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Pedestrian CAE Models & Codes

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Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
Honda Human FE model (Adult) Version 13th June 2011	Geometric reconstruction derived from CT/MRI scans (bones, ligaments) - pelvis and lower limb Articulated rigid body for upper body (lumbar and above) - neck and lumbar divided into 7 and 5 segments	Baseline model represent anthropometry close to 50th percentile male; baseline model can be scaled to any sizes of adult population	whole body kinematics (head, T1, T8, pelvis) during an impact against a small sedan and a large SUV at 40 km/h	Small sedan: Kerrigan, J. R., Murphy, D. B., Drinkwater, D. C., Kam, C. Y., Bose, D., Crandall, J. R. : Kinematic Corridors for PMHS Tested in Full-Scale Pedestrian Impact Tests, 19thESV, Paper number 05-0394 (2005) Large SUV: Kerrigan, J. R., Kam, C. Y., Drinkwater, D. C., Murphy, D. B., Bose, D., Ivarsson, J., Crandall, J. R. : Kinematic Comparison of the POLAR-II and PMHS in Pedestrian Impact Tests with a Sport-Utility Vehicle, IRCOBI Conference (2005)	Source of human response data
				Kikuchi, Y., Takahashi, Y., Mori, F. : Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian, SAE World Congress, Paper Number 2008-01-1243 (2008)	Source of validation results
			Dynamic lateral compression of pelvis (Force-deflection at acetabulum and ilium in both acetabulum and iliac loadings)	Salzar, R. S., Genovese, D., Bass, C. R., Bolton, J. R., Guillemot, H., Damon, A. M., Crandall, J. R. : Load Path Distribution within the Pelvic Structure under Lateral Loading, International Crashworthiness Conference (2008)	Source of human response data
				Takahashi, Y., Suzuki, S., Ikeda, M., Gunji, Y. : Investigation on Pedestrian Pelvis Loading Mechanisms Using Finite Element Simulations, IRCOBI Conference (2010) (To be published)	Source of validation results
			Dynamic 3-point bending of lower limb long bones in lateral-medial direction at mid-shaft, distal third and proximal third	Kerrigan J. R., Bhalla K. S., Madeley N. J., Funk J. R., Bose D., Crandall J. R. : Experiments for Establishing Pedestrian-Impact Lower Limb Injury Criteria, SAE Paper #2003-01-0895 (2003)	Source of human response data
				Takahashi, Y., Kikuchi, Y., Mori, F., Konosu, A. : Advanced FE Lower Limb Model for Pedestrians, 18th ESV, Paper number 218 (2003)	Source of validation results

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
			Dynamic 3-point bending of thigh and leg (with flesh on) in lateral-medial direction at mid-shaft, proximal third (leg only) and distal third	Ivarsson, J., Lessley, D., Kerrigan, J., Bhalla, K., Bose, D., Crandall, J., Kent, R. : Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities, IRCOBI Conference (2004)	Source of human response data
				Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)	Source of validation results
			Dynamic knee ligament distraction to failure at different loading rates for MCL, LCL, ACL (anterior and posterior parts individually) and PCL (anterior and posterior parts individually)	Bose D., Sanghavi P., Kerrigan J. R., Madeley N. J., Bhalla K. S., Crandall J. R. : Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization, International Workshop on Human Subjects for Biomechanical Research, (2002)	Source of human response data
				Takahashi, Y., Kikuchi, Y., Mori, F., Konosu, A. : Advanced FE Lower Limb Model for Pedestrians, 18th ESV, Paper number 218 (2003)	Source of validation results
				Van Dommelen, J. A. W., Ivarsson, B. J., Jolandan, M. M., Millington, S.A., Raut, M., Kerrigan, J.R., Crandall, J.R., Diduch, D.R. : Characterization of the Rate-Dependent Mechanical Properties and Failure of Human Knee Ligament, SAE Paper number 2005-01-0293 (2005)	Source of human response data
				Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)	Source of validation results
			Dynamic 4-point bending of knee joint in valgus bending	Ivarsson, J., Lessley, D., Kerrigan, J., Bhalla, K., Bose, D., Crandall, J., Kent, R. : Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities, IRCOBI Conference (2004)	Source of human response data

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
				Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)	Source of validation results
			General	Takahashi, Y., Kikuchi, Y., Konosu, A., Ishikawa, H., *Development and validation of the finite element model for the human lower limb of pedestrians*, Stapp Car Crash journal, Vol. 44, 2000-101-SC22 (2000)	
Honda Human FE model (Child) Version 1st April 2009	Geometric reconstruction derived from MRI scans from a 6YO child (whole-body external shape, lower limb bones and ligaments) FE model for thigh and leg; Articulated Rigid Body model for pelvis and above representing freedom of motion of spine Represent child-specific anatomical structures such as cartilaginous layers at ends of long bones	Represent 6YO child anthropometry	Dynamic 3-point bending of child femur and child tibia in lateral-medial direction	Ouyang, J. et al.: *Biomechanical Character of Extremity Long Bones in Children and its significance*, Chinese Journal of Clinical Anatomy, Vol.21, No.6, p620-p623 (2003), (in Chinese)	Source of human response data
				Ito, O., Okamoto, M., Takahashi, Y., Mori, F. : *Validation of an FE Lower Limb Model for a Child Pedestrian by Means of Accident Reconstruction*, SAE paper number 2008-01-1240 (2008)	Source of validation results
			Leg fracture prediction validated against CIREN in-depth accident data by means of accident reconstruction	Ito, O., Okamoto, M., Takahashi, Y., Mori, F. : *Validation of an FE Lower Limb Model for a Child Pedestrian by Means of Accident Reconstruction*, SAE paper number 2008-01-1240 (2008)	Source of validation results

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
THUMS Version 1.0, 3.0, 4.0, Daimler THUMS-D based on v3.0		AM50, AF05, 6YO, AM95	injury parameters are accurately predicted	T. Yasuki and Y. Yamamae, Validation of Kinematics and Lower Extremity Injuries Estimated by Total Human Model for Safety in SUV to Pedestrian Impact Test, Journal of Biomechanical Science and Engineering Vol. 5 (2010) , No. 4 Special Issue on Biomechanics in Cardiovascular Systems T. Maeno et al., Development of a Finite Element Model of the Total Human Model for Safety (THUMS) and Application to Car-Pedestrian Collisions, ESV 2001 Watanabe, R., Miyazaki, H., Kitagawa, Y., Yasuki, T., : Research of Collision Speed Dependency of Pedestrian Head and Chest Injuries Using Human FE Model (THUMS Version 4), 22nd ESV, Paper number 11-0043 (2011)	Commercially available (AM50) Toyota in-house models (AF05, 6YO, AM95)
JLR Human FE model Version 8.1, 9.0		child, 5th 50th 95th	See references	HOWARD, M., THOMAS, A., KOCH, D. W., WATSON, J. & HARDY, R. (2000) Validation and Application of a Finite Element Pedestrian Humanoid Model for Use in Pedestrian Accident Simulations. IRCOBI. Montpellier, France, IRCOBI. Developments in the simulation of real world car to pedestrian accidents using a pedestrian humanoid finite element modelR Hardy, J Watson, M Howard - International Journal of Crashworthiness, 2000. HOWARD, M. S. (2002) Pedestrian Accident Simulation and Protection. Technology Evaluation. School of Engineering. Cranfield University.	JLR in-house model

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
MADYMO Human models version 4.2, 4.3, 5.0, 5.1	MADYMO Human Models Manual, Version 7.3, 7.4, 7.4.1, 7.4.2, 7.5, 7.6, TNO Automotive, Delft, The Netherlands, November 2010	3yo, 6yo, 5th F, 50th M, 95th. These models result from a scalable mid-size male pedestrian model	Details see references,	MADYMO Human Models Manual, Version 7.3, TNO Automotive, Delft, The Netherlands, November 2010. Quality report pedestrian models, 1st October 2015, tass international.	Commercially available
IEE-WPI FE Model Version 1.0	Up-right pedestrian model based on WPI study with following improvements 1. introduction of upper body masses represented by rigid bodies 2. more detailed knee modelling (a. ligaments b. non-linear and strain-rate dependent material laws with appropriate failure criteria c. introduction of a simplified knee capsule 3. femur and tibia soft tissue material 4. femur meshed with shell elements	50% male available. 5% female and 6 year old child under development	Model aims at a humanlike interaction with the vehicle bumper and therefore has: - hip- / knee-joint mechanics (ligaments) - tissue / ligament / bone sub-structure - correct anthropometric proportions Rigid-body model validation according to Madymo (c.f. J.van Hoof) FE-model validation according to - J. Kajzer et al - J.R. Kerrigan et al - J.A.W. van Dommelen et al	C. Silvestri - Development and validation of a knee-thigh-hip LS-DYNA model of a 50th percentile male PhD Thesis, Worcester Polytechnic Institute, April 2008 C. Silvestri, M. H. Ray - Development of a Finite Element Model of the Knee-Thigh-Hip of a 50th Percentile Male including Ligaments and Muscles, International Journal of Crashworthiness, Vol. 14, No. 2, pp: 215-229, 2009 FE-based pedestrian modelling to simulate the collision process with a car front-end Dr. Wener Bieck (IEE S.A.) 5. pedestrian protection conference, July 2010 (by Carhs & BGS	IEE in-house model

Pedestrian CAE model		**Pedestrian Sizes**	**Level of Biofidelity**	**References**	**Notes**
PAMCRASH Version 1.0		3yo, 6yo, 5th F, 50th M, 95th. These models result from a scaleable mid-size male pedestrian model	Whole body kinematics based on articulated rigid bodies with focus on humanlike whole body kinematics and head contact times based on corridors from ref. 3 + 4	1. Jason R. Kerrigan, Drew B. Murphy, D. Chris Drinkwater, Check Y. Kam, Dipan Bose, Jeff R. Crandall Kinematic Corridors for PMHS tested in full-scale Pedestrian Impact Tests University of Virginia Center for Applied Biomechanics United States 2. Jason Kerrigan, Carlos Arregui, Jeff Crandall1 Pedestrian Head Impact Dynamics: Comparison of Dummy and PMHS in small Sedan and Large SUV Impacts University of Virginia Center for Applied Biomechanics United States European Center for Injury Prevention, Universidad de Navarra Spain 3. SAE-Proposal J2782,2007, 'Performance Specifications for a 50th Percentile Male Pedestrian Research Dummy'. 4. Ishikawa H., 1993 'Computer Simulation of Impact Response of the Human Body in Car-Pedestrian Accidents'.	Available for PAMCRASH-users (development project partners from ESI).
JAMA Human FE Model Version 13th June 2011	Coupling of the upper body from THUMSTM(Ver.1.4) and the lower body from H-modelTM based Honda Human Pedestrian Model Modifications were made to improve biofidelity and computational stability.	Baseline model represent anthropometry close to 50th percentile male; baseline model can be scaled to any sizes of adult population	whole body kinematics (head, thoracic and lumbar spines, femur, tibia and foot) during an impact against four types of vehicles (minicar, sedan, SUV and minivan), only one trajectory of which is published Injuries not yet	Sugimoto, T., Yamazaki, K., First Results from the JAMA Human Body Model Project, 19th ESV Conference, Paper Number 05-0291 (2005)	Overview
				Kamiji, K., Yamazaki, K., Development of Finite Element Model of Human to Reduce Injuries in Traffic Accidents, Journal of Society of Automotive Engineers of Japan 62(5), pp. 34-39 (2008) (in Japanese)	Source of validation results

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
			satisfactorily reproduced		
Nissan Human FE Model Version 3.0, 4.0 AM95 based on JAMA and GHBMC model.		6yo, 50th Male, 5th Female and 95th Male	AM50% and AC06(6-yr-old): whole body kinematics (head, thoracic and lumbar spines, femur, tibia and foot) during an impact against different types of vehicles to reproduce real world phenomena based on PCDS accident data base. AF05: Good overall kinematics, Excellent detail pelvis injury estimation. AM95%: Good (overall kinematics) Excellent (detail lower injury estimation based on real world accident data)	1. Different Factors Influencing Post-crash Pedestrian Kinematics Y. Kawabe, Murakami, C. Pal and T. Okabe, 2012 SAE International paper no. 2012-01-0271 2. Post-crash Pedestrian Head Kinematics in Real World Accidents Using 6-yr Old Child FE Model C. Pal, K. Yoshiko, O. Tomosaburo, Nissan Motor Company Ltd JSME-CMD symposium Paper no. 2402 3. Analysis of Pedestrian Kinematics and Injury Mechanism In Real World Accidents Murakami, Daisuke; *Pal, Chinmoy; Kawabe, Yoshiko; Okabe Tomosaburo Nissan Motor Company Ltd., Japan FISITA2012 paper no. F2012-F03-010 4. Human FE Model to Estimate Head Contact Time for Pedestrian Protection C. Pal, O. Tomosaburo, Nissan Motor Company Ltd. M. Muthukumar, S. Narayanan, RNTBCI Paper Number 13-0376 5. Estimation of Pelvis Injuries and Head Impact Time using Different Pedestrian Human FE Models Chinmoy Pal and Tomosaburo Okabe Nissan Kulothungan Vimalathithan, Jeyabharath	Accurate for HIT and body contact calculation requirements, as per Euro NCAP protocol. Level pelvis injuries are verified with real world accident data JAMA AM50 upper body and GHBMC AM50 lower leg models are well integrated and modified to suit Euro NCAP protocol requirements.

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
				Manoharan, Muthukumar Muthanandam, and Satheesh Narayanan RNTBCI 2014-01-0522 SAE2014 6. Effect of vehicle's front end profile on pedestrian's lower extremity injury pattern in real world and verification by large male FE Human Model. Chinmoy Pal, Tomosaburo Okabe, Munenori Shinada Nissan Kulothungan Vimalathithan, Jeyabharath Manoharan, RNTBCI 2015-01-1467 SAE2015	
GM/GME Human FE Model Version 8.2.1 Version 1.0		50th Male 6yo, 5th female & 95th male.	Model aims to replace Madymo-Multi-Body -Model in case of whole body kinematics and contact times - Whole body kinematics (head, T1, pelvis, left femur and tibia) during an impact against a small sedan (1400 kg) at 40 kmph - Dynamic 3-point bending of femur in anterior-posterior direction at mid-shaft - Dynamic 3-point bending of leg (with flesh) in lateral-medial direction at mid-calf	1. Deng B et al, "Human model for real-world vehicle-pedestrian impact simulations."INFATS - Proceedings of the 5th International Forum of Automotive Traffic Safety, China : Hunan University, 2007 2. Deng B et al, "Human model for real-world vehicle pedestrian impact simulations." Paper presented at the International Symposium of Human Modeling and Simulation in Automotive Safety, Aschaffenburg, Germany, 2007 3. Unatriou C et al, “A Finite element model of the lower limb for simulating pedestrian impact”, Stapp Car Crash Journal, 49:157-181, 2005 4. Vusirikala N, “ Development of deformable pelvis model for motor vehicle crashes”, GM Internal Report, 2007 5. Vusirikala N, “ Development of whole hip capsule ligament FE model”, GM Internal Report, 2008 6. Vusirikala N, “ Estimation of pedestrian lower leg injury potential using lower extremity human body model”, GM Internal Report, 2008	

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
			- 4-point bending of knee joint in valgus bending - 3-point combined loading test of knee-joint - Quasi-static 3-point bending of femur, tibia and fibula in anterior-posterior and lateral-medial directions - Quasi-static tensile test to failure and dynamic ramp-and-hold tensile test for the MCL - Dynamic lateral compression of pelvis (Force-deflection at acetabulum and ilium in both acetabulum and iliac loadings) - Pelvis – femur hip capsule ligament distraction test - Shearing and bending effects of the knee joint and low and high speed lateral loading	7. Guillemot H, et al, “Pelvic behavior in side impact collisions: Static and dynamic tests on isolated pelvic bones”, SAE Paper # 98-S6-W-37, 1998 8. Stewart KJ, et al, “Spatial Distribution of Hip Capsule Structural and Material Properties”, Journal of Biomechanics, Vol 35, pp. 1491-1498, 2002. 9. Kajzer J, et al, “Shearing and bending effects at the knee joint at low speed lateral loading”, SAE paper No # 1999-01-0712, 1999 10. Kajzer J, et al, “Shearing and bending effects at the knee joint at high speed lateral loading”, IRCOBI Conference, Germany, paper No # 1999-01-0712, 1999 11. Pal C, et al, “Effect of vehicle’s front end profile on pedestrian’s lower extremity injury pattern in real world verification by large male FE human model”, SAE paper No 2015-01-1467, 2015.	

GHBMC M50-PS Adult, Pedestrian, Simplified. Version 1.3 Code: LS-Dyna May 17, 2015	Geometric reconstruction derived from external laser surface scans, bony landmark data, CT, upright MRI and MRI data of one living individual. Surfaces were reconstructed from the laser scan data, bones from CT.	GHBMC M50-PS, Average male subject whose anthropometry matched 15 different measures from Gordon et al.	Geometric biofidelity	Gordon et al. U.S. Army Survey of Anthropometry, ANSUR, 1988 Gayzik, F. S., D. P. Moreno, K. A. Danelson, C. McNally, K. D. Klinich and J. D. Stitzel (2012). "External landmark, body surface, and volume data of a mid-sized male in seated and standing postures." <u>Ann Biomed Eng</u> **40**(9): 2019-2032.	Gordon data were used to select the individual who served as the baseline for the M50-PS model. Gayzik study details methodology for standing posture development.
			Pelvis in lateral compression per Guillemot et al. 1998 and Beason et al. 2003. Cortical bone mapping paper published by Kim et al.	Kim, Y. H., J. E. Kim and A. W. Eberhardt (2012). "A new cortical thickness mapping method with application to an in vivo finite element model." <u>Comput Methods Biomech Biomed Engin</u>. Manual: GHBMC, Male 50th Percentile (M50) Occupant Model, Version 3.0 – Nov. 30th, 2011	Study conducted on GHBMC M50-O (occupant), but same bone mesh, material and failure properties were ported to the GHBMC M50-PS model.
			Mid-shaft femur, bending and combined compression & bending, per Funk et al. 2004 and Ivarsson et al. 2009. Data show good agreement.	Untaroiu, C. D., N. Yue and J. Shin (2013). "A finite element model of the lower limb for simulating automotive impacts." <u>Ann Biomed Eng</u> **41**(3): 513-526. GHBMC M50 Enhancement Report and Quarterly Report, No. GHBMC-FBM-P2- QR1. 10/31/2013. Appendix B, BRM COE Enhancement Reports and Results. Yue, N, Untaroiu C.D. (2014), A Numerical Investigation on the Variation of Hip Injury Tolerance with Occupant Posture during Frontal Collisions, <u>Traffic Injury Prevention,</u> 15(5): 513-522	Study conducted on GHBMC M50-O (occupant), but same bone mesh, material and failure properties were ported to the GHBMC M50-PS model.
GHBMC M50-PS Adult, Pedestrian, Simplified. Version 1.3	Geometric reconstruction derived from external laser surface scans, bony landmark data, CT, upright MRI and MRI data of one living individual. Surfaces were reconstructed	GHBMC M50-PS, Average male subject whose anthropometry matched 15 different measures from Gordon et al.	Proximal femur, compression per Keyak 1998. Data show good agreement.		
			Knee A-P shear per Balasubramanian et al. 2004 posterior shear test of PCL. Data show good agreement.		

Code: LS-Dyna May 17, 2015	from the laser scan data, bones from CT.		Midshaft lower leg, combined compression and bending per Untaroiu et al. 2008. Data show good agreement.		
			Xversion, internal and external rotation of the foot and ankle per Funk et al. 2000 and 2002. Data show good agreement.	J. Shin, Untaroiu, C.D. (2013). "Biomechanical and Injury Response of Human Foot and Ankle under Complex Loading." J Biomech Eng/ASME Transactions, 135(10), 101008 Shin, J., N. Yue and C. D. Untaroiu (2012). "A finite element model of the foot and ankle for automotive impact applications." Ann Biomed Eng **40**(12): 2519-2531.	Study conducted on GHBMC M50-O (occupant), but same bone mesh, material and failure properties were ported to the GHBMC M50-PS model.
GHBMC M50-PS Adult, Pedestrian, Simplified. Version 1.3 Code: LS-Dyna May 17, 2015	Geometric reconstruction derived from external laser surface scans, bony landmark data, CT, upright MRI and MRI data of one living individual. Surfaces were reconstructed from the laser scan data, bones from CT.	GHBMC M50-PS, Average male subject whose anthropometry matched 15 different measures from Gordon et al.	Standing posture Thoracoabdominal impacts per Viano et al. 1989. Impacts to chest, abdomen and pelvis. Data show good agreement.	Untaroiu, C.D., Putnam J.B., Schap, J. , Davis M. L., Gayzik, F. S. (2015) Development and Preliminary Validation of a 50th Percentile Pedestrian Finite Element Model, Proceedings of 2014 ASME IDETC Conference, August 17-20, 2015, Boston, MA, USA	Study Conducted with GHBMC M50-PS components.
			Knee joint 4 point bending per Bose et al. 2004		Study Conducted with GHBMC M50-PS components.
			180 degree lateral impact to assess whole lower limb lateral bending and shear, per Kajzer et al. 1999		Study Conducted with GHBMC M50-PS components.
			Vehicle leading edge to full pedestrian kinematics per Kerrigan et al. 2007 and Untaroiu et al. 2006.		Study Conducted with GHBMC M50-PS full body model.

			Lumbar spine validation in extension, flexion and lateral bending per Rohkmann et al. 2001		
GHBMC M95-PS and F05-PS Pedestrians, Simplified. Version 1.3 Code: LS-Dyna May 17, 2015	Geometric reconstruction derived from external laser surface scans of carefully selected individuals. Surfaces were reconstructed from laser scans. Medical images of small female and large male individuals were available for local verification.	GHBMC M95-PS, Large male subject whose anthropometry matched 15 different measures from Gordon et al. The model was developed by morphing the M50-PS model. GHBMC F05-PS, small female subject whose anthropometry matched 15 different measures from Gordon et al. The model was developed by morphing the M50-PS model.	Geometric biofidelity	Gordon et al. U.S. Army Survey of Anthropometry, ANSUR, 1988 M95 subject data: Vavalle NA, Schoell SL, Weaver AA, Stitzel JD, Gayzik FS. (2014) The Application of Radial Basis Function Interpolation Methods in the Development of a 95th Percentile Male Seated FEA Model. *Stapp Car Crash J. v. 58, pp XX* F05 subject data: Davis ML, Allen BC, Geer CP, Stitzel JD, Gayzik FS. A multi-modality image set for the development of a 5th percentile female finite element model. *International Research Council on the Biomechanics of Injury*, IRCOBI, Sept. 2014, Berlin, Germany, ISSN: 2235-3151	Gordon data were used to select the individual who served as the baseline for the M50-PS model. Vavalle study provides detail on the M95 subject, which was also used in occupant model development. Davis study provides data on F05 subject.

GHBMC M95-PS and F05-PS Pedestrians, Simplified. Version 1.3 Code: LS-Dyna May 17, 2015	Geometric reconstruction derived from external laser surface scans of carefully selected individuals. Surfaces were reconstructed from the laser scans. Medical images of small female and large male individuals were available for local checks.	GHBMC M95-PS, Large male subject whose anthropometry matched 15 different measures from Gordon et al. The model was developed by morphing the M50 model. GHBMC F05-PS, small female subject whose anthropometry matched 15 different measures from Gordon et al. The model was developed by morphing the M50 model.	Standing posture Thoracoabdominal impacts per Viano et al. 1989. Impacts to chest, abdomen and pelvis.	Untaroiu et al. Progress Report regarding the Verification (Validation) of GHBMC Simplified Pedestrian Finite Element Model , *Novemver 2014 report , February 2015 report, May 2015 report.*	Study Conducted with GHBMC M95 and F05-PS components.
			Knee joint 4 point bending per Bose et al. 2004		Study Conducted with GHBMC M95 and F05-PS components.
			180 degree lateral impact to assess whole lower limb lateral bending and shear, per Kajzer et al. 1999		Study Conducted with GHBMC M95 and F05-PS components.
			Vehicle leading edge to full pedestrian kinematics per Kerrigan et al. 2007 and Untaroiu et al. 2006.		Study Conducted with GHBMC M95 and F05-PS full body model.
GHBMC 6YO Pedestrian, Simplified. Version 1.3 Code: LS-Dyna	Geometric reconstruction followed same process as above, this model was initially developed through morphing of the F05 model.	The small female model was deconstructed and regionally scaled to match anthropometry data of the child. Medical image data was used to	Geometric biofidelity	Sources used in model development: Reed et al. SAE Technical Paper 2001-01-1057: Development of anthropometric specifications for the six-year-old OCATD. Snyder et al. 1977: Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design, UMTRI	

May 17, 2015		locally morph the mesh geometry for 6 YO.	Vehicle leading edge to full pedestrian kinematics per Kerrigan et al. 2007 and Untaroiu et al. 2006.	Untaroiu, C.D., Schap, J., Gayzik, S. (2015), A finite Element Model of a 6-year old child for simulating pedestrian impacts, AAAM 2015 Conference.	Conducted with GHBMC 6YO-PS full body model.
GHBMC M50-PS Adult, Pedestrian, Simplified. Version 1.3 Code: PAM-Crash May 17, 2015	Geometric reconstruction derived from external laser surface scans, bony landmark data, CT, upright MRI and MRI data of one living individual. Surfaces were reconstructed from the laser scan data, bones from CT.	GHBMC M50-PS, Average male subject whose anthropometry matched 15 different measures from Gordon et al.	Geometric biofidelity	Gordon et al. U.S. Army Survey of Anthropometry, ANSUR, 1988 Gayzik, F. S., D. P. Moreno, K. A. Danelson, C. McNally, K. D. Klinich and J. D. Stitzel (2012). "External landmark, body surface, and volume data of a mid-sized male in seated and standing postures." Ann Biomed Eng **40**(9): 2019-2032.	Gordon data were used to select the individual who served as the baseline for the M50-PS model. Gayzik study details methodology for standing posture development.
			Pelvis in lateral compression per Guillemot et al. 1998 and Beason et al. 2003. Cortical bone mapping paper published by Kim et al.	GHBMC Quarterly Report – Pam Crash Model Conversion (May 12 2014) User Manual: M50 Occupant Version 4.3 for PAM-CRASH, Nov. 1st, 2014	Study conducted on GHBMC M50-O (occupant), but same bone mesh, material and failure properties were ported to the GHBMC M50-PS model.
			Mid-shaft femur, bending and combined compression & bending, per Funk et al. 2004 and Ivarsson et al. 2009. Data show good agreement.	GHBMC Annual Report – Pam Crash Model Conversion (November 5 2014)	Study conducted on GHBMC M50-O (occupant), but same bone mesh, material and failure properties were ported to the GHBMC M50-PS model.
GHBMC M50-PS	Geometric reconstruction derived from external laser surface scans, bony	GHBMC M50-PS, Average male subject whose anthropometry	Proximal femur, compression per Keyak 1998. Data show good agreement.		

Adult, Pedestrian, Simplified. Version 1.3 Code: PAM-Crash May 17, 2015	landmark data, CT, upright MRI and MRI data of one living individual. Surfaces were reconstructed from the laser scan data, bones from CT.	matched 15 different measures from Gordon et al.	Knee A-P shear per Balasubramanian et al. 2004 posterior shear test of PCL. Data show good agreement.		
			Midshaft lower leg, combined compression and bending per Untaroiu et al. 2008. Data show good agreement.		
			Xversion, internal and external rotation of the foot and ankle per Funk et al. 2000 and 2002. Data show good agreement.	GHBMC Annual Report – Pam Crash Model Conversion (November 5 2014)	Study conducted on GHBMC M50-O (occupant), but same bone mesh, material and failure properties were ported to the GHBMC M50-PS model.
GHBMC M50-PS Adult, Pedestrian, Simplified. Version 1.3 Code: PAM-Crash May 17, 2015	Geometric reconstruction derived from external laser surface scans, bony landmark data, CT, upright MRI and MRI data of one living individual. Surfaces were reconstructed from the laser scan data, bones from CT.	GHBMC M50-PS, Average male subject whose anthropometry matched 15 different measures from Gordon et al.	Standing posture Thoracoabdominal impacts per Viano et al. 1989. Impacts to chest, abdomen and pelvis. Data show good agreement.	GHBMC Quarterly Report – Pam Crash Model Conversion (May 11 2015)	Study Conducted with GHBMC M50-PS components.
			Knee joint 4 point bending per Bose et al. 2004		Study Conducted with GHBMC M50-PS components.
			180 degree lateral impact to assess whole lower limb lateral bending and shear, per Kajzer et al. 1999		Study Conducted with GHBMC M50-PS components.

			Vehicle leading edge to full pedestrian kinematics per Kerrigan et al. 2007 and Untaroiu et al. 2006.		Study Conducted with GHBMC M50-PS full body model.
			Lumbar spine validation in extension, flexion and lateral bending per Rohkmann et al. 2001		

GHBMC M95-PS and F05-PS Pedestrians, Simplified. Version 1.3 Code: PAM-Crash May 17, 2015	Geometric reconstruction derived from external laser surface scans of carefully selected individuals. Surfaces were reconstructed from laser scans. Medical images of small female and large male individuals were available for local verification.	GHBMC M95-PS, Large male subject whose anthropometry matched 15 different measures from Gordon et al. The model was developed by morphing the M50-PS model. GHBMC F05-PS, small female subject whose anthropometry matched 15 different measures from Gordon et al. The model was developed by morphing the M50-PS model.	Geometric biofidelity	Gordon et al. U.S. Army Survey of Anthropometry, ANSUR, 1988 M95 subject data: Vavalle NA, Schoell SL, Weaver AA, Stitzel JD, Gayzik FS. (2014) The Application of Radial Basis Function Interpolation Methods in the Development of a 95th Percentile Male Seated FEA Model. *Stapp Car Crash J. v. 58, pp XX* F05 subject data: Davis ML, Allen BC, Geer CP, Stitzel JD, Gayzik FS. A multi-modality image set for the development of a 5th percentile female finite element model. *International Research Council on the Biomechanics of Injury*, IRCOBI, Sept. 2014, Berlin, Germany, ISSN: 2235-3151	Gordon data were used to select the individual who served as the baseline for the M50-PS model. Vavalle study provides detail on the M95 subject, which was also used in occupant model development. Davis study provides data on F05 subject.
GHBMC M95-PS and F05-PS Pedestrians, Simplified. Version 1.3 Code: PAM-Crash	Geometric reconstruction derived from external laser surface scans of carefully selected individuals. Surfaces were reconstructed from the laser scans. Medical images of small female and large	GHBMC M95-PS, Large male subject whose anthropometry matched 15 different measures from Gordon et al. The model was developed by	Standing posture Thoracoabdominal impacts per Viano et al. 1989. Impacts to chest, abdomen and pelvis.	GHBMC Quarterly Report – Pam Crash Model Conversion (May 11 2015)	Study Conducted with GHBMC M95 and F05-PS components.

May 17, 2015	male individuals were available for local checks.	morphing the M50 model. GHBMC F05-PS, small female subject whose anthropometry matched 15 different measures from Gordon et al. The model was developed by morphing the M50 model.	Knee joint 4 point bending per Bose et al. 2004		Study Conducted with GHBMC M95 and F05-PS components.
			180 degree lateral impact to assess whole lower limb lateral bending and shear, per Kajzer et al. 1999		Study Conducted with GHBMC M95 and F05-PS components.
			Vehicle leading edge to full pedestrian kinematics per Kerrigan et al. 2007 and Untaroiu et al. 2006.		Study Conducted with GHBMC M95 and F05-PS full body model.
GHBMC 6YO Pedestrian, Simplified. Version 1.3 Code: PAM-Crash May 17, 2015	Geometric reconstruction followed same process as above, this model was initially developed through morphing of the F05 model.	The small female model was deconstructed and regionally scaled to match anthropometry data of the child. Medical image data was used to locally morph the mesh geometry for 6 YO.	Geometric biofidelity	Sources used in model development: Reed et al. SAE Technical Paper 2001-01-1057: Development of anthropometric specifications for the six-year-old OCATD. Snyder et al. 1977: Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design, UMTRI	
			Vehicle leading edge to full pedestrian kinematics per Kerrigan et al. 2007 and Untaroiu et al. 2006.	GHBMC Quarterly Report – Pam Crash Model Conversion (August 2015, scheduled)	Conducted with GHBMC 6YO-PS full body model.