EURO NCAP
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Qualification Procedure for Human Body Models

Crash Protection

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PREFACE

DISCLAIMER: Euro NCAP has taken all reasonable care to ensure that the information published in this protocol is accurate and reflects the technical decisions taken by the organisation. In the unlikely event that this protocol contains a typographical error or any other inaccuracy, Euro NCAP reserves the right to make corrections and determine the assessment and subsequent result of the affected requirement(s).

CONTENTS

1 INTRODUCTION

This document supports the Crash Protection – Frontal Impact Protocol by providing details on the required qualification of human body models. Such models can be used to provide respective simulation data to be eligible for the full points for the virtual loadcases.

In addition to this document, it is also necessary to refer to the Euro NCAP Technical Bulletin CP 540 for reference point definitions. Additional reference documents and additional information are available using the following links:

- Euro NCAP | Protocols
- https://openvt.eu/EuroNCAP/hbm4vt-validation-catalogue

In future, qualification procedures for additional HBM anthropometries will be incorporated into the Euro NCAP protocol(s) and this document will also be updated accordingly. Another future update will detail requirements for hashing simulation inputs, essentially making sure that the validation setups have not been modified beyond the specific adaptions allowed to include the respective HBM. Likewise, hashing can be used to determine whether a used HBM was changed compared to a previously qualified version of the model.

1.1 General

In the context of the present document, a human body model (HBM) is considered a detailed model if it represents the human body in accordance with CP 540. Other human models, such as those lacking a skeleton, cannot be qualified with the procedure described here.

2 AVERAGE MALE HUMAN BODY MODEL QUALIFICATION

2.1 Qualification procedure overview

The procedure includes two distinct paths: “full qualification,” which covers all load cases, and “comparability demonstration,” a streamlined path that evaluates a subset of those cases. For a newly developed HBM, or one that fails to meet the comparability requirements in section 2.2.5, full qualification is required. For a previously qualified off-the-shelf HBM, the comparability demonstration alone is sufficient.

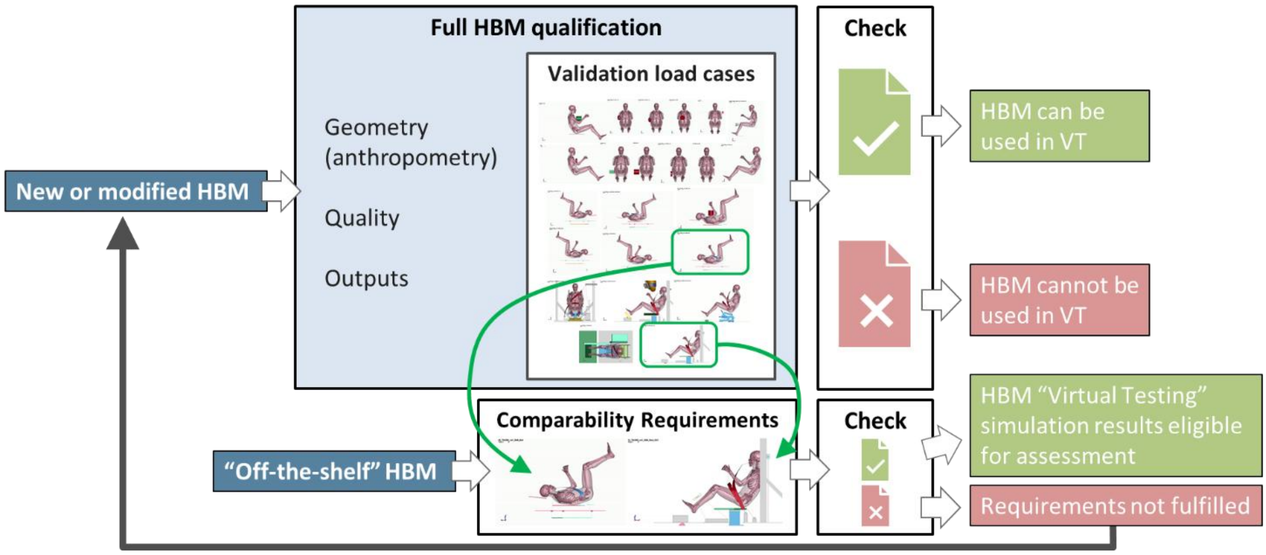

Figure 1: Overview on the possible paths to HBM qualification

2.1.1 Full qualification

Before an HBM can be used for virtual testing at Euro NCAP, evidence must show that the model is sufficiently biofidelic across all validation load cases listed in section 2.2.4. If all criteria in section 2.2.4 are met, Euro NCAP will grant approval of the HBM for use in virtual testing and issue a certificate of qualification.

2.1.2 Comparability demonstration

If an HBM has already been approved for virtual testing by Euro NCAP, the certificate of qualification from section 2.1.1 must be provided along with the comparability demonstration. For this step, only the load cases and criteria in section 2.2.5 must be fulfilled and demonstrated. If these requirements are not met, the full qualification must be repeated.

2.2 Qualification requirements

The HBM qualification requirements for anthropometry, quality, outputs, and validation load cases are detailed in the following sections.

All supporting materials, including experimental data, processing scripts, and simulation models, are available at https://openvt.eu/EuroNCAP/hbm4vt-validation-catalogue. Users may only modify the setups to adjust required parameters, file names, and paths to match their specific HBM.

2.2.1 Anthropometry

To ensure the HBM represents an average adult male anthropometry[1], the following criteria must be met within a 5% tolerance for each.

- Body Mass: 77.3 kg (±3.865 kg)
- Stature: 175.3 cm (±8.765 cm)
- Body Mass Index (BMI): 25.15 kg·m^{-2} (±1.2575 kg·m^{-2})
- Sitting height to stature ratio (SHS): 0.52 (±0.026)

The posture of the HBM must remain unchanged during simulations conducted as part of the comparability demonstration and the *Crash Protection – Frontal Impact Protocol*. Any changes to posture, except for adjustments to the extremities, require a full qualification of the model. Anthropometry and posture data must be entered into the spreadsheet as specified in the VTC protocol.

2.2.2 Model quality

The mesh quality of the original model needs to be documented according to TB CP 520.

2.2.3 HBM outputs

Table I below lists the required outputs that need to be present in the respective solver output files (e.g. binout, HDF5…). The correct IDs for the outputs listed below need to be filled into the HBM ID definition file which needs to be named 00_[HBMname]_[version]_[anthropometry]_IDs.def (e.g. 00_GHBMC_v6.2_50M_IDs.def)

For outputs where local outputs are requested, the sign convention must follow SAE J211 (2007).

A graphical explanation of the listed nodes is provided in the documentation of each loadcase available on https://openvt.eu/EuroNCAP/hbm4vt-validation-catalogue, the appendix or CP 540 as shown in the column "reference".

Table I: Required HBM outputs

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
Head_CoG	Head	Centre of Gravity	Node history (coordinate, displacement, velocity, rot. Velocity, acceleration)	CP 540	x
Head_CoG_loc	Head	Centre of Gravity local	Node history (local displacement, velocity, rot. Velocity, acceleration) – coordinate system is	CP 540	x

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
			defined with the Frankfort plane as x-y plane and z facing downwards in the midsagittal plane		
Clavicle_left_inner	Thorax – clavicle	Node on clavicle bone at 3D midpoint between most medial and lateral nodes of the clavicle	Node history (coordinate, displacement, velocity, acceleration)	Figure 2	
Clavicle_left	Thorax – clavicle	Node on the skin which is closest to the node Clavicle_left_inner projected in anterior direction	Node history (coordinate, displacement, velocity, acceleration)	Figure 3	
Thorax_4IS	Thorax - Skin	Node on the skin at the mid-height of 4th intercostal space on the mid sagittal plane projected anterior	Node history (coordinate, displacement, velocity, acceleration)	Figure 4	
Thorax_4ISi	Thorax – sternum	Node on the anterior surface of the sternum at the height of 4th intercostal space on the mid sagittal plane	Node history (coordinate, displacement, velocity, acceleration)	Figure 4	
Thorax_BxS	Thorax – skin	Node ID on outer skin of thorax at the location where the belt crosses the sternum in mid sagittal plane	Node history (coordinate, displacement, velocity, acceleration)	Table top load case manuals	
Thorax_BxSi	Thorax - sternum	Node ID on the anterior surface of the sternum at the location where the belt crosses the	Node history (coordinate, displacement, velocity, acceleration)	Table top load case manuals	

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
		sternum in mid sagittal plane			
Thorax_R2R7	Thorax – skin	Node on anterior on the outer skin at the midheight between the 2nd and 7th costosternal junction in mid sagittal plane	Node history (coordinate, displacement, velocity, acceleration)	Figure 4	
Thorax_R2R7i	Thorax – sternum	Node on anterior sternum surface at the midheight between the 2nd and 7th costosternal junction in mid sagittal plane	Node history (coordinate, displacement, velocity, acceleration)	Figure 4	
Chest_defl_Sternum_mid	Thorax – sternum	Node on sternum at midpoint between Jugular Notch and xiphoid processuswith local coordinate system in T8	Node history (coordinate, displacement, velocity, acceleration)	Figure 4	
T1	Spine – T1	Node at geometric centre of all nodes of vertebral body of T1	Node history (coordinate, displacement, velocity, acceleration)	Consistent to T8	x
T8	Spine - T8	Node at geometric centre of all nodes of vertebral body of T8	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
L2	Spine – L2	Node at geometric centre of all nodes of vertebral body of L2	Node history (coordinate, displacement, velocity, acceleration)	Consistent to T8	x
Pelvis	Sacrum	Midpoint of right and left posterior superior iliac spines (PSIS)	Node history (coordinate, displacement,	Figure 5	x

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
		connected to sacrum	velocity, acceleration)		
Pubic_Symphysis	Pelvis	Cross section in the midsagittal plane of the pubic symphysis with local coordinate system (SAE)	Cross-sectional Forces and Moments	Figure 6	
AC_right	Pelvis	Node ID on center of right Acetabulum	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
AC_left	Pelvis	Node ID on center of left Acetabulum	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
Hip_center_right	Pelvis	Node representing the center of a sphere fitted into the right acetabulum[1]	Node history (coordinate, displacement, velocity, acceleration)		x
Hip_center_left	Pelvis	Node representing the center of a sphere fitted into the left acetabulum	Node history (coordinate, displacement, velocity, acceleration)		x
SC_left	Scapula	Shoulder reference point left	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
SC_right	Scapula	Shoulder reference point right	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
JN	Sternum	Jugular Notch	Node history (coordinate,	Figure 4	x

[1] Script to derive the center of the sphere will be made available on https://openvt.eu/EuroNCAP/hbm4vt-validation-catalogue/.

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
			displacement, velocity, acceleration)		
XP	Sternum	Tip of xiphoid process	Node history (coordinate, displacement, velocity, acceleration)	Figure 4	x
HM_left	Humerus	Midpoint of the most caudal-lateral and caudal-medial point on lateral epicondyle of the humerus left	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
HM_right	Humerus	Midpoint of the most caudal-lateral and caudal-medial point on lateral epicondyle of the humerus right	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
US_left	Ulna	Tip of ulnar styloid left	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
US_right	Ulna	Tip of ulnar styloid right	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
FE_left	Femur	Midpoint of lateral and medial femoral epicondyle left	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
FE_right	Femur	Midpoint of lateral and medial femoral epicondyle right	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
IM_left	Tibia/Fibula	Inter-malleolar point left	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
IM_right	Tibia/Fibula	Inter-malleolar point right	Node history (coordinate, displacement, velocity, acceleration)	CP 540	x
N_STER_Kroell_1971	Thorax - sternum	Node ID on anterior surface of sternum on Kroell impactor beam axis	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_VERT_Kroell_1971	Spine – T8	Node ID on anterior surface of T8 on Kroell impactor beam axis	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_SKIN_Kroell_1971	Thorax - skin	Node ID on anterior surface of thoracic skin on impactor beam axis	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_PSKI_Kroell_1971|	Thorax – skin	Node ID on posterior surface of thoracic skin on impactor beam axis	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_ACRL_Compigne_2004	Upper Extremities	Most distal node on left acromion	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_ACRR_Compigne_2004	Upper Extremities	Most distal node on right acromion	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_STER_Compigne_2004	Thorax	Node ID on the midpoint of the	Node history (coordinate, displacement,	Loadcase Manual	

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
		manubrium of the sternum	velocity, acceleration)		
N_VERT_Compigne_2004	Thorax	Node ID on the dorsal point of T1 vertebrae	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_STER_Bouquet_1994	Thorax	Node ID on anterior surface of sternum on impactor beam axis	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_VERT_Bouquet_1994	Thorax	Node ID on anterior surface of T8 on impactor beam axis	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_SKIN_Bouquet_1994	Thorax – skin	Node ID on anterior surface of thoracic skin on impactor beam axis	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_SC90_Shaw_2006	Thorax – skin	Node ID on outer skin on the beam axis on the hub side at 90deg	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_SO90_Shaw_2006	Thorax – skin	Node ID on outer skin on the beam axis opposite to the hub at 90deg	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_SC60_Shaw_2006	Thorax-skin	Node ID on outer skin on the beam axis on the hub side at 60deg	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_SO60_Shaw_2006	Thorax – skin	Node ID on outer skin on the beam axis opposite to the hub at 60deg	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
N_RC90_Shaw_2006	Thorax – rib	Node ID on lateral rib end on the beam axis on the hub side at 90deg	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_RO90_Shaw_2006	Thorax – rib	Node ID on lateral rib end on the beam axis opposite to the hub at 90deg	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_RC60_Shaw_2006	Thorax – rib	Node ID on lateral rib end on the beam axis on the hub side at 60deg	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_RO60_Shaw_2006	Thorax – rib	Node ID on lateral rib end on the beam axis opposite to the hub at 60deg	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_4S_Shaw_2007	Thorax – skin	Midpoint between most inferior 4th intercostal junction and most superior point of 4th intercostal junction in midsagittal plane	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
N_8S_Shaw_2007	Thorax – skin	Midpoint between most inferior 4th intercostal junction and most superior point of 8th intercostal junction in midsagittal plane	Node history (coordinate, displacement, velocity, acceleration)	Loadcase Manual	
RibR_1	Thorax - rib	Part IDs which form the **cortical bone** of the 1st rib on the right side	Object (strains)		x
RibR_2	Thorax - rib	Part IDs which form the cortical bone of the 2nd rib on the right side	Object (strains)		x

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
RibR_3	Thorax - rib	Part IDs which form the cortical bone of the 3rd rib on the right side	Object (strains)		x
RibR_4	Thorax - rib	Part IDs which form the cortical bone of the 4th rib on the right side	Object (strains)		x
RibR_5	Thorax - rib	Part IDs which form the cortical bone of the 5th rib on the right side	Object (strains)		x
RibR_6	Thorax - rib	Part IDs which form the cortical bone of the 6th rib on the right side	Object (strains)		x
RibR_7	Thorax - rib	Part IDs which form the cortical bone of the 7th rib on the right side	Object (strains)		x
RibR_8	Thorax - rib	Part IDs which form the cortical bone of the 8th rib on the right side	Object (strains)		x
RibR_9	Thorax - rib	Part IDs which form the cortical bone of the 9th rib on the right side	Object (strains)		x
RibR_10	Thorax - rib	Part IDs which form the cortical bone of the 10th rib on the right side	Object (strains)		x
RibR_11	Thorax - rib	Part IDs which form the cortical bone of the 11th rib on the right side	Object (strains)		x
RibR_12	Thorax - rib	Part IDs which form the cortical bone of the 12th rib on the right side	Object (strains)		x

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
RibL_1	Thorax - rib	Part IDs which form the cortical bone of the 1st rib on the left side	Object (strains)		x
RibL_2	Thorax - rib	Part IDs which form the cortical bone of the 2nd rib on the left side	Object (strains)		x
RibL_3	Thorax - rib	Part IDs which form the cortical bone of the 3rd rib on the left side	Object (strains)		x
RibL_4	Thorax - rib	Part IDs which form the cortical bone of the 4th rib on the left side	Object (strains)		x
RibL_5	Thorax - rib	Part IDs which form the cortical bone of the 5th rib on the left side	Object (strains)		x
RibL_6	Thorax - rib	Part IDs which form the cortical bone of the 6th rib on the left side	Object (strains)		x
RibL_7	Thorax - rib	Part IDs which form the cortical bone of the 7th rib on the left side	Object (strains)		x
RibL_8	Thorax - rib	Part IDs which form the cortical bone of the 8th rib on the left side	Object (strains)		x
RibL_9	Thorax - rib	Part IDs which form the cortical bone of the 9th rib on the left side	Object (strains)		x
RibL_10	Thorax - rib	Part IDs which form the cortical bone of the 10th rib on the left side	Object (strains)		x
RibL_11	Thorax - rib	Part IDs which form the cortical	Object (strains)		x

Short name in ID.def file	Body region	Detailed Location	Output type	Reference	Used also in virtual testing
		bone of the 11th rib on the left side			
RibL_12	Thorax - rib	Part IDs which form the cortical bone of the 12th rib on the left side	Object (strains)		x
Ribs_Cort	Thorax - rib	Part IDs of all cortical rib bones	Object (strains)		x
HBM_all	Whole HBM	Part IDs of all HBM parts	Energies and added mass		x

2.2.4 Validation loadcases

To demonstrate the HBM's biofidelity, all of the evaluations listed in Table II have to be performed and the minimum objective metric score value has to be achieved.

The boundary condition models are updated if issues with an HBM or solver version are identified. All revisions of the models on the 3rd digit do not require a re-run.

The scoring methodology compares simulation data to PMHS test data using statistical response corridors generated by ARCGen[2]. In essence, ARCGen constructs these corridors by applying arc-length re-parameterization and signal registration to align experimental signals, compute a characteristic average, and define statistical confidence regions based on variability in the data[2]. Two complementary scores are calculated to assess the similarity between simulation results and experimental data.

1) The **Ellipse Score** evaluates how well the simulation data aligns with the characteristic average response by determining whether each simulation point falls within statistical confidence regions defined by ellipses. A point inside the 1 SD ellipse receives a score of 1, a point outside the 2 SD ellipse receives a score of 0, and points between these boundaries are assigned a linearly scaled score.
2) The **Dynamic Arc-Length Warping (DALW)** Score refines the assessment by optimizing the alignment of simulation and test data before applying the same ellipse-based scoring method. This process dynamically adjusts the arc-length mapping of the simulation data to better match the characteristic average, ensuring that variations in response trajectories are accounted for. The methodology follows a similar approach to the alignment process used for the magnitude score in ISO 18571, where dynamic time warping is applied to enhance curve comparisons in biofidelity evaluations. The final score reflects the best achievable fit while preserving the underlying structure of the data.

[2] Hartlen, D. C., & Cronin, D. S. (2022). Arc-Length Re-Parametrization and Signal Registration to Determine a Characteristic Average and Statistical Response Corridors of Biomechanical Data. Frontiers in Bioengineering and Biotechnology, 10, 843148. https://doi.org/10.3389/fbioe.2022.843148

This dual-scoring approach provides a robust and adaptive evaluation of biofidelity, incorporating both localized fit and optimized alignment.

Scores are calculated between x_min and x_max provided in Table II below only. The differences between the required minimum scores are based on the varying quality of the available PMHS test data, boundary condition models and current state of the art of the HBMs used to create the corridors. For the PMHS, unscaled data was used except for Compigne et al., 2004 due to the very low mass and height. Where chest depths were used for normalisation, it is indicated as "compression". In these cases, the individual PMHS chest depth was used to normalize the response. Likewise, the assessment script relies on the HBM chest depth, to normalize its response.

Scores marked with "-" are not used for scoring, but results need to be provided to Euro NCAP. These will be used for monitoring and potentially updating the procedure in the future. The detailed methodology of the scores will be published in a peer-reviewed paper (Ressi et al., 2025 – manuscript in preparation). The list of state-of-the-art HBMs used to derive the minimum threshold is provided in Appendix Section 4. While the current version of the threshold is mainly driven by the state of the art, it is aimed to achieve an increase of the thresholds until 2029 to showcase biofidelic behaviour of the HBMs used for virtual testing.

The scores have to be calculated with the Jupyter notebook available on https://openvt.eu/EuroNCAP/hbm4vt-validation-catalogue for the respective load case. The binary solver output files (e.g. binout, HDF5…) need to be shared together with the processed csv files with the Euro NCAP secretariat.

Table II: Required HBM outputs

	Configuration	Evaluation	x_min	x_max	Min. Ellipse Score	Min. DALW Score
Bouquet et al., 1994 – Hub Impact, v0.3.1						
	Pelvis Low Speed	Force – Time	0	36ms (end of test data)	-	-
	Pelvis High Speed	Force – Time	0	36ms (end of test data)	0.14	0.46
	Sternum Low Speed	Force – Time	0	57ms (end of test data)	-	0.50
	Sternum High Speed	Force – Time	0	57ms (end of test data)	-	0.66
Cesari & Bouquet, 1990, v0.1.5						
	-	Only one test curve available so far	-	-	-	-
Compigne et al., 2004; v0.2.7[3]						
	3 m/s 0°	Only two test curves	-	-	-	-
	4 m/s 0°	Force – Deflection	0	Cut unloading at 80% of max deflection	-	0.11
	6 m/s 0°	Only two test curves	-	-	-	-
	1.5 m/s 0°	Force – Deflection	0	Cut unloading at	0.11	0.14

[3] It is still under investigation why scores for several models are very low in this load case.

				80% of max deflection		
	1.5 m/s 15°	Force – Deflection	0	Cut unloading at 80% of max deflection	-	-
	1.5 m/s -15°	Force – Deflection	0	Cut unloading at 80% of max deflection	-	-
Forman et al., 2005; v0.2.4						
	Tabletop Test	Force-Chest Compression	Cut data so that only data ≥ 5% of f_max remains	Up to max. arc length of characteristic average	0.16	0.25
Forman et al., 2013; v0.7.6						
	Far Side Sled Tests	Waiting for test data	0	250 ms	-	-
Kent et al. 2004 - tabletop; v0.8.9						
	Hub	Force - Compression	Cut data so that only data ≥ 5% of f_max remains	max. arc length of characteristic average	0.70	0.85
	Belt	Force - Compression	Cut data so that only data ≥ 5% of f_max remains	max. arc length of characteristic average	0.57	0.80
	Double-Belt	Force - Compression	Cut data so that only data ≥ 5% of f_max remains	max. arc length of characteristic average	0.61	0.84
	Distributed Belt	Force - Compression	Cut data so that only data ≥ 5% of f_max remains	max. arc length of characteristic average	0.78	0.86
Kroell et al., 1971 (taking Lebarbé & Petit (2012) into account); v0.2.5						
	Hub Impact High Speed	Force-(Hub)Displacement	0	Cut unloading at 80% of max deflection	0.16	0.56
Leport et al., 2007; v0.2.2						
	Hub Test	Impactor Force – Time	0	44 ms (end of test data)	-	0.55
		PSIS Force – Time	0	44 ms (end of test data)	-	0.49
	Mini Sled	Impactor Force – Time	0	44 ms (end of test data)	0.26	0.50
		PSIS Force – Time	0	44 ms (end of test data)	0.11	0.52
Lopez-Valdes, 2017 – Frontal Sledtest; v0.6.5						

	Restraint Condition A	Head X Displ- Time	0	159 ms (end of test curves)	-	0.64
		T8 X-Displ – Time	0	159 ms (end of test curves)	-	0.68
		T1 X-Displ – Time	0	159 ms (end of test curves)	0.23	0.85
		Pelvis X-Displ Time	0	159 ms (end of test curves)	0.62	0.94
	Restraint Condition B	Head X Displ- Time	0	159 ms (end of test curves)	0.58	0.78
		T8 X-Displ – Time	0	159 ms (end of test curves)	-	-
		T1 X-Displ – Time	0	159 ms (end of test curves)	-	-
		Pelvis X-Displ Time	0	159 ms (end of test curves)	-	0.57
Petit et al., 2019 – Farside Sledtest; v0.7.9						
		Head y displacement – time	0	200 ms (end of simulations)	0.12	0.87
		Head z displacement - time	0	200 ms (end of simulations)	-	0.49
Rupp et al., 2008; v0.1.14[4]						
	4.9 m/s	Force – Time for left and right knee	0	40 ms (end of loading)	-	0.16
	3.5 m/s	Force – Time for left and right knee	0	50 ms (end of loading)	-	0.20
	1.2 m/s	Force – Time for left and right knee	0	69 ms (end of loading)	-	0.17
Salzar et al., 2009; v0.5.3						
	0.5 m/s	Force - Compression	0	max. arclength of characteristic average	0.40	0.60
	1 m/s	Force - Compression	0	max. arclength of characteristic average	0.68	0.77
G. Shaw et al., 2004; v0.3.2						
	Up to 50% chest depth	Only one test curve	-	-	-	-
	Up to 30% chest depth	Force – Compression	Force >0	Unloading cut at max. force	-	0.27

[4] The thresholds of this loadcase are still under review. Issues with the boundary condition model were observed for one HBM.

J. M. Shaw et al., 2006; v0.4.1						
	Lateral impact (90°)	Force - Compression	0	Displacement and force at 100 ms	-	0.49
	Oblique impact (60°)	Force - Compression	0	Displacement and force at 100 ms	-	0.33
G. Shaw et al., 2007; v0.4.0						
	Non-injurious U – 3rd left rib	Force Displacement	0	Up to max. arc length of characteristic average	-	-
	Non-injurious M – mid sternum	Force Displacement	0	Up to max. arc length of characteristic average	-	-
	Non-injurious L – 6th right rib	Force Displacement	0	Up to max. arc length of characteristic average	-	0.49
	Injurious	Only 2 curves (will be used later for rib fracture risk)	-	-	-	-
G. Shaw et al., 2009; v0.9.0						
	Config. 1	no trajectories available	0	-	-	-
	Config. 2	Head x displacement – time	0	240 ms (end of test curves)	0.24	0.59
		Head y displacement – time	0	240 ms (end of test curves)	-	0.43
		Head z displacement – time	0	240 ms (end of test curves)	-	0.19
		T1 x displacement – time	0	240 ms (end of test curves)	-	0.27
		T1 y displacement – time	0	240 ms (end of test curves)	-	0.22
		T1 z displacement – time	0	240 ms (end of test curves)	-	-
		T8 x displacement – time	0	240 ms (end of test curves)	-	0.40
		T8 y displacement – time	0	240 ms (end of test curves)	-	0.34
		T8 z displacement – time	0	240 ms (end of test curves)	-	-
		Pelvis x displacement – time	0	240 ms (end of test curves)	-	0.29

		Pelvis y displacement – time	0	240 ms (end of test curves)	-	0.36
		Pelvis z displacement – time	0	240 ms (end of test curves)	-	-
		Chest Deflection - Time	0	150 ms (end of test curves)	-	0.52
Uriot et al. 2015; v0.6.6						
	Seat Configuration Front	Hip x-displ vs. time	0	110 ms (max. test data)	0.67	0.95
		Pelvis rotation vs. time	0	110 ms (max. test data)	-	0.21
	Seat Configuration rear	Hip x-displ vs. time	0	110 ms (max. test data)	-	0.72
		Pelvis rotation vs. time	0	110 ms (max. test data)	0.12	0.27
Viano, 1989; v0.6.7						
	Hip High Speed	Force-Compression	0	Up to max. arc length of characteristic average (test curves at max force)	0.25	0.51
	Hip Medium Speed	No test data available	-	-	-	-
	Hip Low Speed	Force-Compression	0	Up to max. arc length of characteristic average	0.25	0.57
	Abdomen High Speed	Force-Compression	0	Up to max. arc length of characteristic average	0.20	0.24
	Abdomen Medium Speed	Force-Compression	0	Up to max. arc length of characteristic average	-	-
	Abdomen Low Speed	Force-Compression	0	Up to max. arc length of characteristic average	0.32	0.45
	Thorax High Speed	Force-Compression	0	Up to max. arc length of characteristic average	0.51	0.61
	Thorax Medium Speed	Force-Compression	0	Up to max. arc length of	0.22	0.24

				characteristic average		
	Thorax Low Speed	Force-Compression	0	Up to max. arc length of characteristic average	-	-
Yoganandan et al., 1997; v0.5.7						
	Hub Impact	Force - Compression	0	Unloading cut at 80% of max. displacement	0.32	0.82

2.2.5 Comparability loadcases

To verify that the original HBM behaves as it should and was not modified, the evaluations listed in the table below have to be performed and the objective metric score has to be within the defined tolerance to demonstrate that the results are in line with the reference results, i.e., their scores are within +/- 0.1 compared to the reference value documented in the report of the full validation [or at least within the limits defined in the table below][5].

The scores have to be calculated with the Jupyter notebook available on https://openvt.eu/EuroNCAP/hbm4vt-validation-catalogue for the respective load case. The binary solver output files (e.g. binout, HDF5…) need to be shared together with the processed csv files with the Euro NCAP secretariat.

	Configuration	Evaluation	x_min	x_max	Minimum - Maximum Ellipse score	Minimum - Maximum Warpage score
Kent et al. 2004 v0.8.9						
	Belt	Force - Compression	Cut data so that only data ≥ 5% of f_max remains	max. arc length of characteristic average	0.57-0.98	0.80-1.00
Shaw et al., 2009 v0.9.0						
	Config. 2	Head x displacement – time	0	240 ms (end of test curves)	0.24-0.89	0.59-1.00
		Chest Deflection - Time	0	150 ms (end of test curves)	0.09-0.37	0.52-0.74

[5] Approach currently under review. As soon as more data is available, this option might be deleted in the next version of the protocol.

3 APPENDIX – REFERENCE NODES

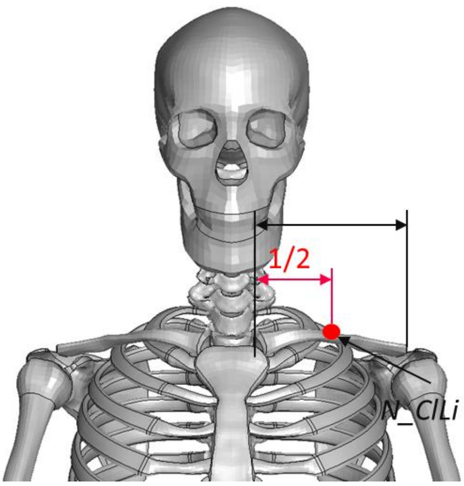

Figure 2: Clavicle_left_inner: Node on anterior surface of left clavicle bone closest to the 3D midpoint between most medial and lateral nodes of the clavicle

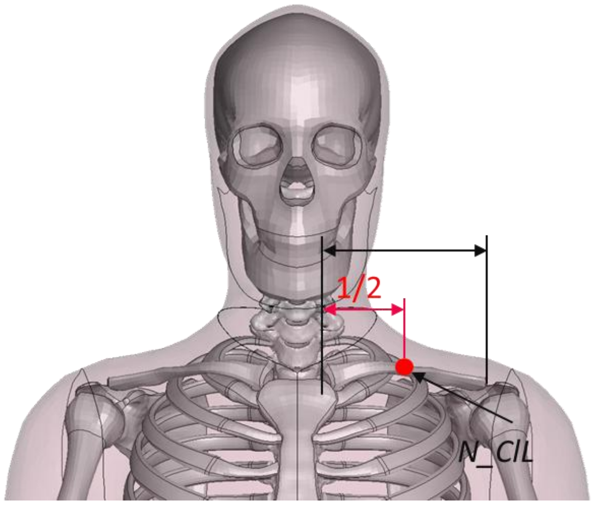

Figure 3: Clavicle_left: Node on the skin which is closest to the node Clavicle_left_inner projected in anterior direction.

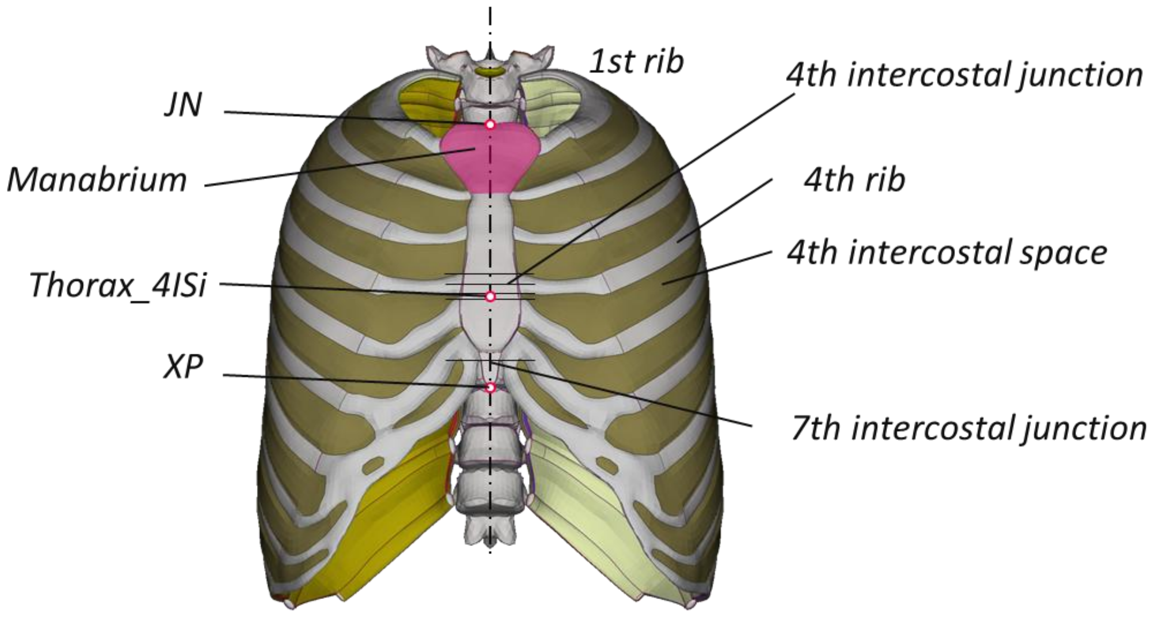

Figure 4: Nodes on the sternum

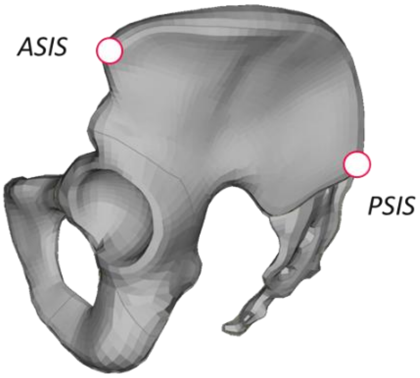

Figure 5: Pelvis landmarks

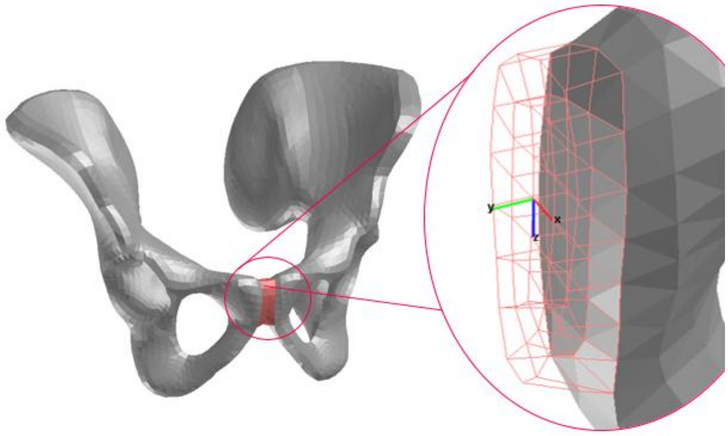

Figure 6: Local coordinate system in mid-sagittal pubic symphysis cross-section where y faces normal to the cross-sectional surface and x facing anterior and z inferior

4 APPENDIX – LIST OF HBMS USED TO DEFINE MINIMUM THRESHOLDS

LS Dyna:

- THUMS_v4.1_50M (run by 4 different users)
- GHBMC_M50-O_v6.2 (run by 2 different users)
- HANS_v1.0_50M
- VIVA+_50M
- HBM-C_v1.5_50M
- SAFER HBM V11.1.0
- THUMS_v7_50M
- GHBMC_M50-OS_v2.3

VPS:

- THUMS_v4.1_50M