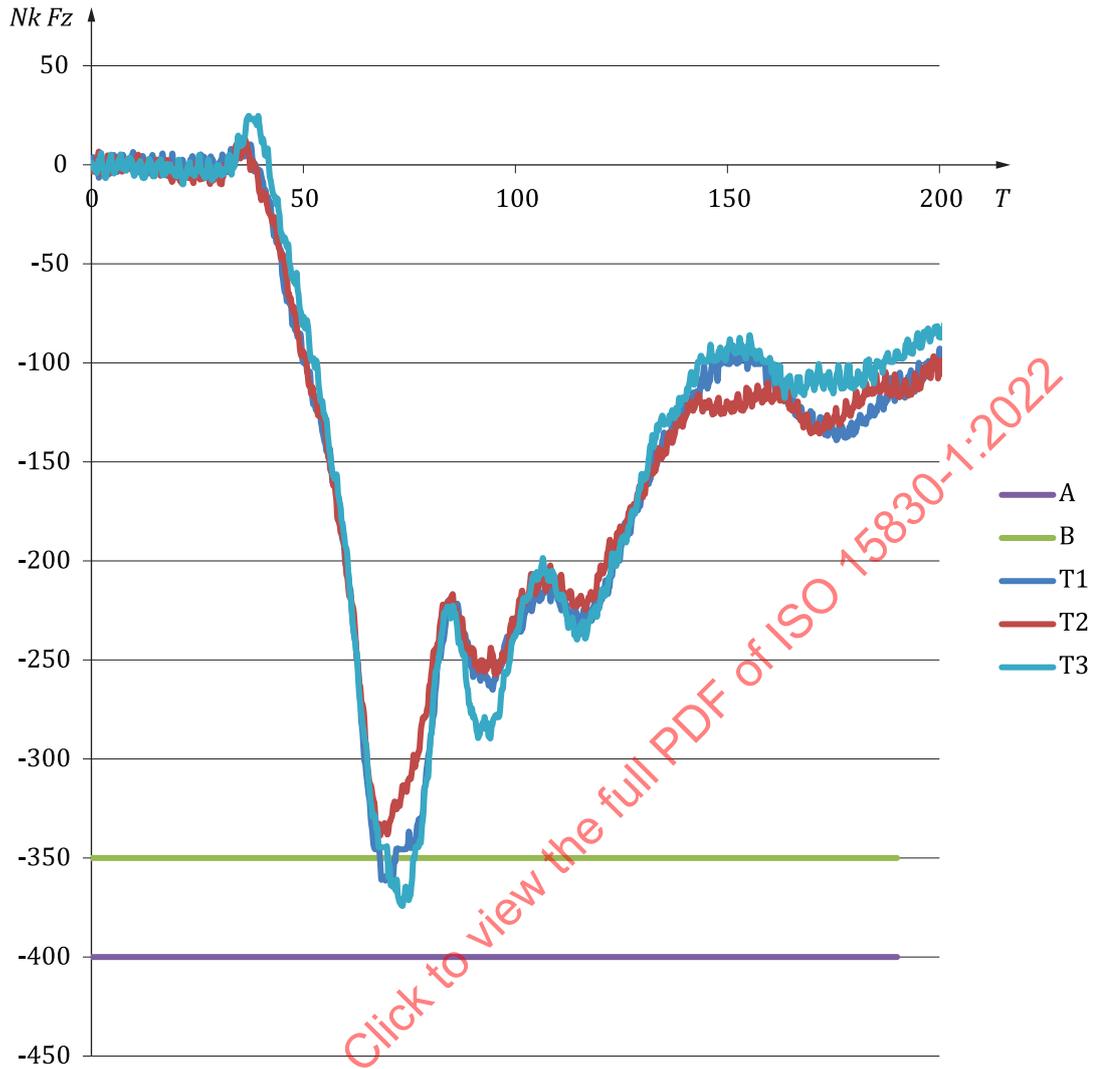
Key

T	time (ms)
Nk Fz	upper neck *Fz* (N)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure C.15 — Neck test 2 - 6,7g sled - peak F_z tension force

The biofidelity rating for neck test 2, peak F_x shear force was 0 for all tests. See Figure C.16.
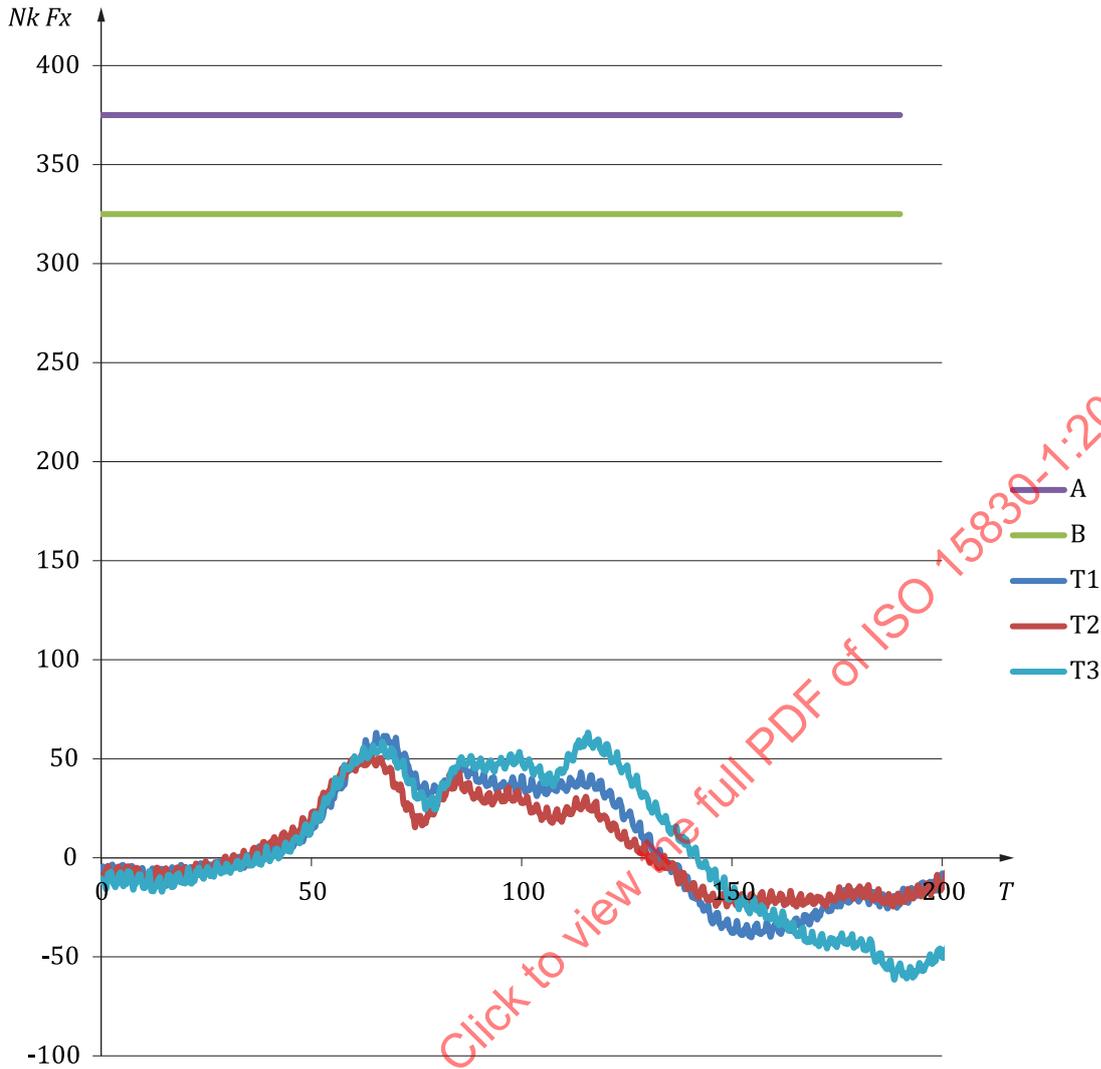
Key

T	time (ms)
$Nk\ Fx$	upper neck Fx (N)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure C.16 — Neck test 2 - 6,7g sled - peak F_x shear force

The biofidelity rating for neck test 2, peak head resultant acceleration was 5 for all tests. See Figure C.17.
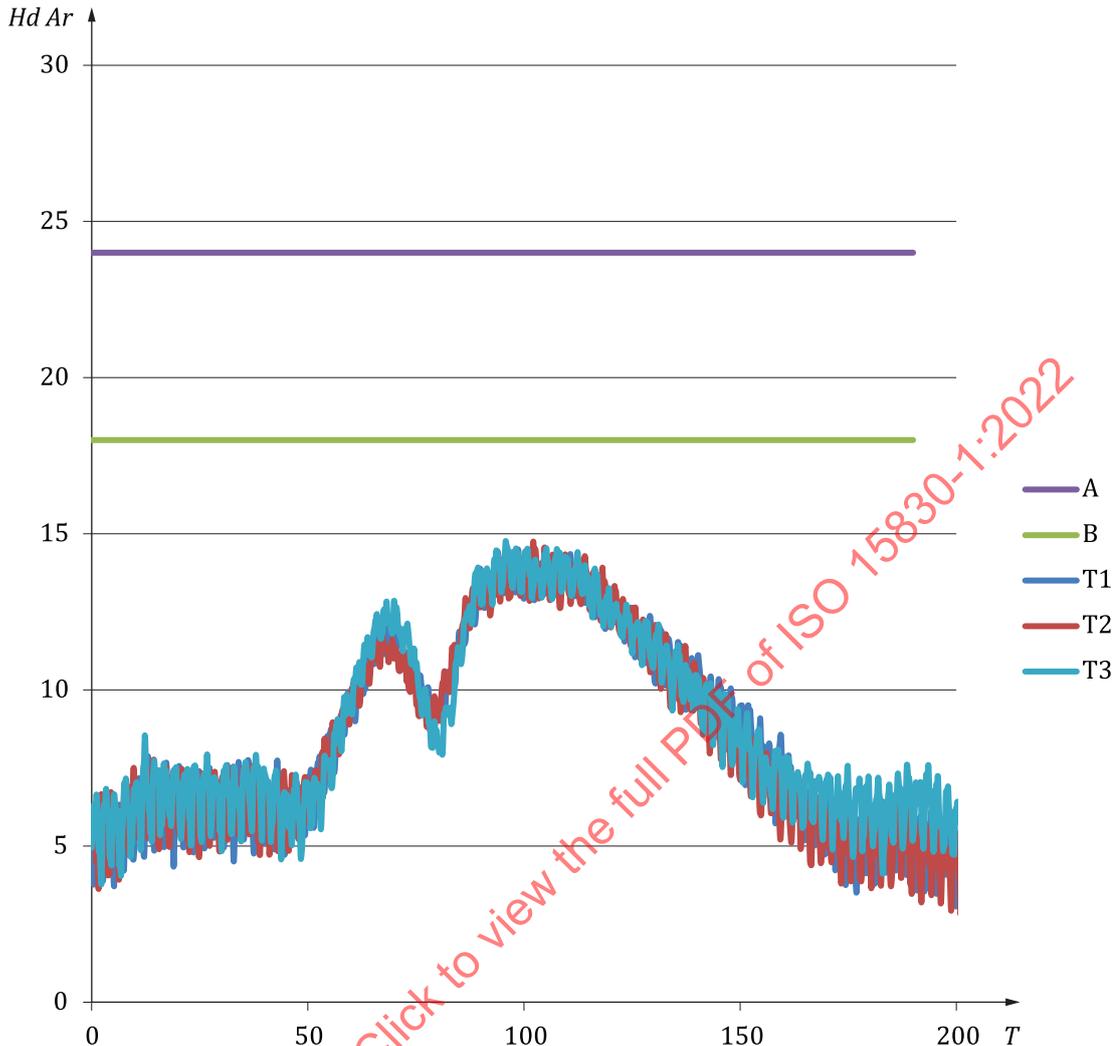
Key

T	time (ms)
Hd Ar	head resultant acceleration (*g*)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure C.17 — Neck test 2 - 6,7*g* sled - peak head resultant acceleration

The biofidelity rating for neck test 2 is summarized in Table C.3.

Table C.3 — Neck test 2 - 6,7g sled test results

Measure	Lower bound	Upper bound	Run #1	Run #2	Run #3	Avg. rating	Weight factor	Rating
Head flexion angle (degrees)	40	50	NM	NM	NM		7	
Rating [a]			-	-	-	-		
Peak moment A-P axis at OC, M_x (Nm)	40	50	13	13	15		7	
Rating			0	0	0	0,0		
Peak moment R-L axis OC, M_y (Nm)	20	30	4	4	3		3	
Rating			0	0	0	0,0		
Peak twist moment, M_z (Nm)	15	20	8	9	9		4	2,1
Rating			0	0	0	0,0		
Peak shear force OC, F_y (N)	750	850	427	428	428		7	
Rating			0	0	0	0,0		
Peak tension force OC, F_z (N) [b]	350	400	363	339	374		6	
Rating			10	5	10	8,3		
Peak A-P shear force, F_x (N)	325	375	63	55	63		3	
Rating			0	0	0	0,0		
Peak resultant head acceleration (g) [c]	18	24	13	13	13		4	
Rating			5	5	5	5,0		
[a] Since the head flexion angles were not measured the biofidelity ratings were removed.								
[b] The peak neck tension values and biofidelity ratings were corrected after removing the zero offset.								
[c] The peak resultant head acceleration values were corrected.								

C.3.3   Neck test 3 – 12,2g sled test

The biofidelity rating for neck test 3, peak T1 lateral acceleration was 10 for all tests. See Figure C.18.
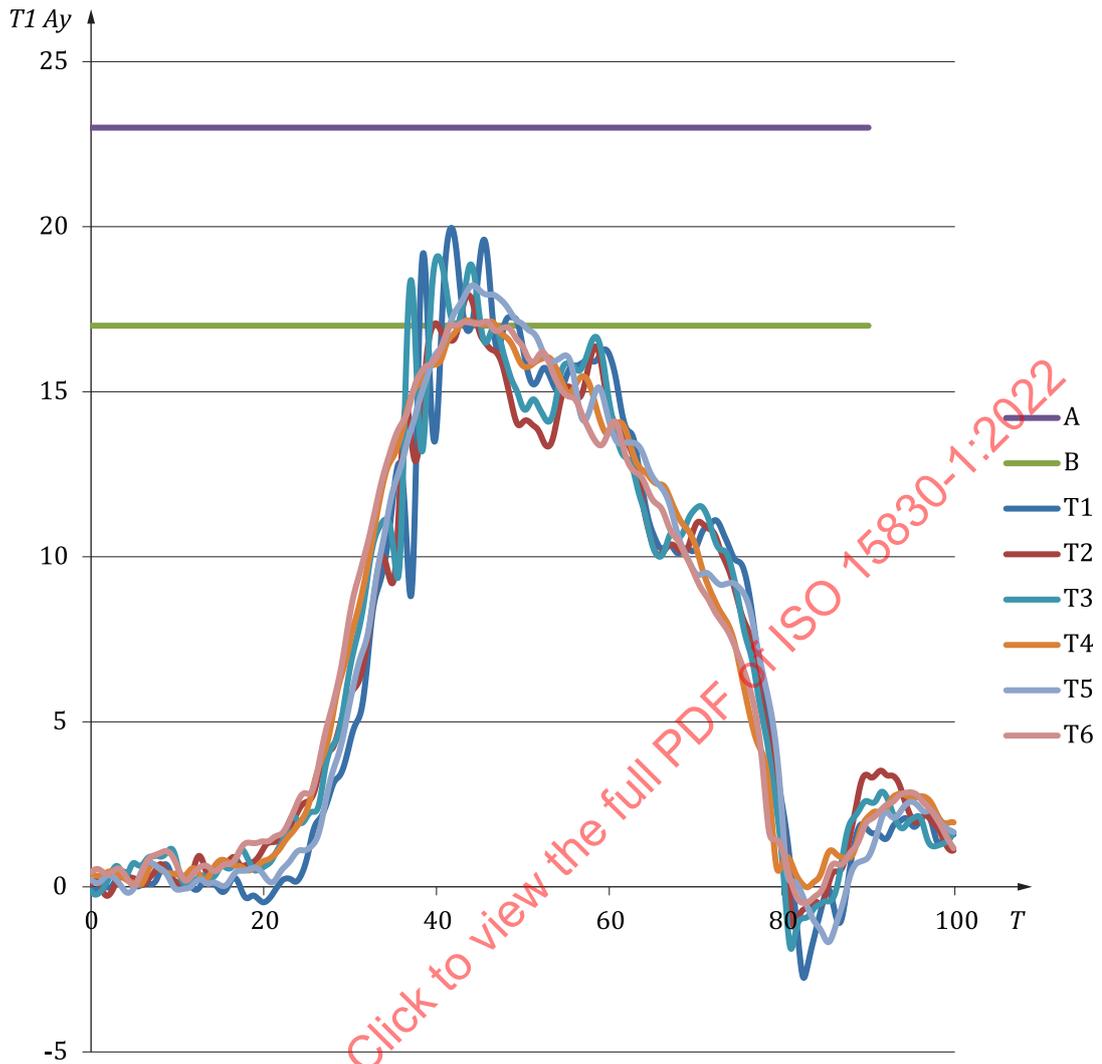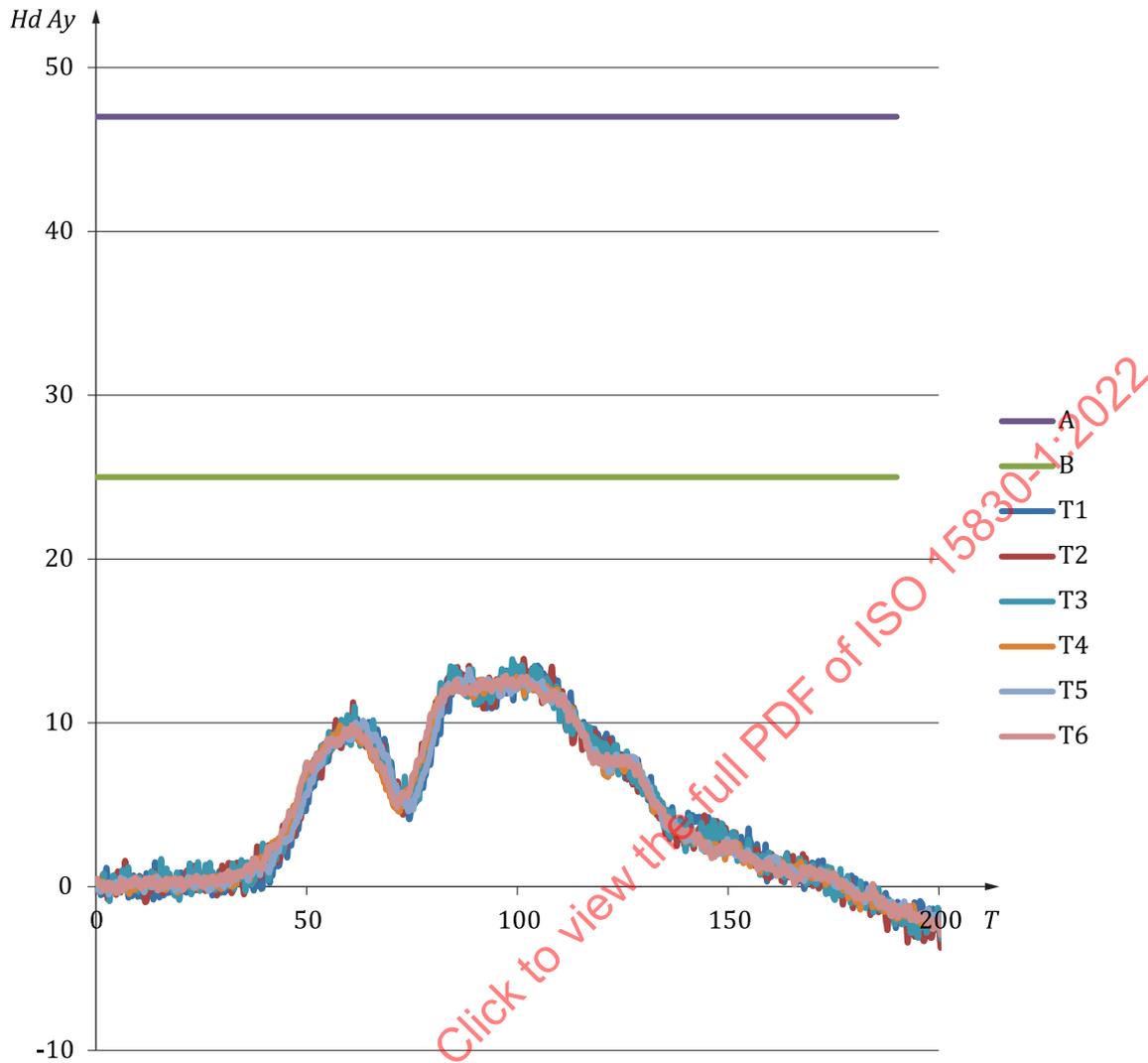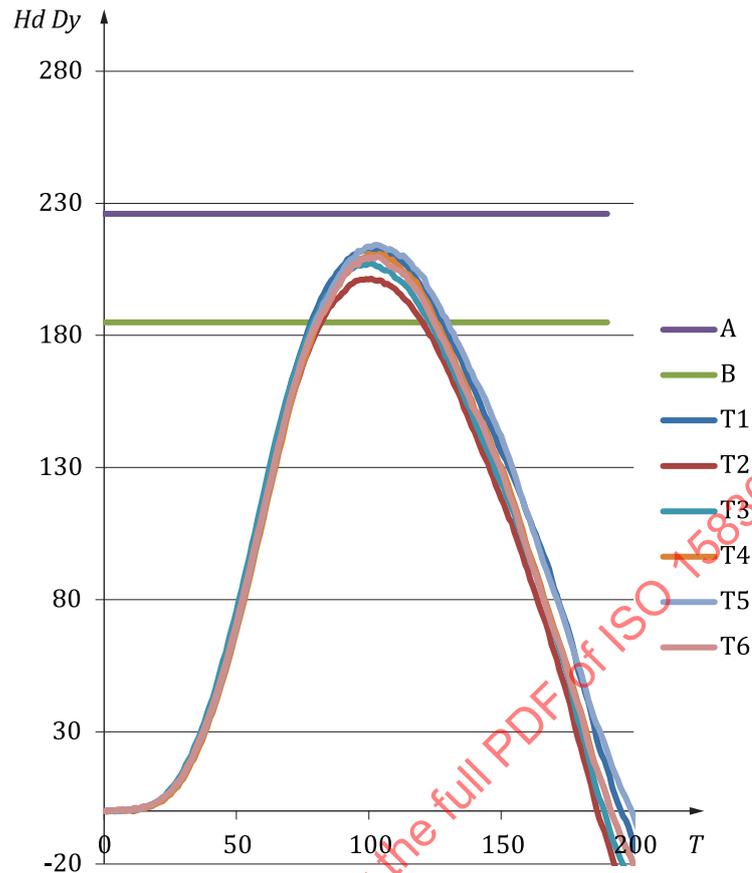
Key
T   time (ms)
T1 Ay   T1 lateral acceleration (*g*)
A   ISO/TR 9790 upper corridor
B   ISO/TR 9790 lower corridor
T1   test number WSID1-70425-1
T2   test number WSID1-70424-3
T3   test number WSID1-70424-4
T4   test number WSID2-70425-1
T5   test number WSID2-70424-3
T6   test number WSID2-70424-4

**Figure C.18 — Neck test 3 - 12,2*g* sled - T1 lateral acceleration**

The biofidelity rating for neck test 3, peak head lateral acceleration was 5 for all tests. See Figure C.19.

Key

T	time (ms)
$Hd\,Ay$	head lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70425-1
T2	test number WSID1-70424-3
T3	test number WSID1-70424-4
T4	test number WSID2-70425-1
T5	test number WSID2-70424-3
T6	test number WSID2-70424-4

Figure C.19 — Neck test 3 - 12,2g sled - head lateral acceleration

The biofidelity rating for neck test 3, peak head lateral displacement relative to sled was 10 for all tests. See Figure C.20.

Key

T   time (ms)

Hd Dy   head lateral displacement with respect to sled (mm)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   test number WSID1-70425-1

T2   test number WSID1-70424-3

T3   test number WSID1-70424-4

T4   test number WSID2-70425-1

T5   test number WSID2-70424-3

T6   test number WSID2-70424-4

Figure C.20 — Neck test 3 - 12,2*g* sled - head lateral displacement relative to sled

The biofidelity rating for neck test 3, peak flexion angle was 5 for three tests and 10 for three tests. See Figure C.21.
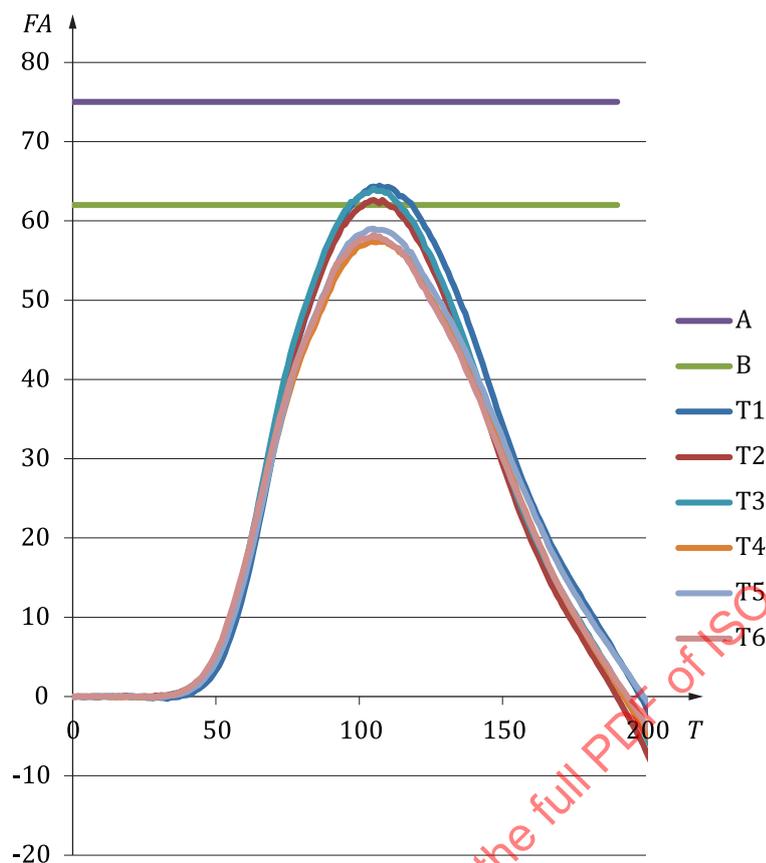
Key

T	time (ms)
FA	flexion angle (°)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70425-1
T2	test number WSID1-70424-3
T3	test number WSID1-70424-4
T4	test number WSID2-70425-1
T5	test number WSID2-70424-3
T6	test number WSID2-70424-4

Figure C.21 — Neck test 3 - 12,2g sled - flexion angle

The biofidelity rating for neck test 3, peak twist angle was 0 for all tests. See Figure C.22.
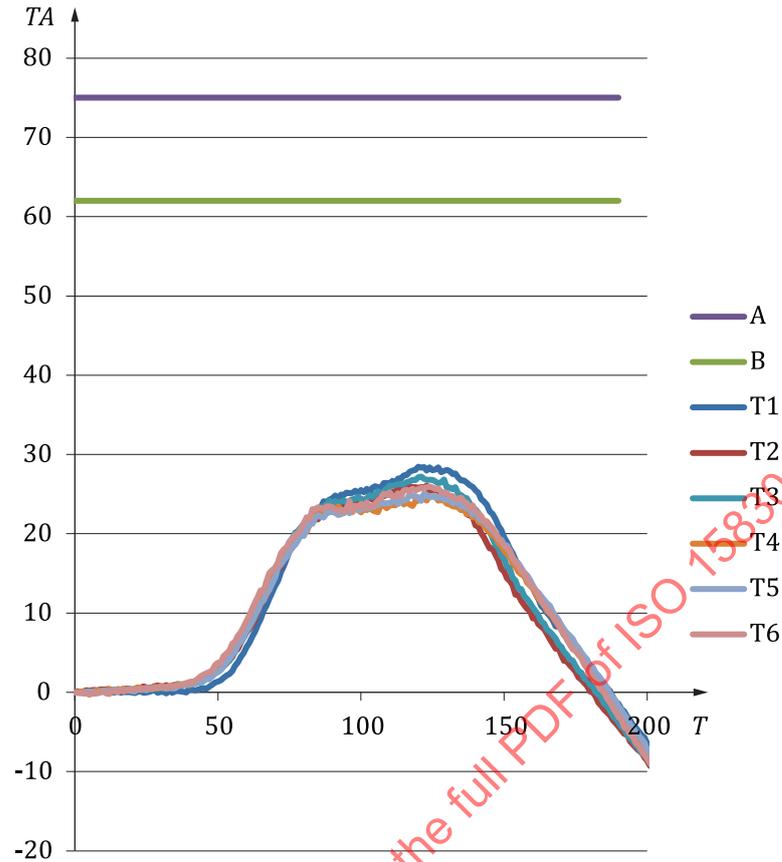
Key

T   time (ms)

TA   twist angle (°)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   test number WSID1-70425-1

T2   test number WSID1-70424-3

T3   test number WSID1-70424-4

T4   test number WSID2-70425-1

T5   test number WSID2-70424-3

T6   test number WSID2-70424-4

Figure C.22 — Neck test 3 - 12,2*g* sled - twist angle

The biofidelity rating for neck test 3 is summarized in Table C.4.

Table C.4 — Neck test 3 - 12,2*g* sled test results

Measure	Lower bound	Upper bound	Run						Avg. rating	Weight factor	Rating
			#1	#2	#3	#4	#5	#6			
Peak lateral acceleration of T1 (*g*)	17	23	20	18	19	17	18	17		5	
Rating			10	10	10	10	10	10	10,0		
Peak lateral acceleration of head CG (*g*)	25	47	14	14	14	13	13	13		5	
Rating			5	5	5	5	5	5	5,0		

Table C.4 *(continued)*

Measure	Lower bound	Upper bound	Run						Avg. rating	Weight factor	Rating
			#1	#2	#3	#4	#5	#6			
Peak horizontal displacement of head CG relative to sled (mm)	185	226	213	202	207	211	214	210		8	7,2
Rating			10	10	10	10	10	10	10,0		
Peak flexion angle (°)	62	75	64	63	64	58	59	58		7	
Rating			10	10	10	5	5	5	7,5		
Peak twist angle (°)	62	75	28	26	27	25	25	26		4	
Rating			0	0	0	0	0	0	0,0		

C.4 Shoulder

C.4.1 Shoulder test 1 – 4,5 m/s pendulum test

The biofidelity rating for shoulder test 1, pendulum force was 10 for all tests. See Figure C.23.

Key

T	time (ms)	T1	test number W009-PRSH-2
F	pendulum force (kN)	T2	test number W009-PRSH-3
A	ISO/TR 9790 upper corridor	T3	test number W009-PRSH-4
B	ISO/TR 9790 lower corridor		
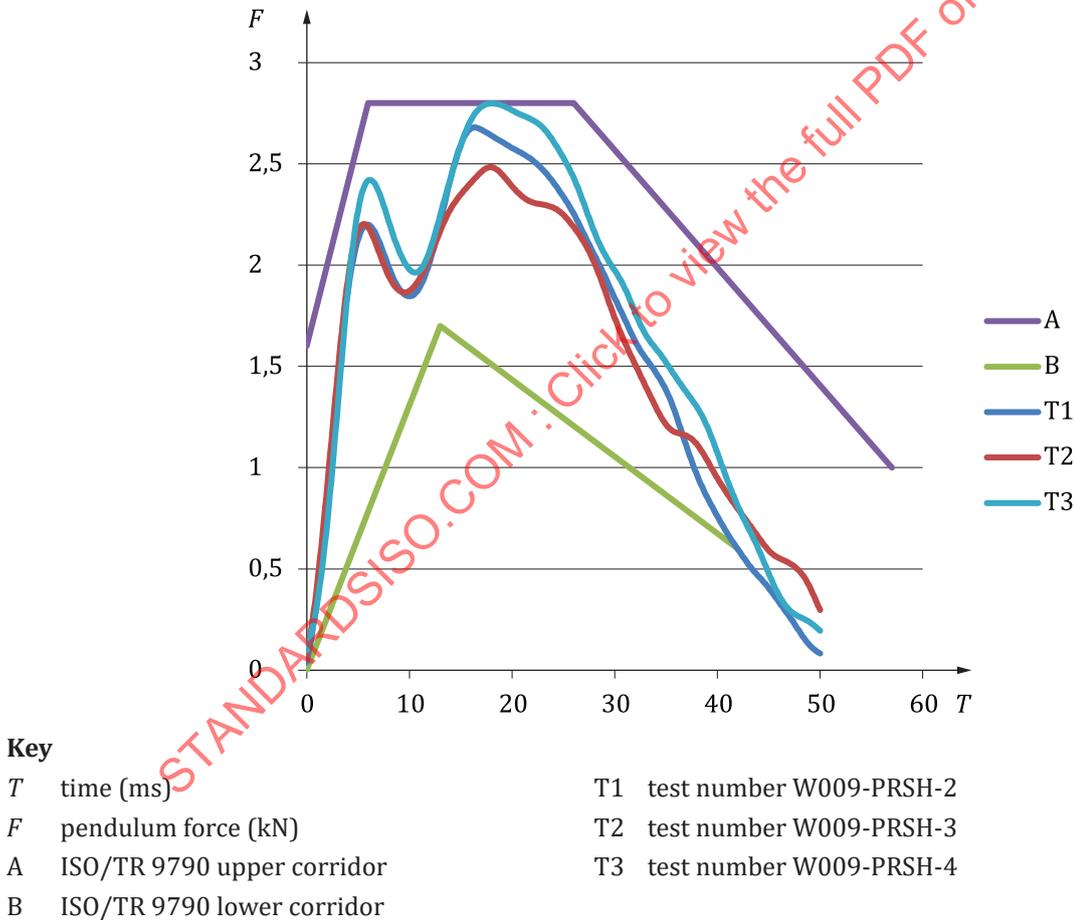
Figure C.23 — Shoulder test 1 – pendulum force

The biofidelity rating for shoulder test 1, peak shoulder rib deflection was 10 for all tests. See Figure C.24.
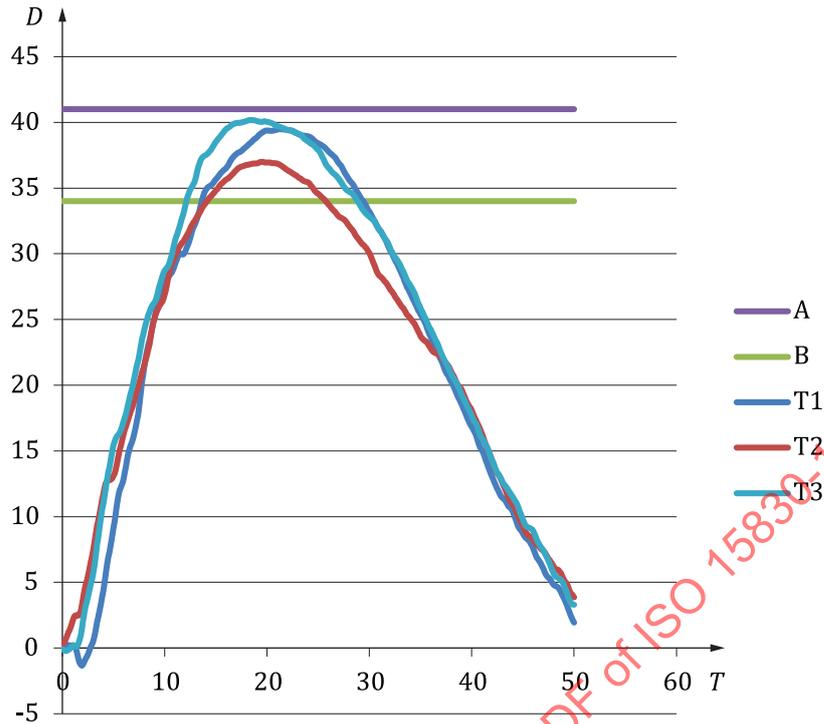
Key

T time (ms)

D shoulder deflection (mm)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   test number W009-PRSH-2

T2   test number W009-PRSH-3

T3   test number W009-PRSH-4

Figure C.24 — Shoulder test 1 – shoulder rib deflection

The biofidelity rating for shoulder test 1 is summarized in Table C.5.

Table C.5 — Shoulder test 1 – 4,5 m/s pendulum test results

Measure	Lower bound	Upper bound	Run			Avg. rating	Weight factor	Rating
			#1	#2	#3			
Shoulder pendulum force (kN)	Plot	Plot	Plot	Plot	Plot		8	10
Rating			10	10	10	10,0		
Peak shoulder deflection (mm)	34	41	39	37	40		6	
Rating			10	10	10	10,0		

C.4.2   Shoulder test 2 – 7,2*g* sled test

The biofidelity rating for shoulder test 2, peak T1 lateral acceleration was 10 for all tests. See Figure C.25.
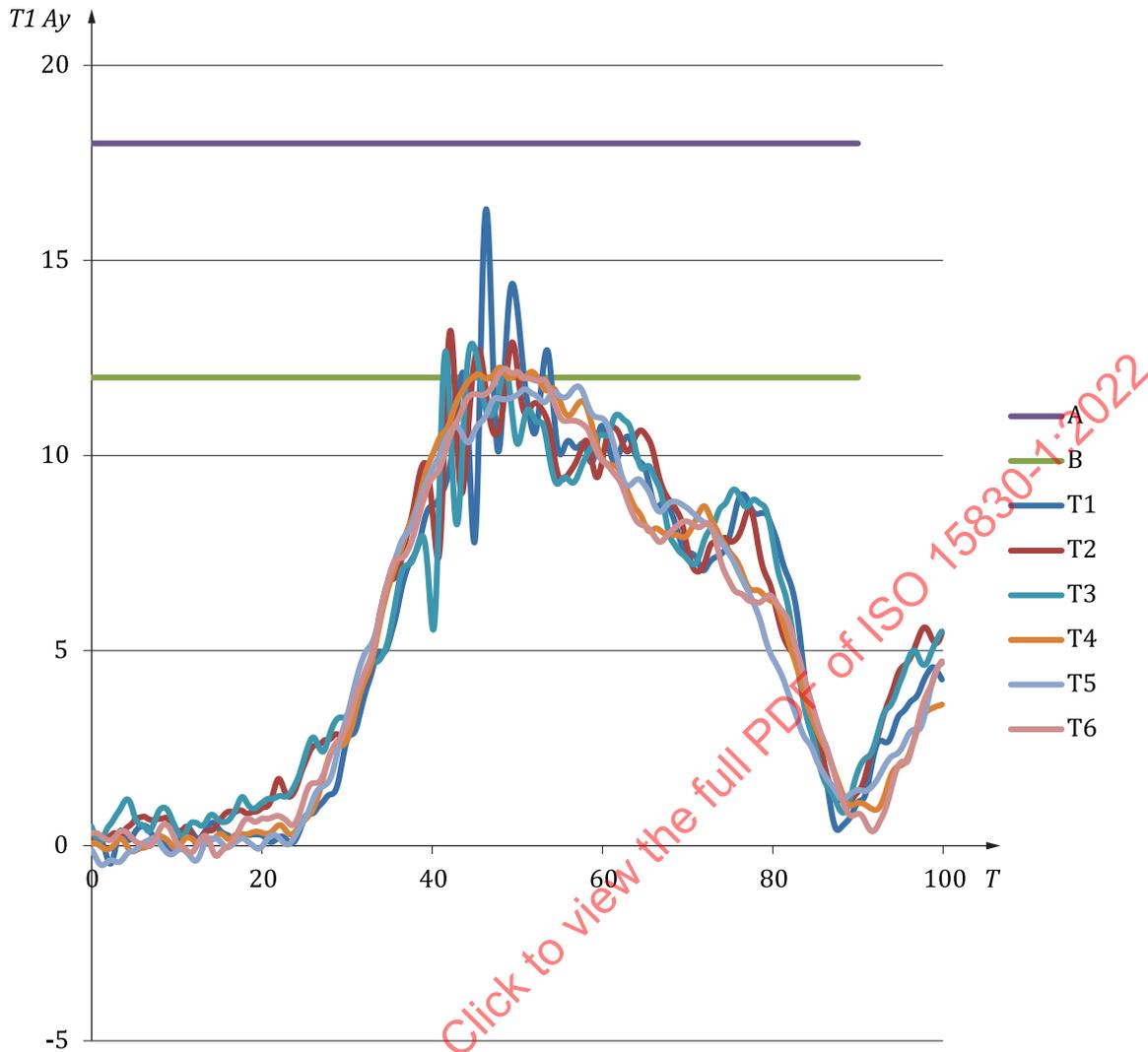
Key

T	time (ms)
$T1\ Ay$	lateral T1 acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure C.25 — Shoulder test 2 – 7,2g sled – peak lateral T1 acceleration

The biofidelity rating for shoulder test 2, peak T1 lateral displacement relative to sled was 10 for all tests. See Figure C.26.
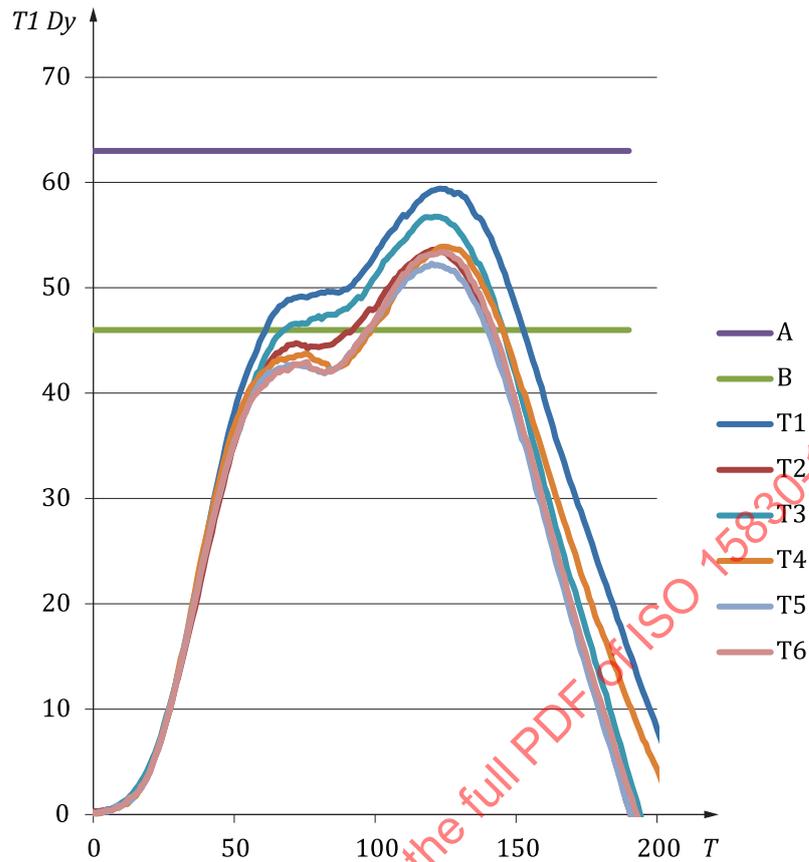
Key

T	time (ms)
T1 Dy	lateral T1 displacement with respect to head (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure C.26 — Shoulder test 2 – 7,2*g* sled – peak lateral T1 displacement relative to sled

The biofidelity rating for shoulder test 2 is summarized in Table C.6.

Table C.6 — Shoulder test 2 – 7,2*g* sled test results

Measure	Lower bound	Upper bound	Run						Avg. rating	Weight factor	Rating
			#1	#2	#3	#4	#5	#6			
Horizontal acceleration T1 (*g*)	12	18	16	13	13	12	12	12		6	
Rating			10	10	10	10	10	10	10,0		
Horizontal displacement T1 relative to sled (mm)	46	63	59	54	57	54	52	53		6	10,0
Rating			10	10	10	10	10	10	10,0		
NOTE All test results were rounded to the nearest whole number.											

C.4.3 Shoulder test 3 – 12,2*g* sled test

The biofidelity rating for shoulder test 3, peak T1 lateral acceleration was 10 for all tests. See Figure C.27.
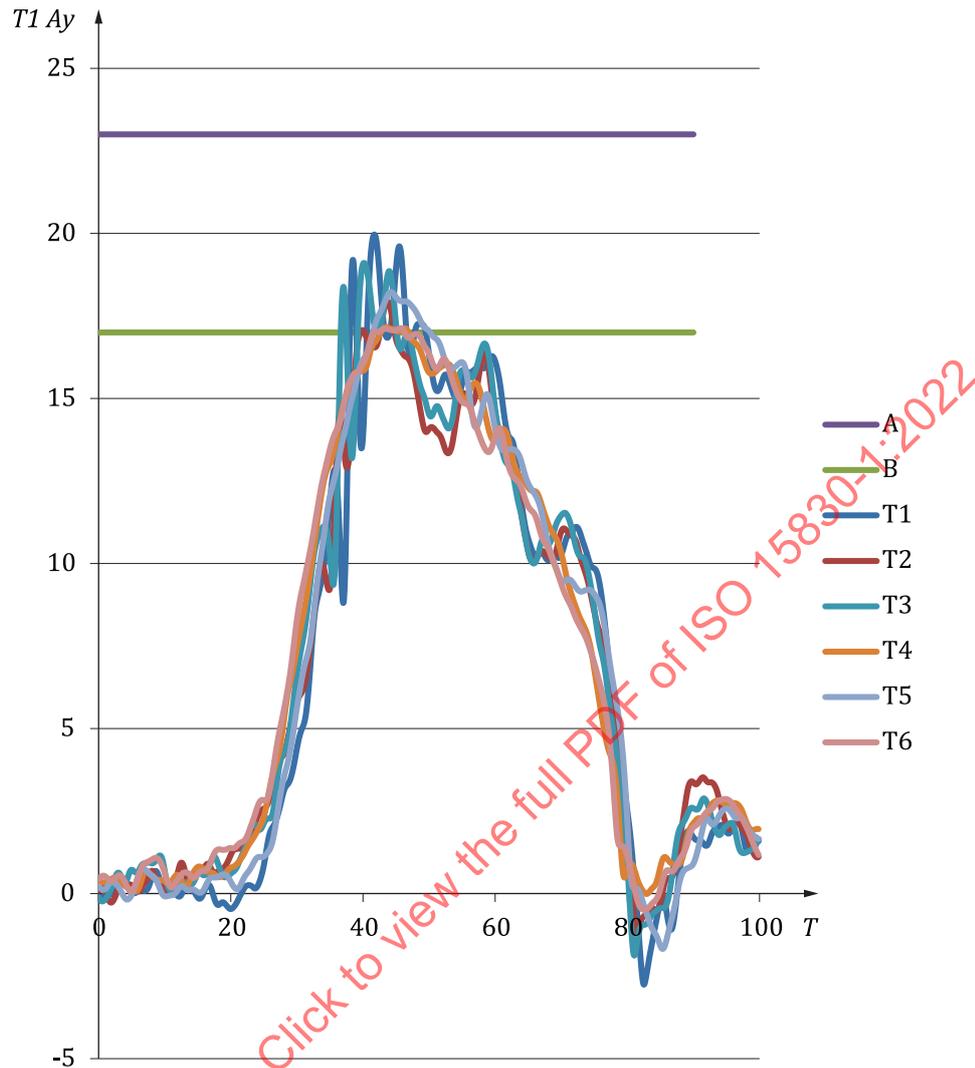
Key

T	time (ms)
T1 Ay	lateral T1 acceleration (*g*)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70425-1
T2	test number WSID1-70424-3
T3	test number WSID1-70424-4
T4	test number WSID2-70425-1
T5	test number WSID2-70424-3
T6	test number WSID2-70424-4

Figure C.27 — Shoulder test 3 – 12,2*g* sled peak lateral T1 acceleration

The biofidelity rating for shoulder test 3 is summarized in Table C.7.

Table C.7 — Shoulder test 3 – 12,2*g* sled test results

Measure	Lower bound	Upper bound	Run						Avg. rating	Weight factor	Rating
			#1	#2	#3	#4	#5	#6			
Peak lateral acceleration T1 (*g*)	17	23	20	18	19	17	18	17		6	10,0
Rating			10	10	10	10	10	10	10,0		

C.5   Thorax

C.5.1   Thorax test 1 – 4,3 m/s pendulum test

The biofidelity rating for thorax test 1, pendulum force was 10 for all tests. See Figure C.28.
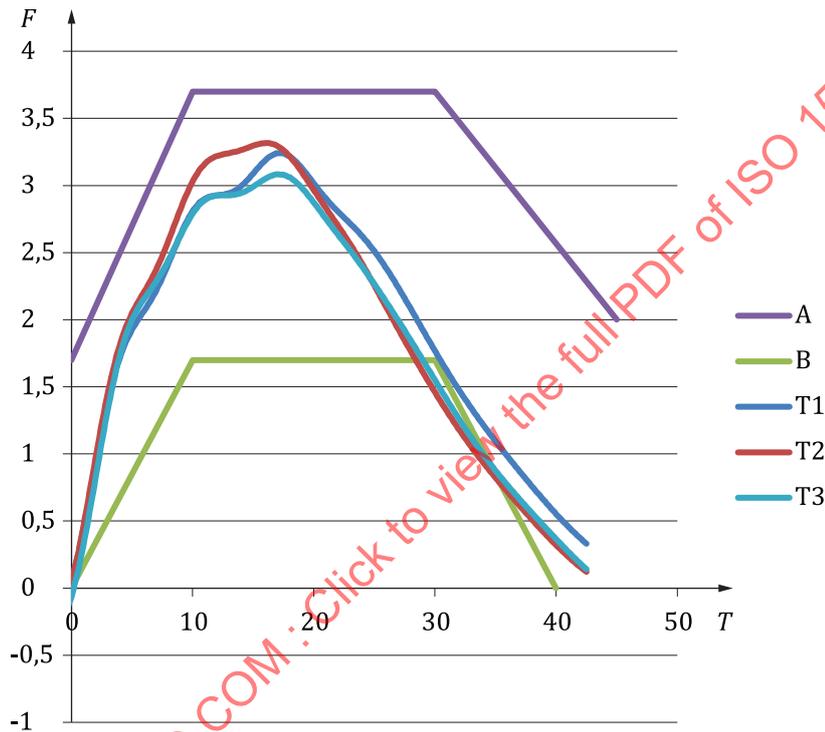
Key

T   time (ms)
F   pendulum force (kN)
A   ISO/TR 9790 upper corridor
B   ISO/TR 9790 lower corridor
T1   test number W009-BDRPH-9
T2   test number W009-BDRPH-10
T3   test number W009-BDRPH-11

Figure C.28 — Thorax test 1 - pendulum force

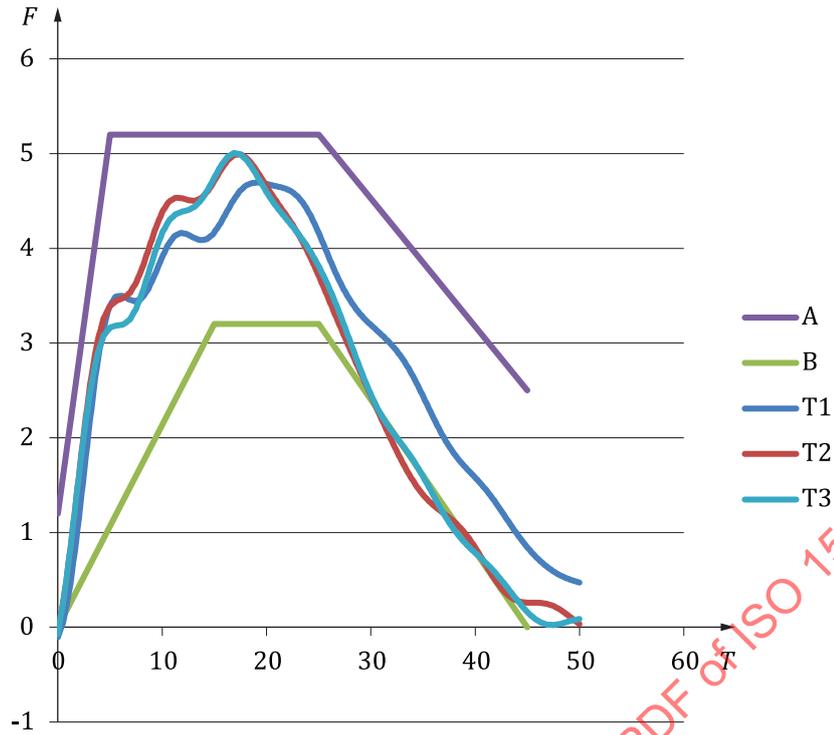The biofidelity rating for thorax test 1, T1 lateral acceleration was 5 for all tests. See Figure C.29.
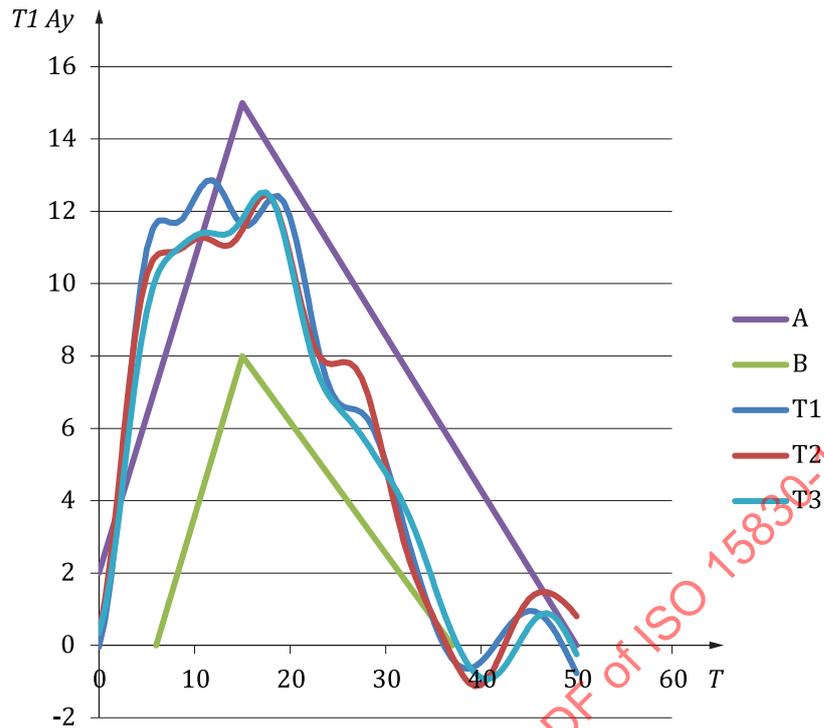
Key

T	time (ms)
T1 Ay	upper spine lateral acceleration (*g*)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number W009-BDRPH-9
T2	test number W009-BDRPH-10
T3	test number W009-BDRPH-11

Figure C.29 — Thorax test 1 - T1 lateral acceleration

The biofidelity rating for thorax test 1 is summarized in Table C.8.

Table C.8 — Thorax test 1 – 4,3 m/s pendulum test results

Measure	Lower bound	Upper bound	Run			Avg. rating	Weight factor	Rating
			#1	#2	#3			
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot		9	
Rating			10	10	10	10,0		7,8
T1 lateral acceleration (*g*)	Plot	Plot	Plot	Plot	Plot		7	
Rating			5	5	5	5,0		

C.5.2 Thorax test 2 – 6,7 m/s pendulum test

The biofidelity rating for thorax test 2, pendulum force was 10 for all tests. See Figure C.30.

Key

T time (ms)

F pendulum force (kN)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   test number W009-PRTHS1

T2   test number W009-PRTHS2

T3   test number W009-PRTHS3
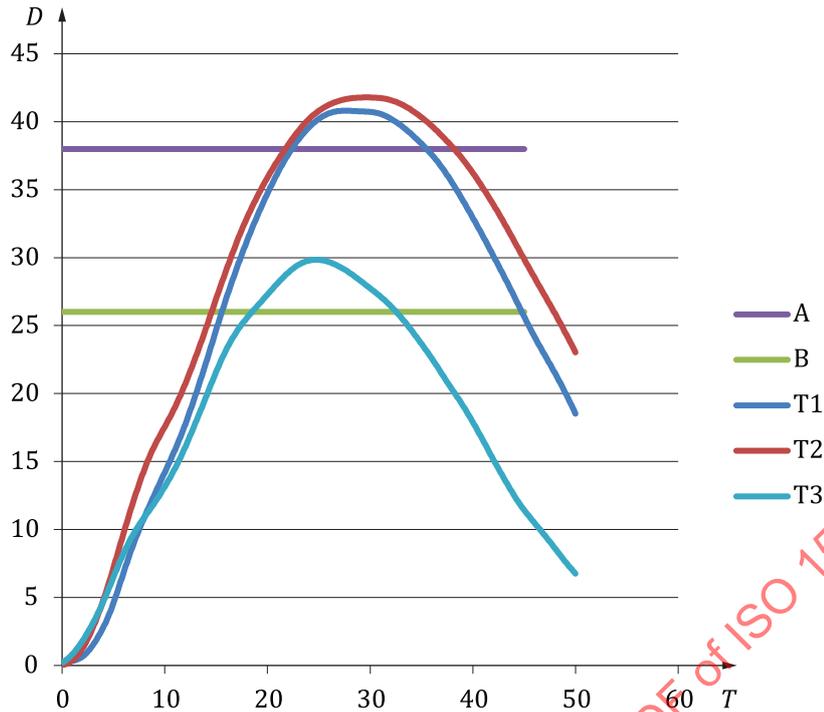
Figure C.30 — Thorax test 2 – pendulum force

The biofidelity rating for thorax test 2 is summarized in Table C.9.

Table C.9 — Thorax test 2 – 6,7 m/s pendulum test results

Measure	Lower bound	Upper bound	Run			Avg. rating	Weight factor	Rating
			#1	#2	#3			
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot		9	10,0
Rating			10	10	10	10,0		

C.5.3   Thorax test 3 – 1 m rigid drop test

The biofidelity rating for thorax test 3, plate force was 10 for all tests. See Figure C.31.
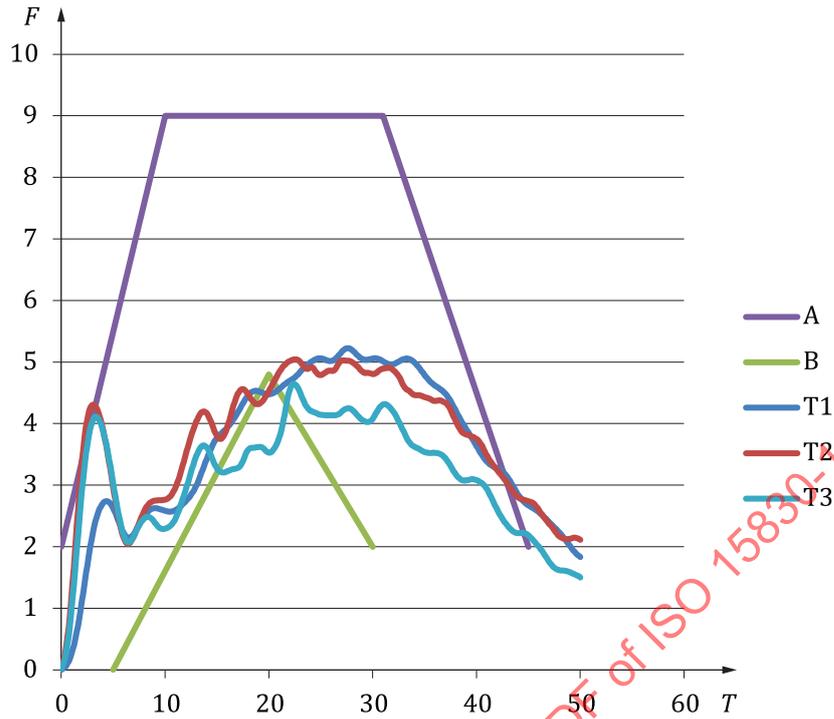
Key

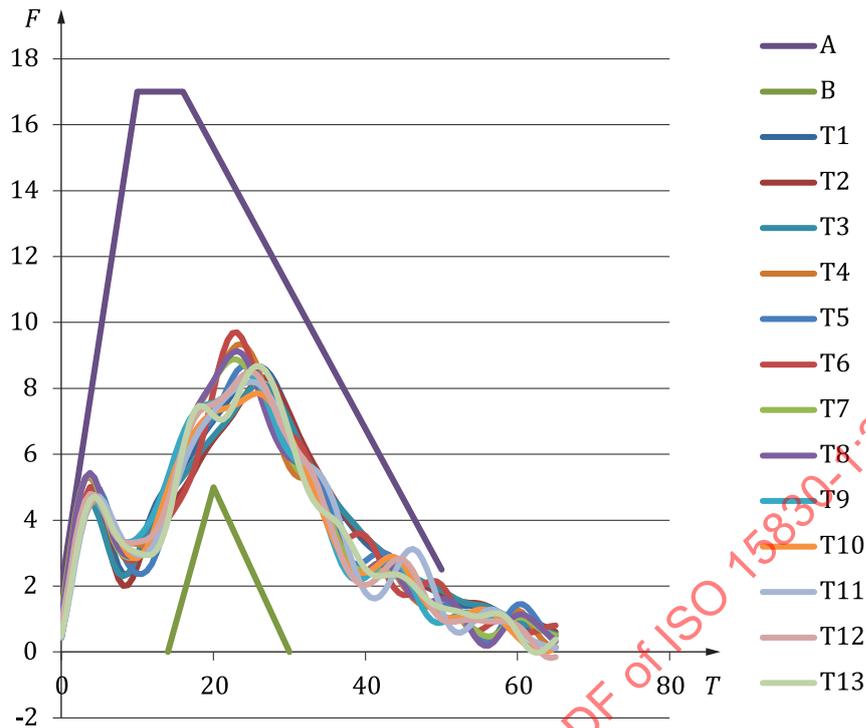|	
T	time (ms)
F	plate force (kN)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number W009-BDRPH-1
T2	test number W009-BDRPH-2
T3	test number W009-BDRPH-3

Figure C.31 — Thorax test 3 – plate force

The biofidelity rating for thorax test 3, peak rib deflection was 5 for two tests and 10 for one test. See Figure C.32.

Key

T time (ms)

D rib 2 deflection (mm)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number W009-BDRPH-1

T2 test number W009-BDRPH-2

T3 test number W009-BDRPH-3

Figure C.32 — Thorax test 3 – rib deflection

The biofidelity rating for thorax test 3 is summarized in Table C.10.

Table C.10 — Thorax test 3 – 1 m rigid drop test results

Measure	Lower bound	Upper bound	Run			Avg. rating	Weight factor	Rating
			#1	#2	#3			
Thorax plate force (kN)	Plot	Plot	Plot	Plot	Plot		8	
Rating			10	10	10	10,0		8,3
Peak deflection impacted rib (mm)	26	38	41	42	30		8	
Rating			5	5	10	6,7		

C.5.4   Thorax test 5 – 6,8 m/s Heidelberg rigid sled test

The biofidelity rating for thorax test 5, plate force was 10 for all tests. See Figure C.33.

Key

T	time (ms)
F	plate force (kN)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28642
T2	test number H28643
T3	test number H28644
T4	test number 070215-1 WS1
T5	test number 070215-2 WS1
T6	test number 070215-3 WS1
T7	test number 070216-1 WS1
T8	test number 070216-2 WS1
T9	test number 070215-1 WS2
T10	test number 070215-2 WS2
T11	test number 070215-3 WS2
T12	test number 070216-1 WS2
T13	test number 070216-2 WS2

Figure C.33 — Thorax test 5 – plate force

The biofidelity rating for thorax test 5, peak T1 lateral acceleration was 5 for two tests and 0 for 11 tests. See Figure C.34.
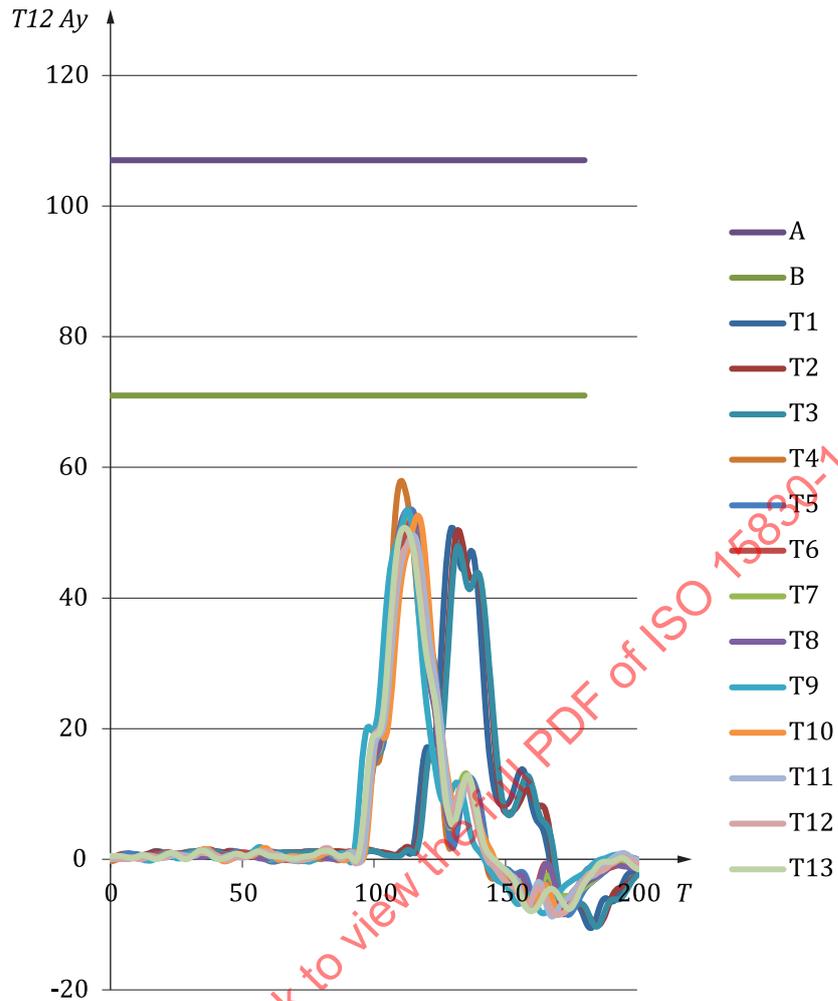
Key
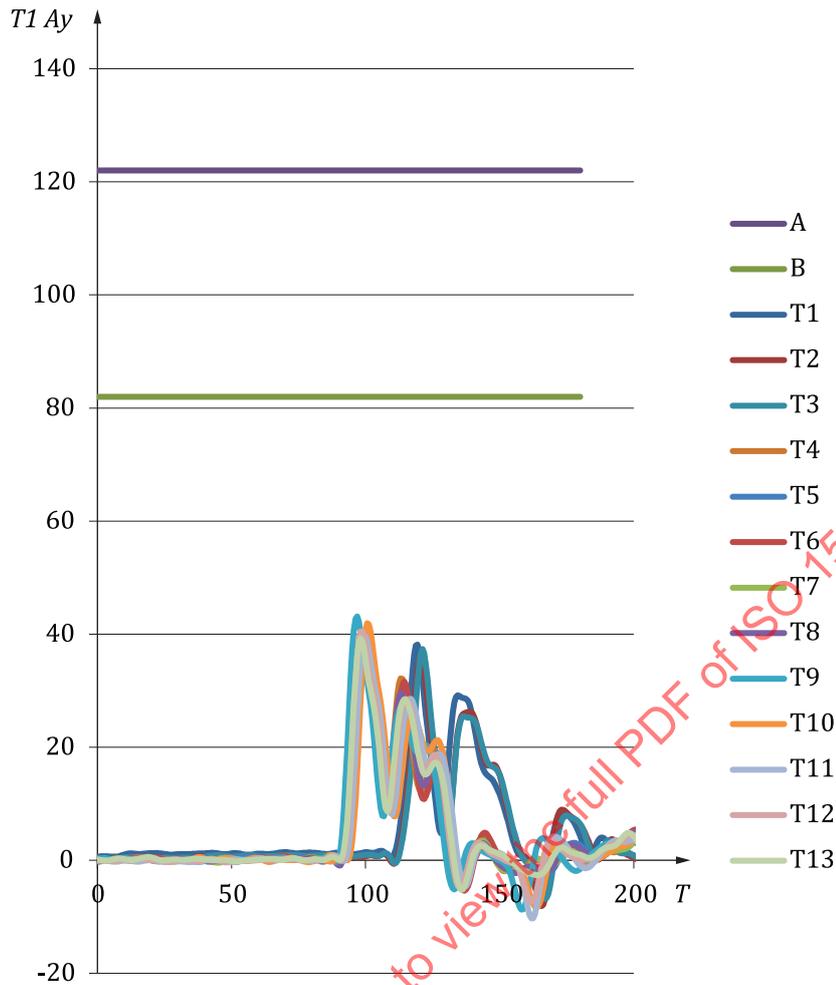
T	time (ms)	T6	test number 070215-3 WS1
T1 Ay	upper spine lateral acceleration (*g*)	T7	test number 070216-1 WS1
A	ISO/TR 9790 upper corridor	T8	test number 070216-2 WS1
B	ISO/TR 9790 lower corridor	T9	test number 070215-1 WS2
T1	test number H28642	T10	test number 070215-2 WS2
T2	test number H28643	T11	test number 070215-3 WS2
T3	test number H28644	T12	test number 070216-1 WS2
T4	test number 070215-1 WS1	T13	test number 070216-2 WS2
T5	test number 070215-2 WS1		

Figure C.34 — Thorax test 5 – T1 acceleration

The biofidelity rating for thorax test 5, peak T12 lateral acceleration was 5 for all tests. See Figure C.35.

Key

T	time (ms)	T6	test number 070215-3 WS1
T12 Ay	lower spine lateral acceleration (*g*)	T7	test number 070216-1 WS1
A	ISO/TR 9790 upper corridor	T8	test number 070216-2 WS1
B	ISO/TR 9790 lower corridor	T9	test number 070215-1 WS2
T1	test number H28642	T10	test number 070215-2 WS2
T2	test number H28643	T11	test number 070215-3 WS2
T3	test number H28644	T12	test number 070216-1 WS2
T4	test number 070215-1 WS1	T13	test number 070216-2 WS2
T5	test number 070215-2 WS1		

Figure C.35 — Thorax test 5 – T12 acceleration

The biofidelity rating for thorax test 5, peak rib acceleration was 10 for all tests. See Figure C.36.
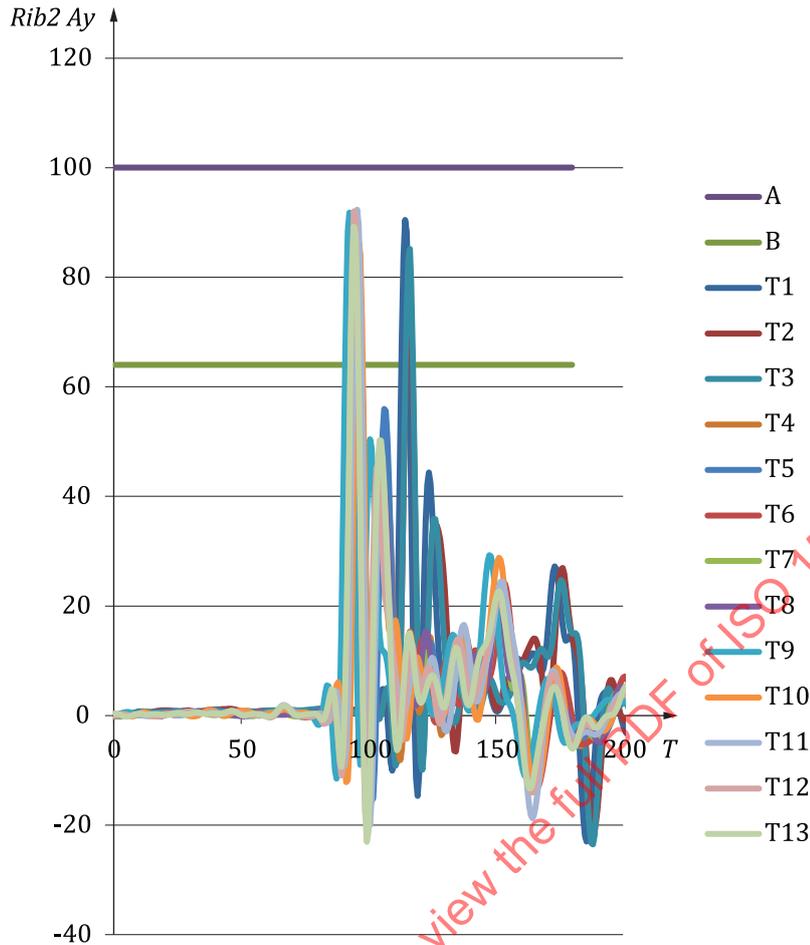
Key

T	time (ms)
Rib2 Ay	rib 2 lateral acceleration (*g*)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28642
T2	test number H28643
T3	test number H28644
T4	test number 070215-1 WS1
T5	test number 070215-2 WS1
T6	test number 070215-3 WS1
T7	test number 070216-1 WS1
T8	test number 070216-2 WS1
T9	test number 070215-1 WS2
T10	test number 070215-2 WS2
T11	test number 070215-3 WS2
T12	test number 070216-1 WS2
T13	test number 070216-2 WS2

Figure C.36 — Thorax test 5 – rib acceleration

The biofidelity rating for thorax test 5 is summarized in Table C.11.

**Table C.11 — Thorax test 5 – 6,8 m/s Heidelberg rigid sled test results**

Measure	Lower bound	Upper bound	Run	Avg. rating	Weight factor	Rating
Thorax plate force (kN)	Plot	Plot	Plot		8	
Rating			All tests 10	10,0		
Peak upper spine lateral acceleration (g)	82	122	39 average		7	6,4
Rating			Two tests 5, 11 tests 0	0,8		
Peak lower spine lateral acceleration (g)	71	107	52 average		7	
Rating			All tests 5	5,0		
Peak lateral acceleration impacted rib (g)	64	100	86 average		6	
Rating			All tests 10	10,0		

C.6   Abdomen

C.6.1   Abdomen test 1 – 1,0 m drop onto rigid armrest test

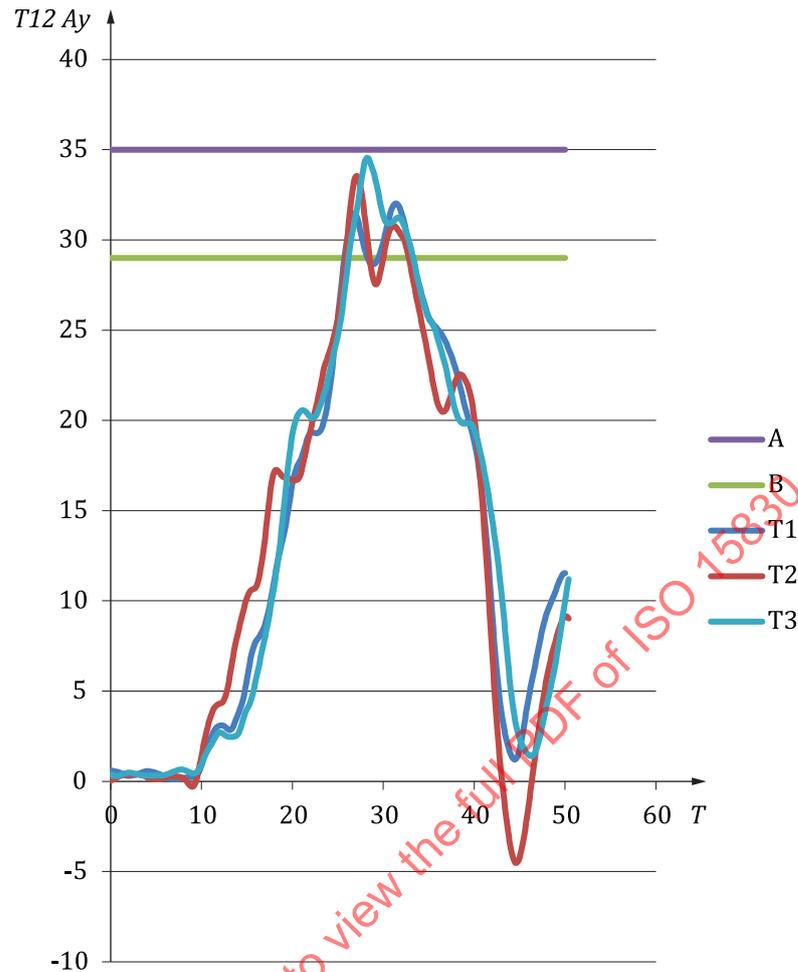The biofidelity rating for abdomen test 1, armrest force was 10 for all tests. See Figure C.37.
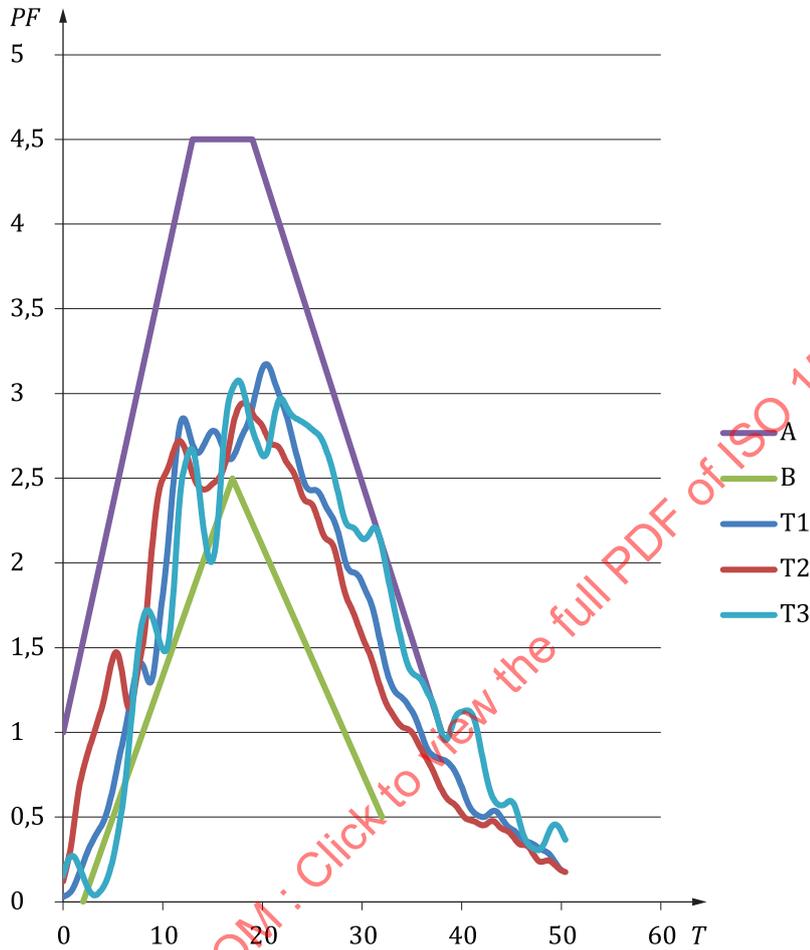
Key

T time (ms)

PF plate force (kN)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   test number WS009-BDRAL-1

T2   test number WS009-BDRAL-2

T3   test number WS009-BDRAL-3

Figure C.37 — Abdomen test 1 – armrest force

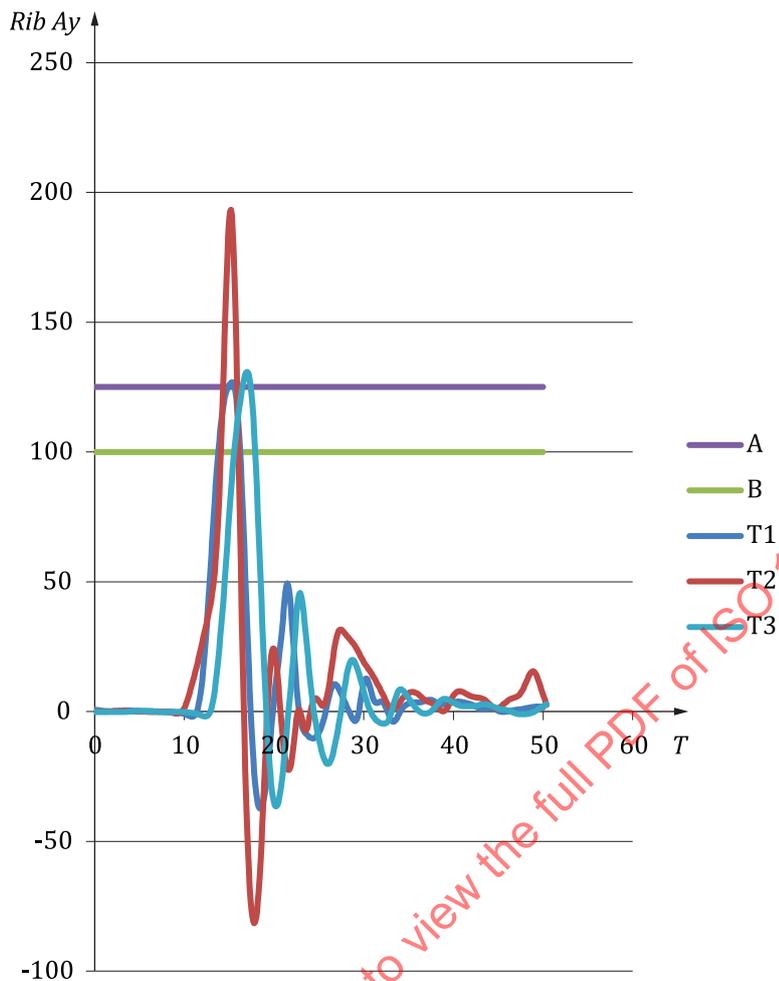The biofidelity rating for abdomen test 1, peak T12 lateral acceleration was 10 for all tests. See Figure C.38.

Key

T	time (ms)
T12 Ay	lower spine lateral acceleration (*g*)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WS009-BDRAL-1
T2	test number WS009-BDRAL-2
T3	test number WS009-BDRAL-3

Figure C.38 — Abdomen test 1 - T12 lateral acceleration

The biofidelity rating for abdomen test 1, peak rib acceleration was 0 for one test and 5 for two tests. See Figure C.39.
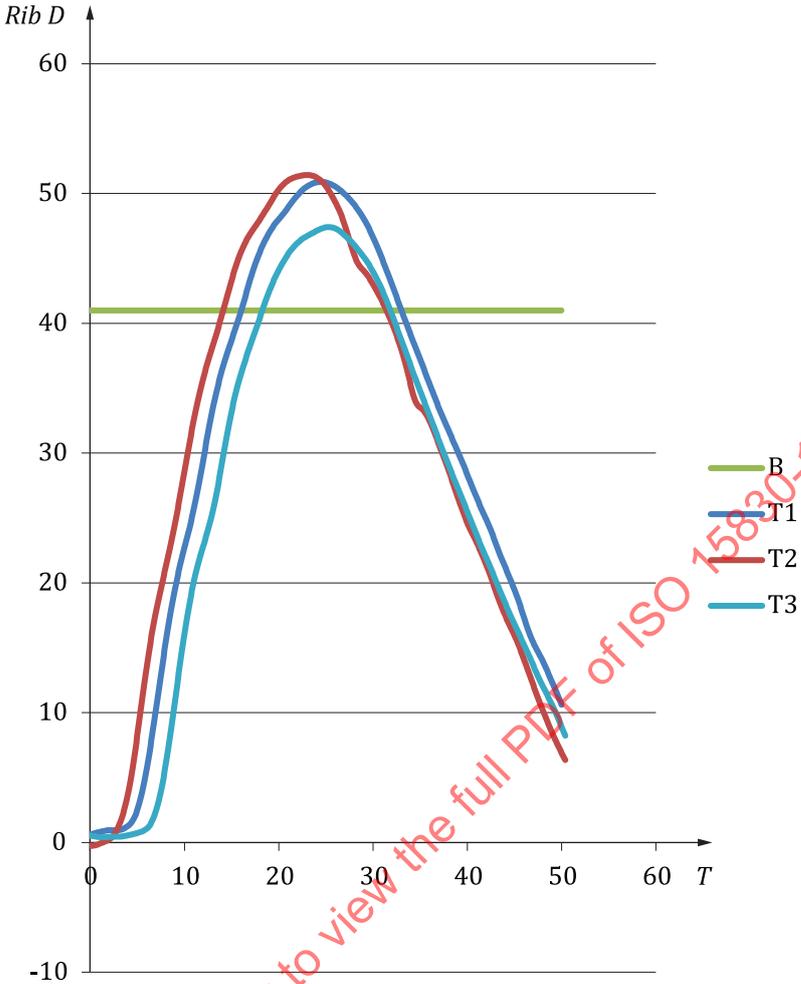
Key

T	time (ms)
Rib Ay	impacted rib lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WS009-BDRAL-1
T2	test number WS009-BDRAL-2
T3	test number WS009-BDRAL-3

Figure C.39 — Abdomen test 1 - rib acceleration

The biofidelity rating for abdomen test 1, peak rib deflection was 10 for all tests. See Figure C.40.

Key

T	time (ms)
Rib D	impacted rib lateral deflection (mm)
B	ISO/TR 9790 lower corridor
T1	test number WS009-BDRAL-1
T2	test number WS009-BDRAL-2
T3	test number WS009-BDRAL-3

Figure C.40 — Abdomen test 1 - rib deflection

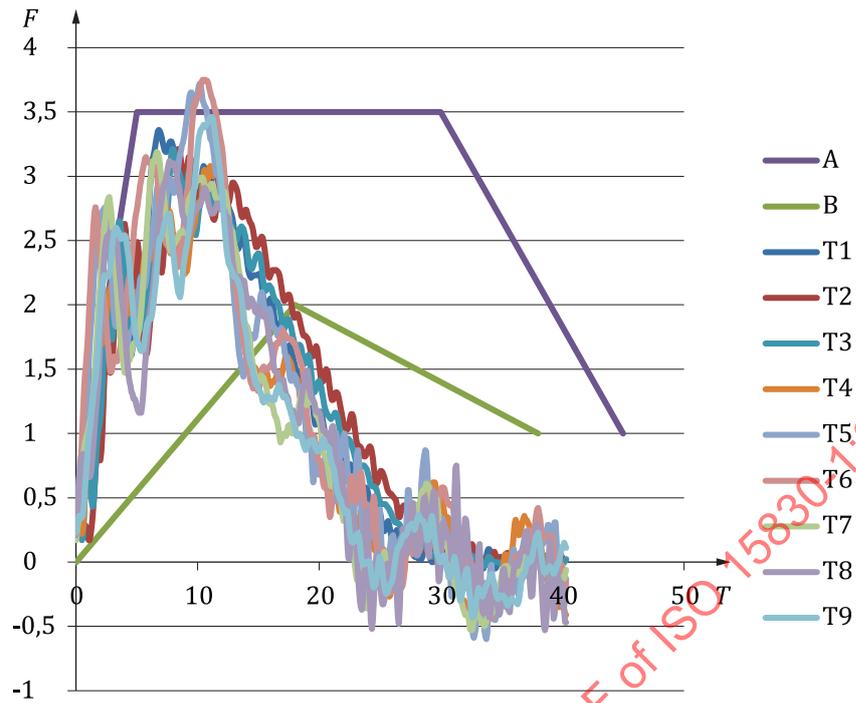The biofidelity rating for abdomen test 1 is summarized in Table C.12.

Table C.12 — Abdomen test 1 - 1 m rigid armrest test results

Measure	Lower bound	Upper bound	Run #1	Run #2	Run #3	Avg. rating	Weight factor	Rating
Armrest force (kN)	Plot	Plot	Plot	Plot	Plot		9	
Rating			10	10	10	10,0		
T12 lateral acceleration (*g*)	29	35	32	34	35		6	
Rating			10	10	10	10,0		9,0
Peak acceleration of impacted rib (*g*)	100	125	127	193	130		4	
Rating			5	0	5	3,3		
Abdomen rib deflection (mm)	41		51	51	47		9	
Rating			10	10	10	10,0		

C.6.2 Abdomen test 3 – 6,8 m/s WSU rigid sled test

The biofidelity ratings of tests T5 and T6 were corrected. The biofidelity rating for abdomen test 3, plate force was 5 for two tests and 10 for seven tests. See Figure C.41.

Key

T	time (ms)
F	plate force (kN)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28774
T2	test number H28775
T3	test number H28776
T4	test number 070410-1 WS1
T5	test number 070410-2 WS1
T6	test number 070410-3 WS1
T7	test number 070410-1 WS2
T8	test number 070410-2 WS2
T9	test number 070410-3 WS2

Figure C.41 — Abdomen test 3 - plate force

The biofidelity rating for abdomen test 3 is summarized in Table C.13.

**Table C.13 — Abdomen test 3 - 6,8 m/s WSU rigid sled test results**

Measure	Lower bound	Upper bound	Run	Avg. rating	Weight factor	Rating
Abdomen plate force (kN)	Plot	Plot	Plot		9	8,9
Rating [a]	Plot	Plot	two tests 5; seven tests 10	8,9		
[a] The biofidelity rating of two tests was changed from 10 to 5.						

C.7   Pelvis

C.7.1   Pelvis test 1 – 6,0 m/s pendulum test

The biofidelity rating for pelvis test 1, pendulum force was 10 for all tests. See Figure C.42.
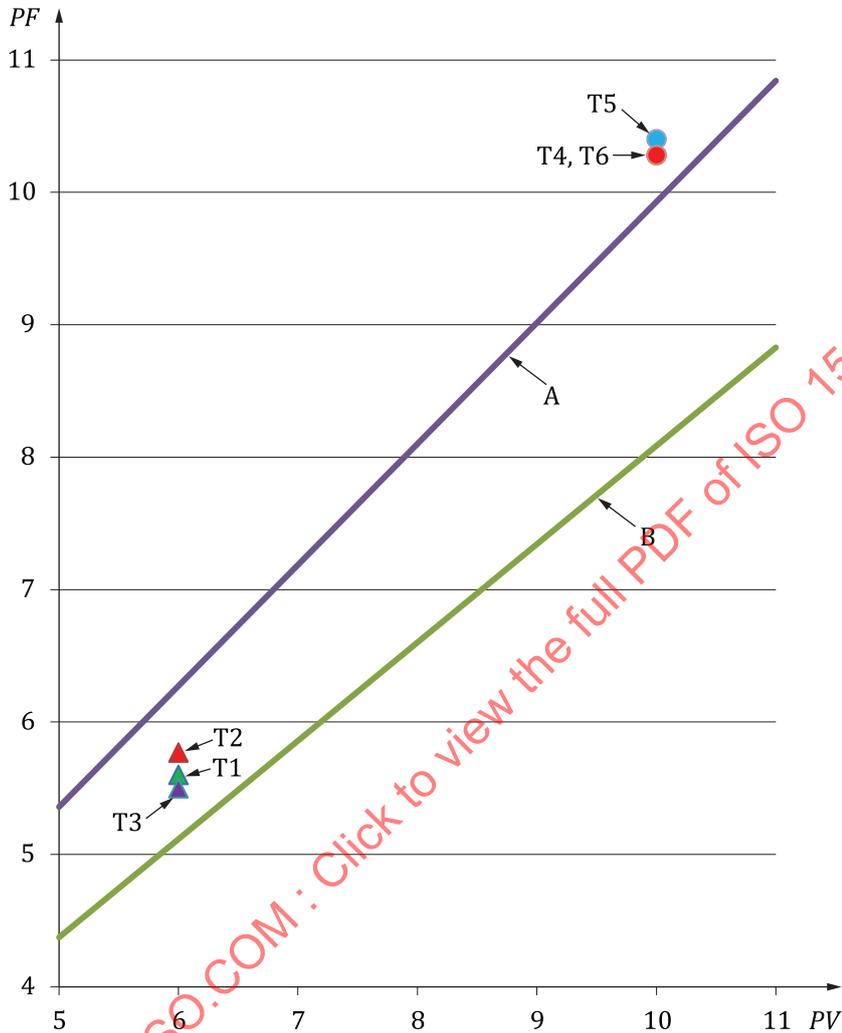
Key

PV	pendulum velocity (m/s)	T1 Pelvis test 1	test number WS009-PRPLS1
PF	pendulum force (kN)	T2 Pelvis test 1	test number WS009-PRPLS2
A	ISO/TR 9790 upper corridor	T3 Pelvis test 1	test number WS009-PRPLS3
B	ISO/TR 9790 lower corridor	T4 Pelvis test 2	test number WS009-PRPHS1
		T5 Pelvis test 2	test number WS009-PRPHS2
		T6 Pelvis test 2	test number WS009-PRPHS3

Figure C.42 — Pelvis test 1 and 2 - pendulum force

The biofidelity rating for pelvis test 1 is summarized in Table C.14.

Table C.14 — Pelvis test 1 – 6,0 m/s pendulum test results

| Measure	Lower bound	Upper bound	Run			Avg. rating	Weight factor	Rating
			#1	#2	#3			
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot		9	10,0
Rating			10	10	10	10,0		

C.7.2 Pelvis test 2 – 10,0 m/s pendulum test

The biofidelity rating for pelvis test 2, pendulum force was 5 for all tests. See Figure C.42. The biofidelity rating for pelvis test 2 is summarized in Table C.15.

Table C.15 — Pelvis test 2 - 10,0 m/s pendulum test results

Measure	Lower bound	Upper bound	Run			Avg. rating	Weight factor	Rating
			#1	#2	#3			
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot		9	5,0
Rating			5	5	5	5,0		

C.7.3 Pelvis test 3 – 0,5 m rigid drop test

The biofidelity rating for pelvis test 3, peak pelvis lateral acceleration was 5 for all tests. See Figure C.43.
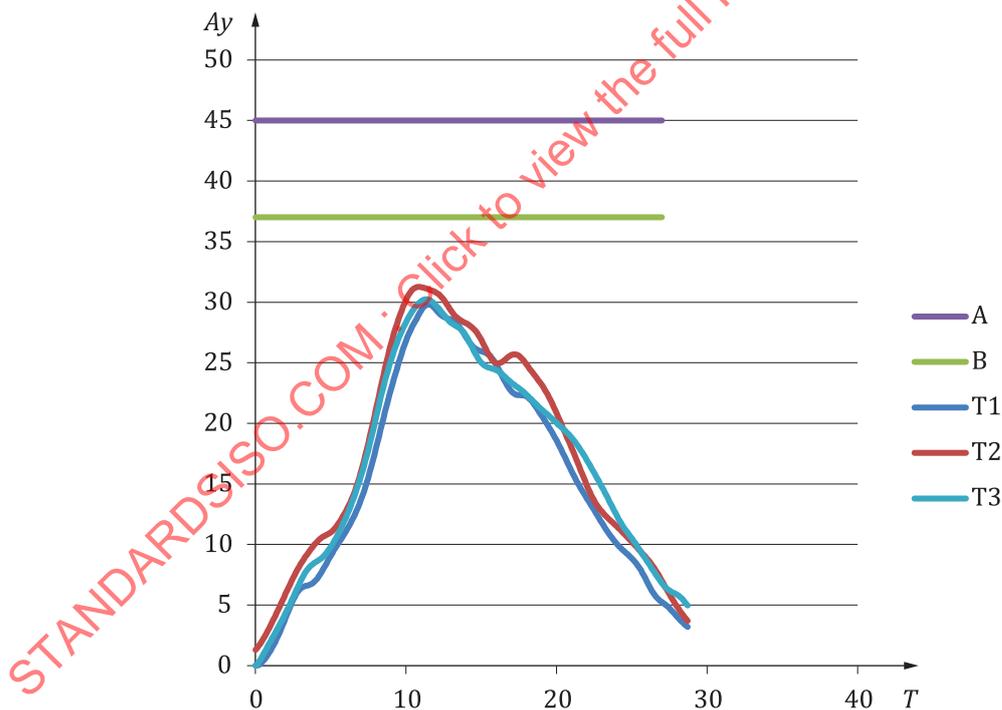
Key

T time (ms)

Ay lateral acceleration (g)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   test number WS009-BDRPL1

T2   test number WS009-BDPRL2

T3   test number WS009-BDRPL3

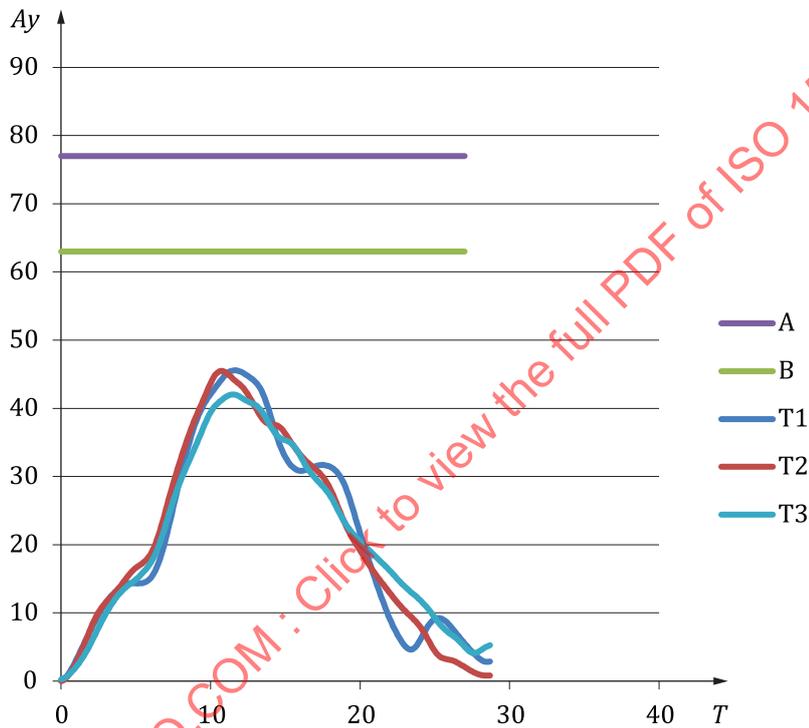**Figure C.43 — Pelvis test 3 – pelvis lateral acceleration**

The biofidelity rating for pelvis test 3 is summarized in Table C.16.

Table C.16 — Pelvis test 3 – 0,5 m rigid drop test results

Measure	Lower bound	Upper bound	Run #1	Run #2	Run #3	Avg. rating	Weight factor	Rating
Peak pelvis acceleration (g)	37	45	30	31	30		7	5,0
Rating						5,0		

C.7.4   Pelvis test 4 – 1,0 m rigid drop test

The biofidelity rating for pelvis test 4, peak pelvis lateral acceleration was 0 for all tests. See Figure C.44. Note the test numbers of T1, T2 and T3 were corrected.

Key

T time (ms)

Ay lateral acceleration (g)

A   ISO/TR 9790 upper corridor

B   ISO/TR 9790 lower corridor

T1   test number WS009-BDRPH1

T2   test number WS009-BDRPH2

T3   test number WS009-BDRPH3

Figure C.44 — Pelvis test 4 – pelvis lateral acceleration

The biofidelity rating for pelvis test 4 is summarized in Table C.17.