Injury Probability Function for Tibia Fracture

Item	Sub-Item	Proposer	Approach	Rationale	Reference
Overall reference		JASIC	-	-	[1] Takahashi, Y., Matsuoka, F., Okuyama, H. and Imaizumi, I., "Development of Injury Probability Functions for the Flexible Pedestrian Legform Impactor," SAE Int. J. Passeng. Cars - Mech. Syst. 5(1):2012, doi:10.4271/2012-01-0277.
		BASt	-	-	
Biomechanical data	Loading configuration	JASIC	- Dynamic three point bending - Lateromedial direction	Accident data shows that 71.2 % of pedestrians were hit by a car in lateral direction [2]	[2] Okamoto, Y., Sugimoto, T., Enomoto, K., Kikuchi, J., “Pedestrian Head Impact Conditions Depending on the Vehicle Front Shape and Its Construction - Full Model Simulation”, Traffic Injury Prevention, Volume 4, Issue 1, 2003, doi: 10.1080/15389580309856.
		BASt			
	Data source	JASIC	- Kerrigan et al. (2004) [3] containing data from Nyquist et al. (1985) [4], Kerrigan et al. (2003a) [5] and Kerrigan et al. (2003b) [6]	- Loading rate above 1 m/s based on strain rate from FE impact simulations at 40 km/h [3]	[3] Kerrigan, J. R., Drinkwater, D. C., Kam, C. Y., Murphy, D. B., Ivarsson, B. J., Crandall, J. R., Patrie, J., “Tolerance of the Human Leg and Thigh in Dynamic Latero-Medial Bending”, ICRASH, 2004, doi: 10.1533/ijcr.2004.0315. [4] Nyquist, G. W., Cheng, R., El-Bohy, A. A. R., King, A. I., “Tibia Bending: Strength and Response,” SAE Technical Paper 851728, 1985, doi: 10.4271/851728. [5] 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 Technical Paper 2003-01-0895, 2003, doi: 10.4271/2003-01-0895. [6] Kerrigan, J. R., Bhalla, K. S., Madeley, N. J., Crandall, J. R., Deng, B., “Response Corridors for the Human Leg in 3-Point Lateral Bending”, 7th US National Congress on Computational Mechanics, 2003.
		BASt			
	Gender	JASIC	- Both male and female data were included	- Lindahl et al. [7] performed quasi-static tensile tests of the femur and humerus specimens of various age and gender, and found that the gender differences in the failure strength, failure displacement and elastic modulus were statistically insignificant - The results of F-test and subsequent t-test on the elastic modulus and the ultimate stress of the femoral cortical bone for male and female from Takahashi et al. [8] showed that the difference in the mean was statistically insignificant at the 5% significance level	[7] Lindahl, O., Lindgren, A. G. H., “Cortical Bone in Man”, Acta Orthopaedica Scandinavica, 38, 1967, doi: 10.3109/17453676708989628. [8] 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, Paper No. 2000-01-SC22, 2000.
		BASt			
	Scaling method	JASIC	- Geometrical scaling under the assumption that mass density and Young's modulus are identical	- Mather [9] calculated that the lower bending torelance of female femora than male femora was due entirely to the smaller dimensions of females, rather than to a difference in the material strength of the bone tissue	[9] Mather, B.S. "Variation with Age and Sex in Strength of the Femur", Medical and Biological Engineering, 6: 129-132, 1968.
		BASt			
	Standard values for scaling	JASIC	- Standard lengths taken from UMTRI study - Tibia Height (distance from the bottom of the foot to the top of the tibial plateau) : 483 mm (for Nyquist study [4]) - Tibia Length (length of tibia) : 402 mm (for three Kerrigan studies [3, 5, 6])	- FlexPLI dimensions are almost identical to those of EEVC legform - The dimensions were determined from the anthropometric data for the average adult male in a standing position from the study done by UMTRI [10, 11, 12] - Tibia Height and Tibia Length from the UMTRI study are 483 mm and 402 mm, respsectively [10]	[10] Schneider, L. W., Robbins, D. H., Pflug, M. A., Snyder, R. G., “Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family”, Volume 1, Report Number UMTRI-83-53-1, 1983. [11] European Experimental Vehicles Committee (EEVC), “Proposals for Methods to Evaluate Pedestrian Protection for Passenger Cars, EEVC Working Group 10 Report”, 1994. [12] Cesari, D., Bermond, F., Caire, Y., Bouquet, R., “Optimization of Pedestrian Leg Injury Protection Using a Biofidelic Human Leg”, IRCOBI Conference, 1994.
		BASt			
	Number of data used	JASIC	- 19 data in total - 8 data from Nyquist study [4] (one scaled data from Nyquist study omitted as an outlier based on the result of Grubbs' test [1]) - 11 data from three Kerrigan studies [3, 5, 6]	See above	See above
		BASt			

Human injury probability function	Statistical method used	JASIC	- Survival model with Weibull distribution - Nyquist data : right censored - Kerrigan data : uncensored	- Nyquist data are right censored due to attenuation of peak values from filtering [4] - Kerrigan data are to be treated as uncensored because they present unfiltered peak values [3] - Kent et al. [13] showed that when logistic regression is applied to the dataset that contains uncensored data, then unrealistic injury probability functions may be given, such as the injury probability functions in the form of decreasing functions - Weibull distribution was chosen because the distribution is capable of representing asymmetric distribution and ensuring zero injury probability at zero loading	[13] Kent, R. W., Funk, J. R., “Data Censoring and Parametric Distribution Assignment in the Development of Injury Risk Functions from Biomechanical Data,” SAE Technical Paper 2004-01-0317, 2004, doi: 10.4271/2004-01-0317.
		BASt			
	Statistical significance of human injury probability function	JASIC	- Use p-value for intercept and scale values of the probability function	- Intercept and scale values were statistically significant (p<0.01) [1]	See above
		BASt			
FlexPLI injury probability function	Transfer function	JASIC	- Transfer function from human tibia bending moment to FlexPLI tibia bending moment was developed using linear regression function obtained from correlation between peak bending moment values from human and FlexPLI FE models in collisions with 18 simplified vehicle models at 40 km/h [14]	- Human and FlexPLI FE models were extensively validated against experimental data [15] - 18 simplified vehicle models were developed to represent a variety of vehicles with different geometric and stiffness characteristics by applying L18 orthogonal array [16]	[14] Japan Automobile Manufacturers Association, Japan Automobile Research Institute, “Development of a FE Flex-GTR-prototype Model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models”, 8th Flex-TEG Meeting Document, Number TEG-096, 2009. [15] Japan Automobile Standards Internationalization Center (JASIC), "Experimental Validation of Human and FlexPLI FE Models", 5th GTR9 Phase-2 Informal Group Meeting, Document Number GTR9-5-12, 2012. [16] Konosu A, Issiki T, Takahashi Y, "Evaluation of the Validity of the Tibia Fracture Assessment using the Upper Tibia Acceleration Employed in the TRL Legform Impactor", Proceedings of IRCOBI Conference, 2009.
		BASt			
	FlexPLI injury probability function	JASIC	- Replace human tibia bending moment with FlexPLI tibia bending moment by simply applying the transfer function - FlexPLI tibia fracture probability function is given in [1]	See above	See above
		BASt			
FlexPLI injury threshold	Idea behind choice of probability	JASIC	- FlexPLI tibia bending moment threshold was determined at the same level of injury probability with threshold for EEVC legform specified in GTR9	- GTR9 Phase-2 is a replacement of EEVC legform with FlexPLI - EEVC legform and FlexPLI use different tibia fracture measures (acceleration vs. bending moment)	-
		BASt			
	Probability chosen	JASIC	- 30% probability of tibia fracture was used	- Tibia fracture probability function was developed as a function of tibia acceleration by re-analysing data from Bunketorp et al. [17] - Fracture data due to indirect loading were omitted to be consistent with EEVC legform measurement (use upper tibia acceleration only) [1] - Isolated fibula fracture was omitted to develop a function for tibia fracture [1] - Acceleration data were geometrically scaled using Tibia Length of 402 mm from UMTRI anthropometric study [1] - Weibull survival model was applied to be consistent with the function for tibia bending moment [1] - Upper tibia acceleration of 170 G corresponded to injury probability of 30% [1]	[17] Bunketorp, O., Romanus, B., Hansson, T., Aldman, D., Thorngren, L., Eppinger, R. H., “Experimental Study of a Compliant Bumper System,” SAE Technical Paper 831623, 1983, doi: 10.4271/831623.
		BASt			
	Proposed injury threshold	JASIC	340 Nm	See above	See above
		BASt	340 Nm		

Injury Probability Function for MCL Failure GTR9-7-07

Item	Sub-Item	Proposer	Approach	Rationale	Reference
Overall reference		JASIC	-	-	[1] Takahashi, Y., Matsuoka, F., Okuyama, H. and Imaizumi, I., "Development of Injury Probability Functions for the Flexible Pedestrian Legform Impactor," SAE Int. J. Passeng. Cars - Mech. Syst. 5(1):2012, doi:10.4271/2012-01-0277.
		BASt			
Biomechanical data	Loading configuration	JASIC	- Dynamic valgus bending	Accident data shows that 71.2 % of pedestrians were hit by a car in lateral direction [2]	[2] Okamoto, Y., Sugimoto, T., Enomoto, K., Kikuchi, J., "Pedestrian Head Impact Conditions Depending on the Vehicle Front Shape and Its Construction - Full Model Simulation", Traffic Injury Prevention, Volume 4, Issue 1, 2003, doi: 10.1080/15389580309856.
		BASt			
	Data source	JASIC	- Ivarsson et al. (2004) [3] (presenting injury probability functions based on biomechanical data from Bose et al. (2004) [4]) - Konosu et al. (2001) [5] (presenting injury probability functions based on biomechanical data from Kajzer et al. (1997) [5]) - Develop an MCL failure probability function by averaging the function presented by Ivarsson et al. and the function obtained by re-analysing data presented in Konosu et al.	- The only dynamic valgus loading response data available from the literature - Ivarsson et al. provides MCL failure probability functions developed using the Weibull survival model, without providing tabulated data - Konosu et al. provides both the probability function developed using a diffenrent statistical method and tabulated biomechanical data - Weibull survival model was applied to the data from Konosu et al. to develop a function consistent with that presented in Ivarsson et al.	[3] 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. [4] Bose, D., Bhalla, K., Rooij, L., Millington, S., Studley, A., Crandall, J., "Response of the Knee Joint to the Pedestrian Impact Loading Environment," SAE Technical Paper 2004-01-1608, 2004, doi: 10.4271/2004-01-1608. [5] Konosu, A., Ishikawa, H., Tanahashi, M., "Reconsideration of Injury Criteria for Pedestrian Subsystem Legform Test - Problems of Rigid Legform Impactor -", 17th ESV Conference, 2001. [6] Kajzer, J., Schroeder, G., Ishikawa, H., Matsui, Y., Bosch, U., "Shearing and Bending Effect at the Knee Joint at High Speed Lateral Loading," SAE Technical Paper 973326, 1997, doi: 10.4271/973326.
		BASt			
	Gender	JASIC	- All the biomechanical data available were used regardless of the gender	- No control over gender since Ivarsson et al. provides probability functions only	-
		BASt			
	Scaling method	JASIC	- Scaling was not applied	- MCL failure probability function was developed as a function of the knee bending angle - Angle does not scale	-
		BASt			
	Number of data used	JASIC	- The MCL failure probability function from Ivarsson et al. [3] was based on 8 tests from Bose et al. [4] - 12 data from Kajzer et al. [6] were analyzed using Weibull survival model - 20 data in total were taken into account in the averaged MCL failure probability function	See above	See above
		BASt			
Human injury probability function	Statistical method used	JASIC	- Survival model with Weibull distribution - The function for definition B of injury timing from Ivarsson et al. [3] was used - For the data from Kajzer et al. [6], no injury and injury data were treated as right censored and uncensored data, respectively - The functions from Ivarsson et al. [3] and from the analysis of data from Kajzer et al. [6] were averaged for knee valgus bending angle	- Definition A from Ivarsson et al. [3] is too conservative because in the 8 tests from Bose et al. [4] 6 tests resulted in only partial failure of MCL - The physically measured knee valgus bending angle was averaged to avoid averaging the statistically estimated probability values	See above
		BASt			
	Statistical significance of human injury probability function	JASIC	- As for the analysis of the data from Kajzer et al. [6], the intercept and scale values of the probability function were statistically significant ($p<0.01$) [1]	-	See above
		BASt			

FlexPLI injury probability function	Transfer function	JASIC	- Transfer function from human knee valgus bending angle to FlexPLI MCL elongation was developed using linear regression function obtained from correlation between peak values from human and FlexPLI FE models in collisions with 18 simplified vehicle models at 40 km/h [7]	- Human and FlexPLI FE models were extensively validated against experimental data [8] - 18 simplified vehicle models were developed to represent a variety of vehicles with different geometric and stiffness characteristics by applying L18 orthogonal array [9]	[7] Japan Automobile Manufacturers Association, Japan Automobile Research Institute, "Development of a FE Flex-GTR-prototype Model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models", 8th Flex-TEG Meeting Document, Number TEG-096, 2009. [8] Japan Automobile Standards Internationalization Center (JASIC), "Experimental Validation of Human and FlexPLI FE Models", 5th GTR9 Phase-2 Informal Group Meeting, Document Number GTR9-5-12, 2012. [9] Konosu A, Issiki T, Takahashi Y, "Evaluation of the Validity of the Tibia Fracture Assessment using the Upper Tibia Acceleration Employed in the TRL Legform Impactor", Proceedings of IRCOBI Conference, 2009.
		BASt			
	FlexPLI injury probability function	JASIC	- Human knee valgus bending angle was converted to FlexPLI MCL elongation by applying the transfer function - 10% compensation was applied to the converted MCL elongation to compensate for the lack of muscle tone - FlexPLI MCL failure probability function is given in [1]	- Lloyd et al. [10] found from the results of the volunteer tests that the knee valgus bending moment was increased by 10 ± 6.3% due to the muscle tone	[10] Lloyd, D., Buchanan, T., "Strategies of Muscular Support of Varus and Valgus Isometric Loads at the Human Knee", Journal of Biomechanics, Volume 34, 2001, doi:10.1016/S0021-9290(01)00095-1.
		BASt			
FlexPLI injury threshold	Idea behind choice of probability	JASIC	- FlexPLI MCL failure threshold was determined by taking into account the equivalence to the threshold for EEVC legform specified in GTR9	- GTR9 Phase-2 is a replacement of EEVC legform with FlexPLI	-
		BASt			
	Proposed injury threshold	JASIC	22 mm	- Very good correlation was found between the EEVC legform Knee bending angle and the FlexPLI MCL elongation (R=0.90) [7] - Using the linear regression function developed in [7], 22 mm of FlexPLI MCL elongation converts to 18.1 deg of EEVC legform Knee bending angle, showing that 22 mm threshold is more stringent than 19 deg threshold specified in the current GTR9	See above
		BASt	22 mm		