24 April 2006
3rd Flex-TEG MT
BASt, Bergisch

Evaluation Activities on Injury Assessment Ability of the Flexible Pedestrian Legform Impactor GT Alpha (Flex-GTα)

Atsuhiro Konosu
Flex-TEG Chairperson /Japan

Background

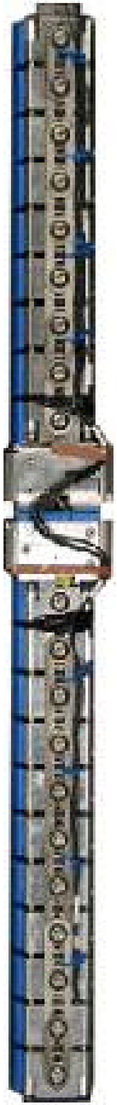
- The Flexible Pedestrian Legform Impactor GT Alpha (Flex-GTα) was developed in March 2006.
- Flex-GTα obtained a modified knee bending limit and also other modified specifications compared with those of Flex-G.
- Especially for the modifications on the specifications have brought a better injury assessment ability to Flex-GTα.
- This presentation explains the evaluation activities concerning the injury assessment ability of Flex-GTα.

Evaluation Activities
(Part 1)

Comparison of Flex-GTa, Flex-G, and the Human FE Model

Impactors

Flex-G

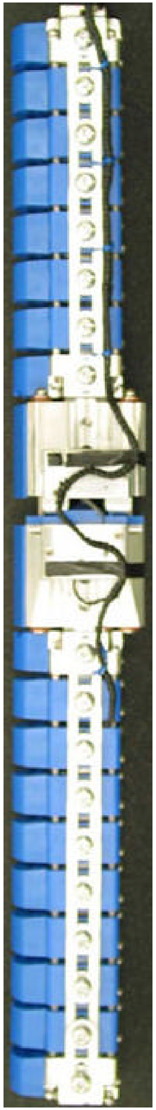


Knee
Flexible bending with ligament restraint system

Thigh
Flexible bending

Leg
Flexible bending

Flex-GTα



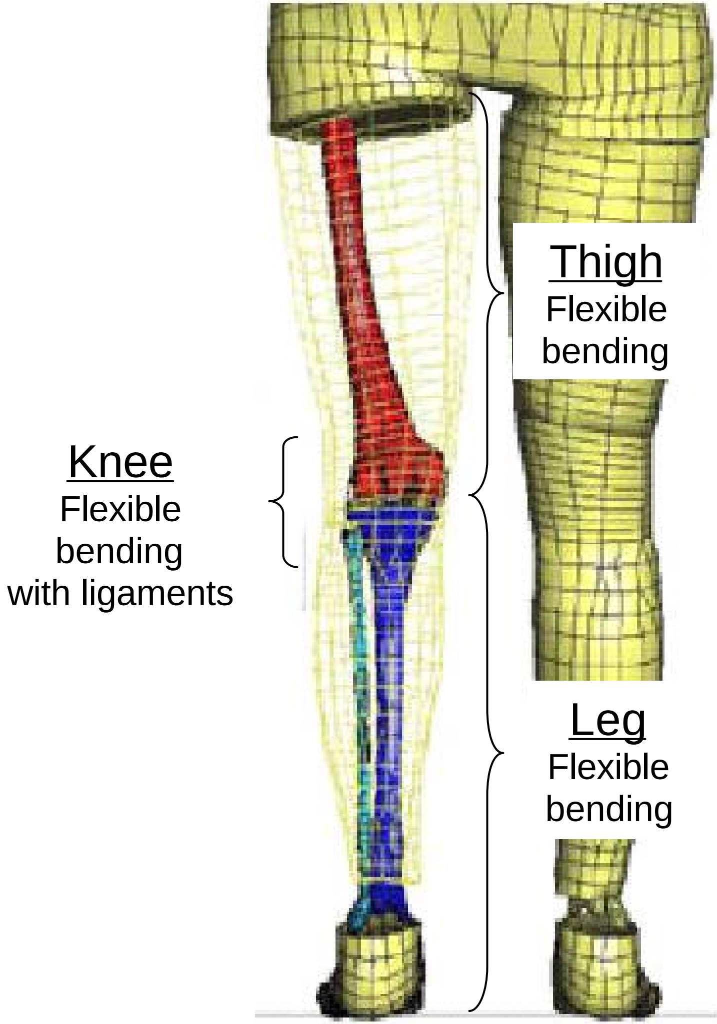
Knee
Flexible bending with ligament restraint system

Thigh
Flexible bending

Leg
Flexible bending

Simulation Model

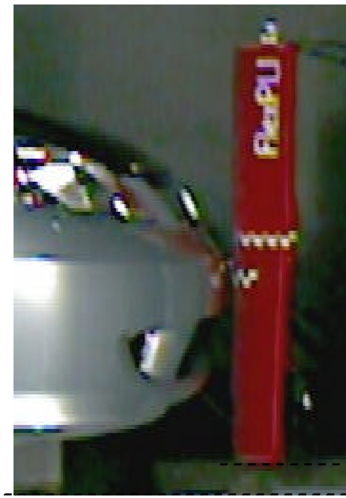
Human FE Model



Reference: Takahashi, T. et al. , Development and Validation of the Finite Element Model for the Human Lower Limb of Pedestrians, 44th Stapp Car Crash Conference

Test Conditions

Sedan 1
(2004 year model)



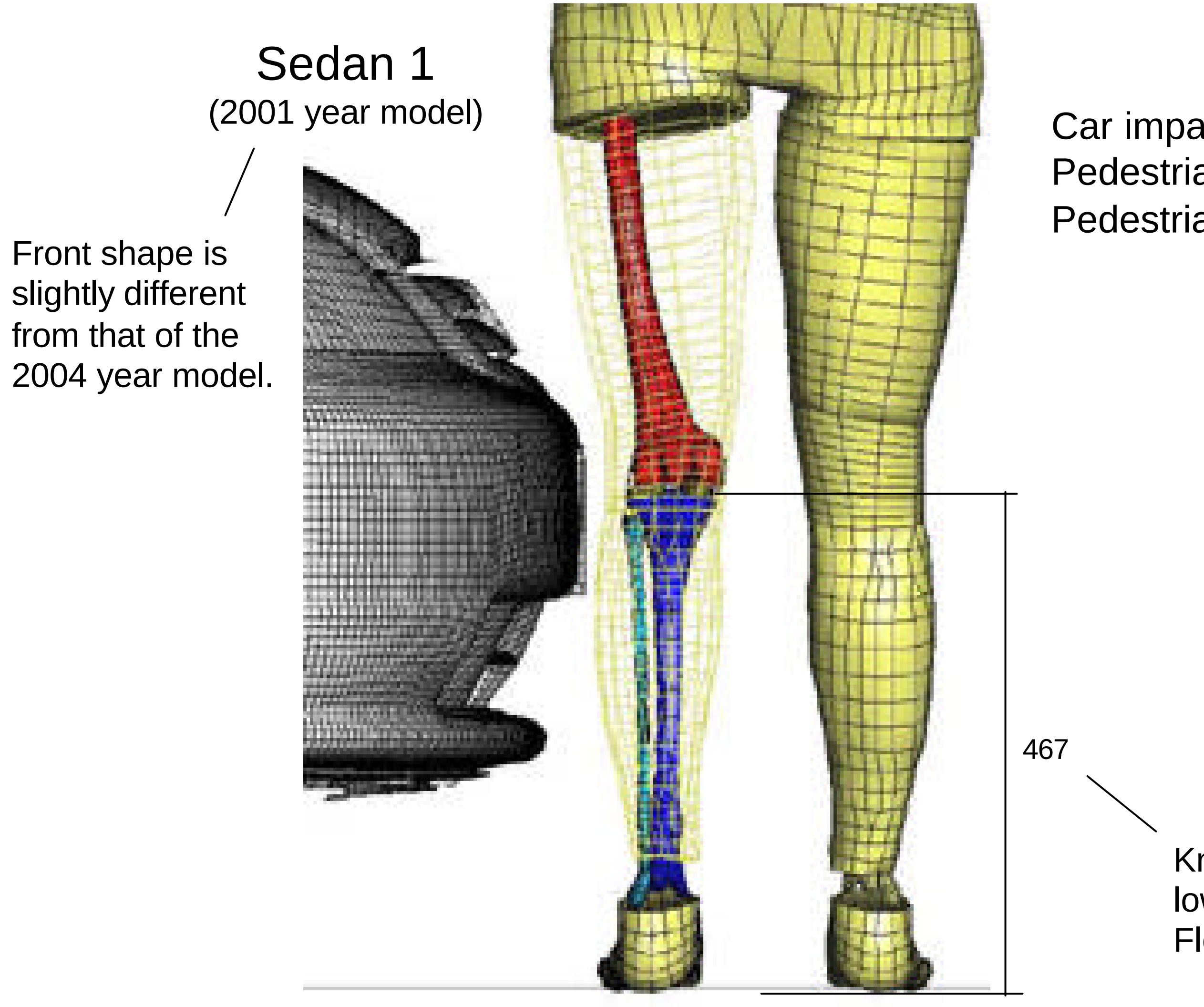
Impact speed: 11.1 m/s

Impact location: Car Center

+25mm

Ground level

Simulation Conditions

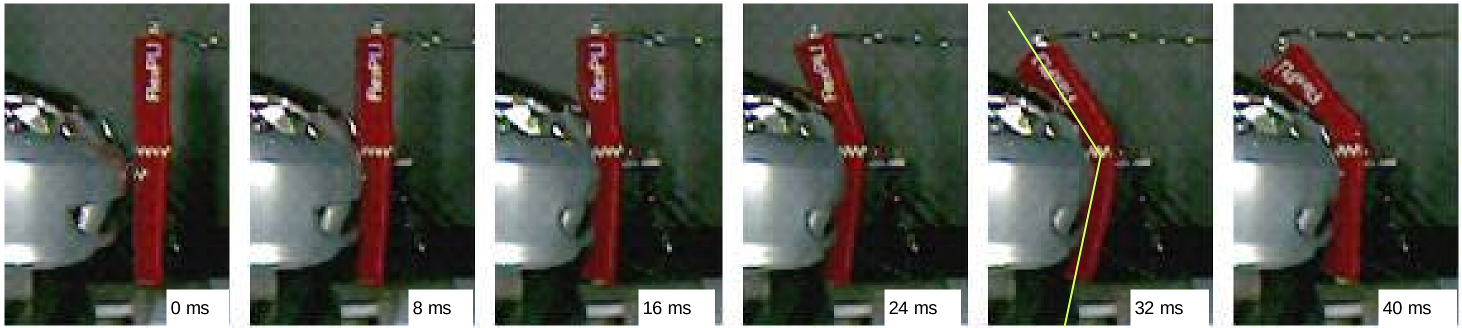


Car impact speed : 11.1 m/s
Pedestrian position : car center
Pedestrian leg statue: gate stance

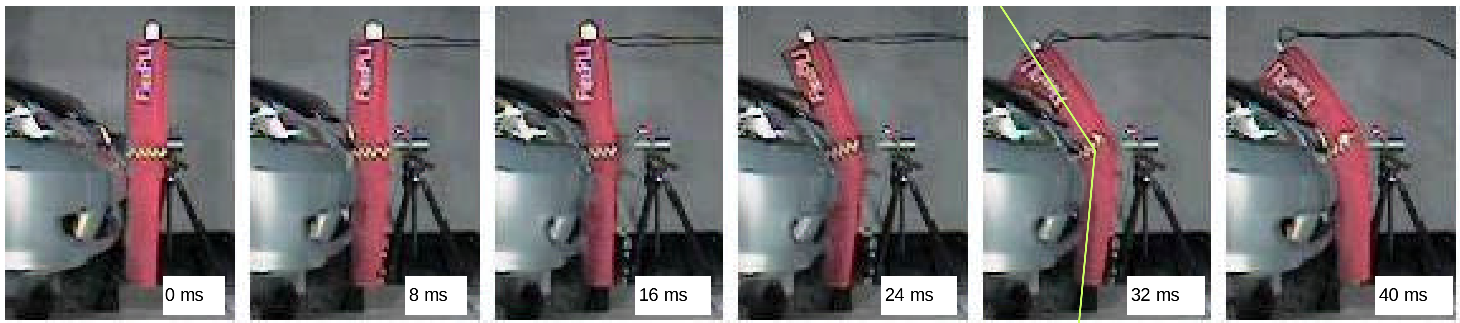
Comparison

Flex-G bending is the severest of the three.

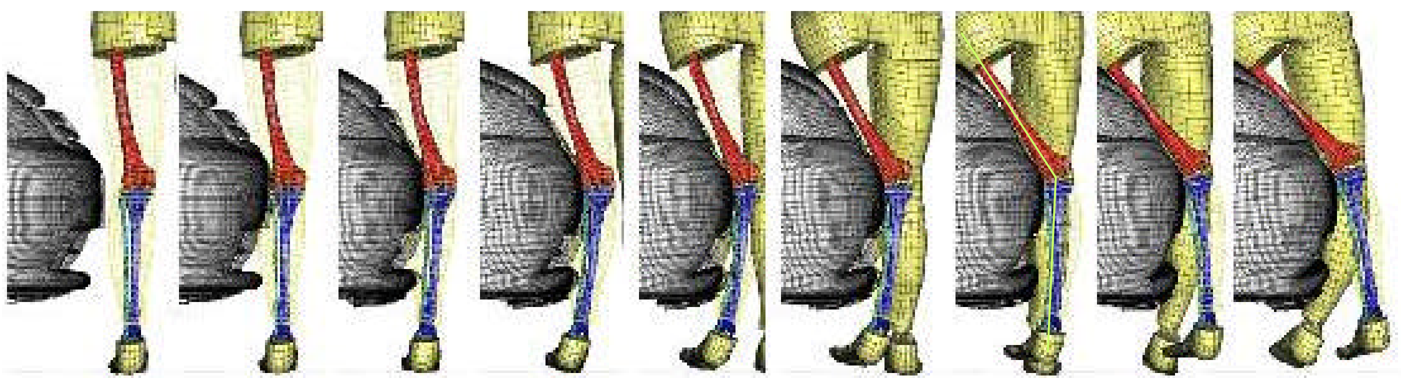
Flex-G



Flex-GTα



Human
FE model

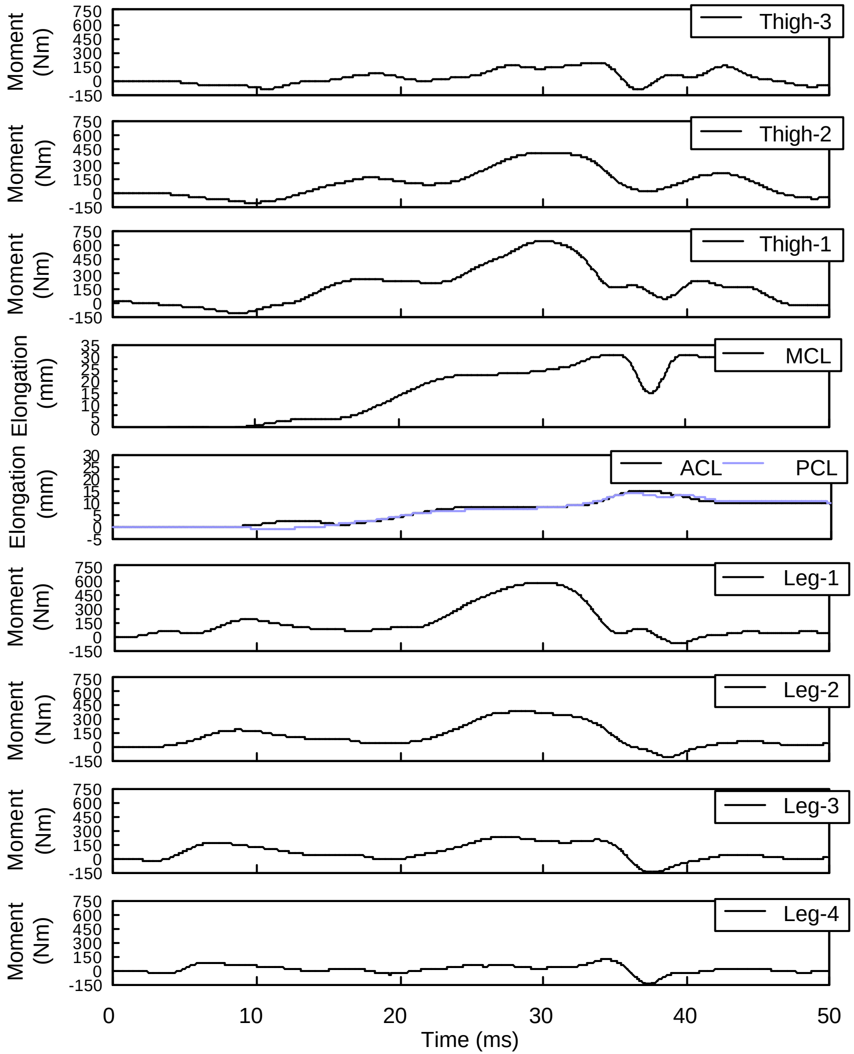


0ms 5ms 10ms 15ms 20ms 25ms 30ms 35ms 40ms

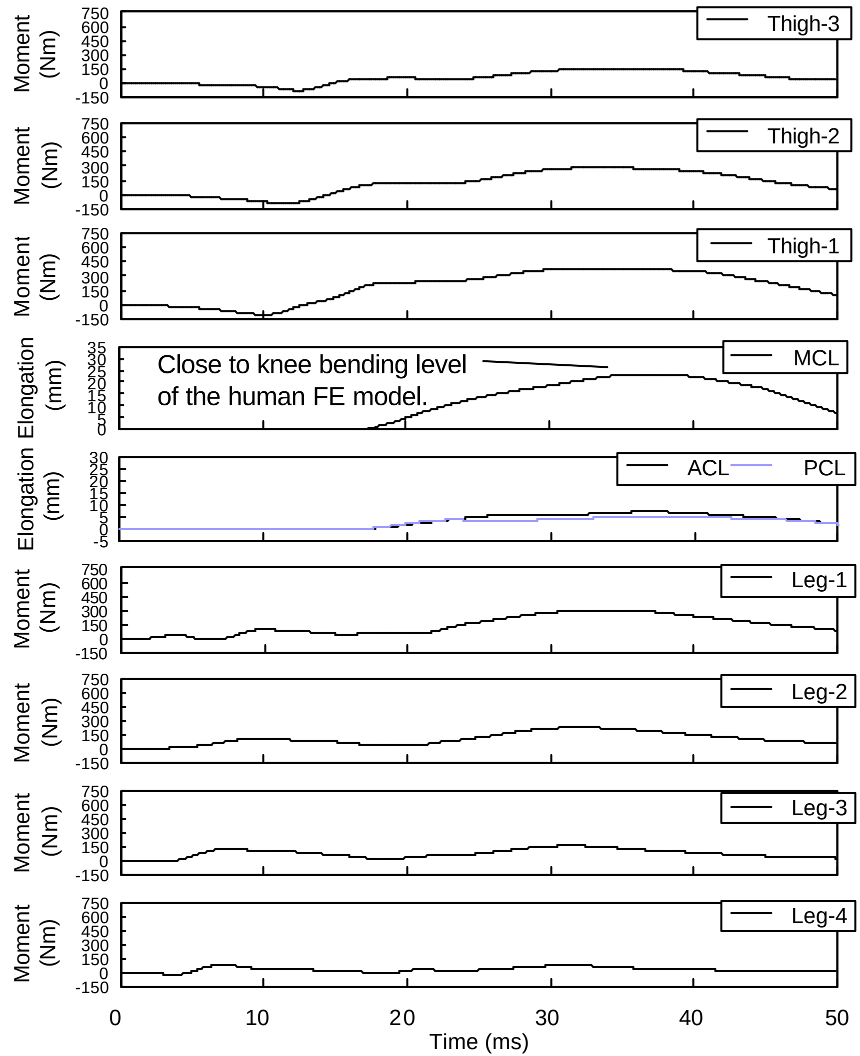
Test Results

Flex-GTα outputs are moderate as compared with those of Flex-G

Flex-G



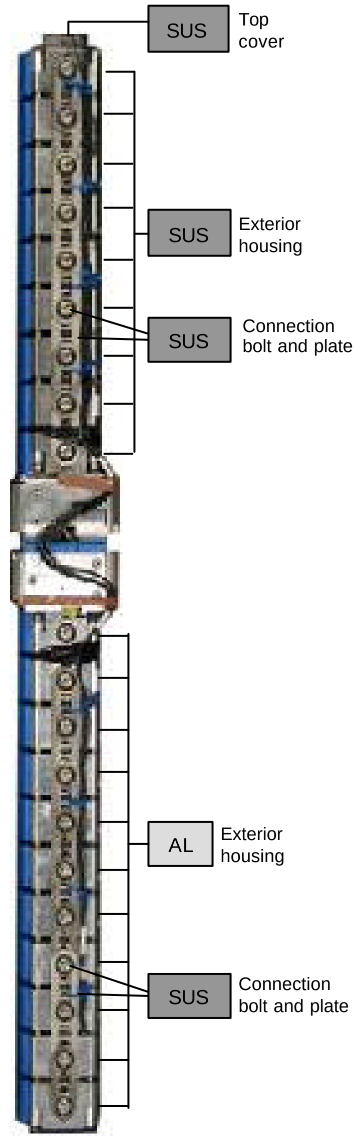
Flex-GTα



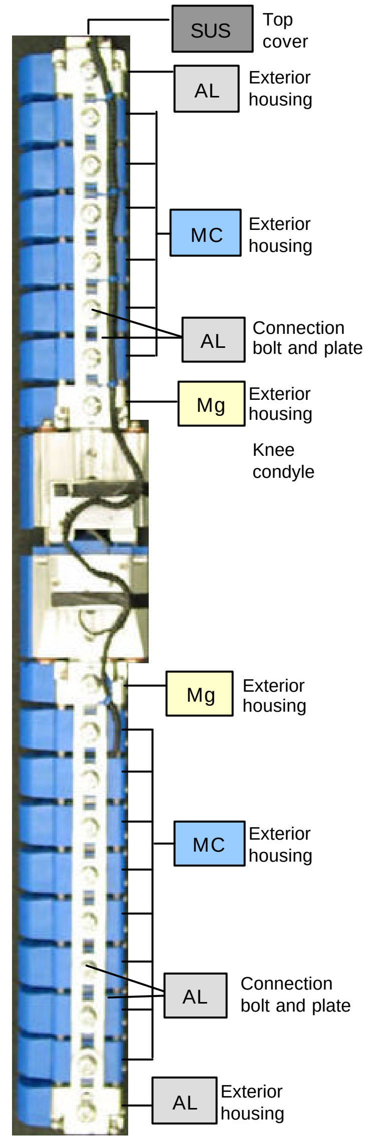
Discussions on Part 1

- Flex-GTα uses lighter materials for the long bone parts as compared with those of Flex-G.
- The use of lighter materials enable Flex-GTα to give impact phenomena comparable with those of the human FE model.

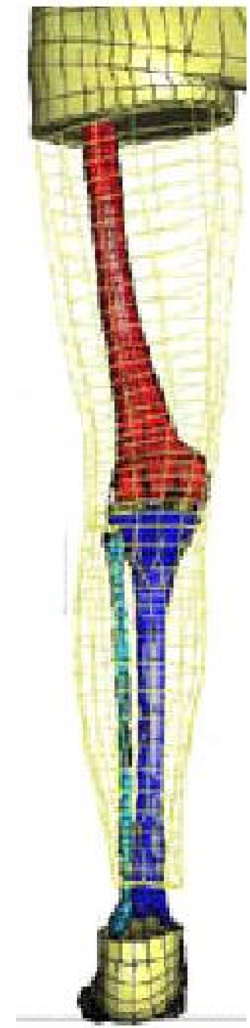
Flex-G



Flex-GTα



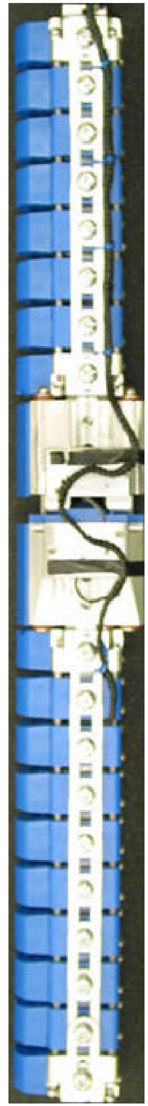
Human FE Model

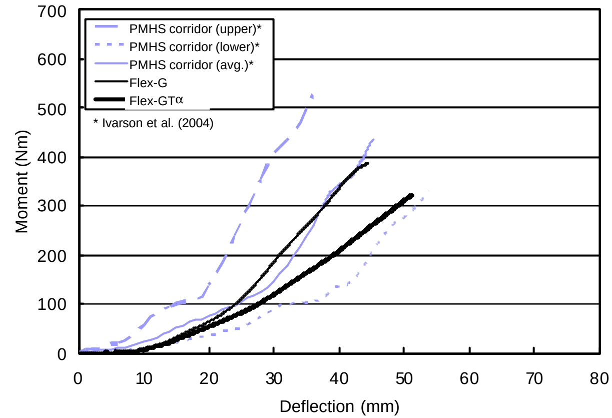


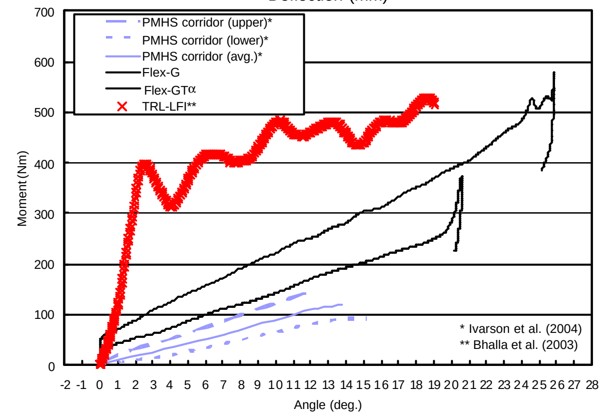
Discussions on Part 1, cont.

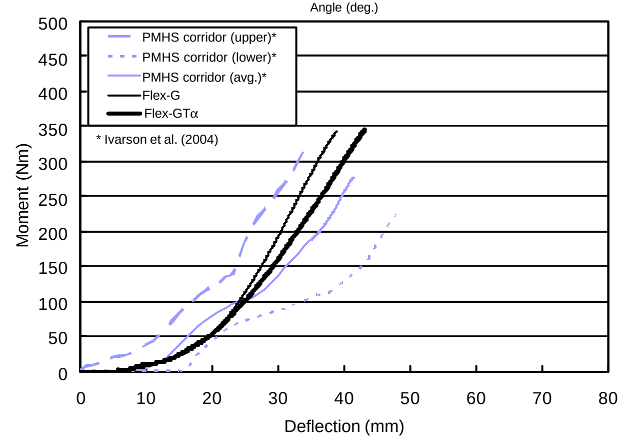
- Besides, Flex-GTα has slightly softer bending stiffness of long bone parts, and slightly greater bending stiffness of knee as compared with those of Flex-G.
- These bending stiffness enables Flex-GTα to give impact phenomena comparable with those of the human FE model.

Flex-GTα



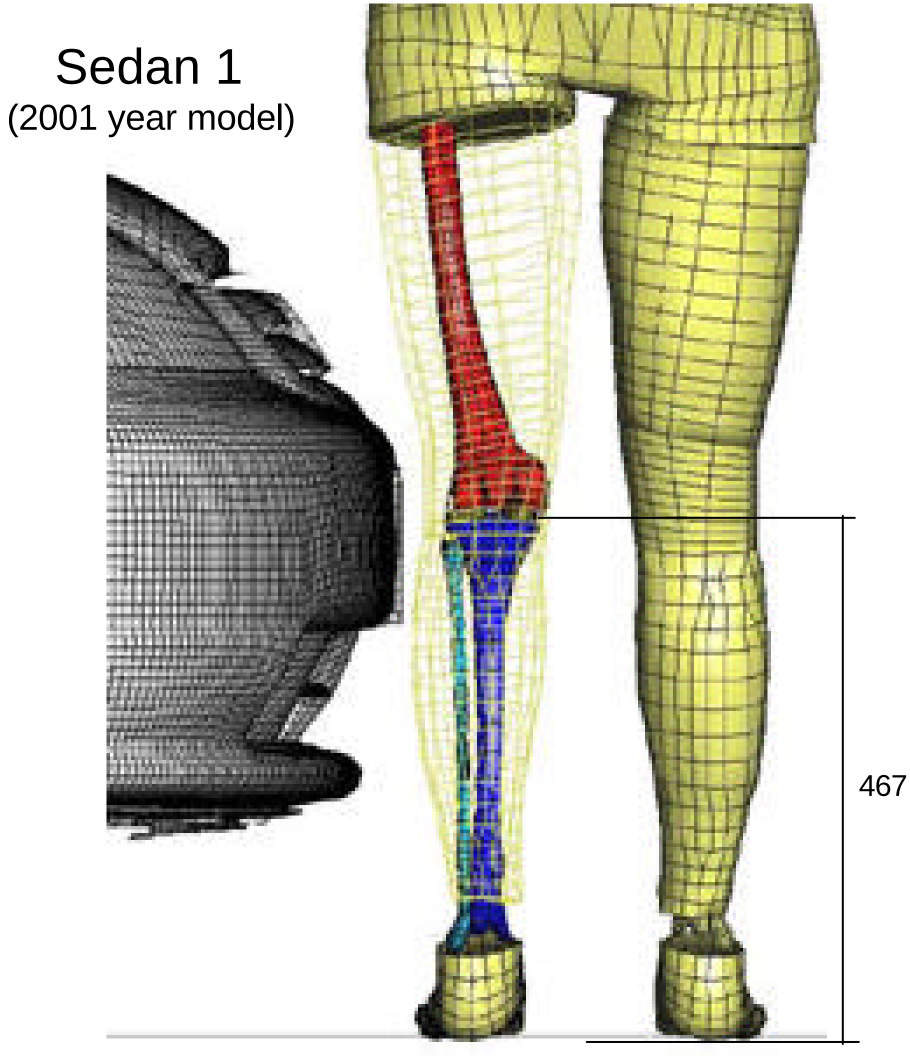






Discussions on Part 1, cont.

- The conditions of human FE model simulation, however, is slightly different from the those of Flex-GTα test.
- Therefore, additional evaluations are necessary for finalization of Flex-GT specifications.



Conclusions on Part 1

- In this study, the impact phenomena of Flex-G, Flex-GTα, and the human FE model were compared.
- The impact phenomenon of Flex-G is the severest of the three, whereas, the impact phenomena of Flex-GTα and the human FE model were comparable.
- The results indicated that 1) the use of lighter materials for long bones, 2) slightly softer bending stiffness for long bones, and 3) slightly greater bending stiffness for knee enables Flex-GTα to give an impact phenomenon comparable with that of the human FE model.
- The conditions of human FE model simulation, however, is slightly different from the those of Flex-GTα test, therefore, additional evaluations are necessary.

Evaluation Activities
(Part 2)

Reconstruction Test on the PMHS Test Using Flex-GTa

PMHS Test Data

PMHS test conditions and results

Car information			Pedestrian information						
Car	Test No.	Impact speed (m/s)	Gender	Age (year)	H_T (cm)	W_T (kg)	Lower extrimity injury Thigh	Knee	Leg
C1	T3	8.9	Male	48	170	62	-	-	FX (fibula and tibia)
	T4	8.9	Male	58	185	85	-	-	FX (fibula and tibia)
C3	Y1	8.3	Male	70	167	68	-	-	FX (fibula and tibia)

C1: Ishikawa et al. (1993), C3: Schroeder et al. (2000)

H_T: Total body height, W_T: Total body weight, FX: Fracture

Test Conditions

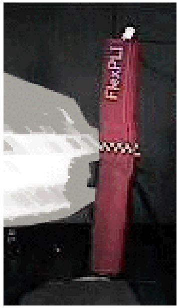
Reconstruction test conditions on PMHS tests

Car	Impact speed (m/s)	Impactor	Impact location (mm) *	
			horizontal	vertical (H_{KR}**)
C1	8.9	Flex-GTα	R 200	537
C3	8.3	Flex-GTα	R 200	bumper center height

* Estimated from literature(C1: Ishikawa (1993), C3: Schroeder (2000)).

** H_K: Knee height relative to car.

Car: C1



Car: C3

Tentative Thresholds

Tentative Thresholds for Flex-GTα

Body regions		50% injury risk level for 50 percentile American male (tentative)	References
Leg	(Tibia)	BM (312 - 350 Nm)	BM (312 Nm): Kerrigan et al., 2004 BM (350 Nm): INF GR/PS/82
Knee	(MCL)	EL (19.5 - 21.6 mm)**	BA (18 deg).: Ivarsson et al., 2004 BA (20 deg).: INF GR/PS/82
	(ACL, PCL)	EL (11.2 mm)***	SD (10 mm): IHRA/PS/309
Thigh	(Femur)	BM (372-447 Nm)	BM (372 - 447 Nm): Kerrigan et al., 2004 BM (390 - 395 Nm): Kennedy et al., 2004

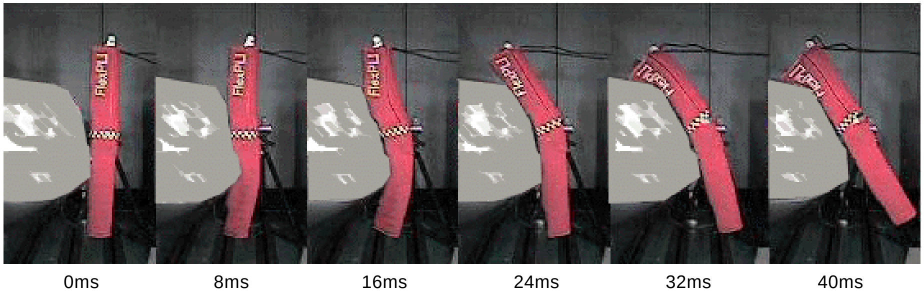
* BM: Bending moment, EL: Elongation, BA: Bending angle, SD: Shearing displacement.

** Estimated values for Flex-GTα from BA (18-20 deg.).

*** Estimated values for Flex-GTα from SD (10 mm).

Reconstruction Test Results (Car: C1)

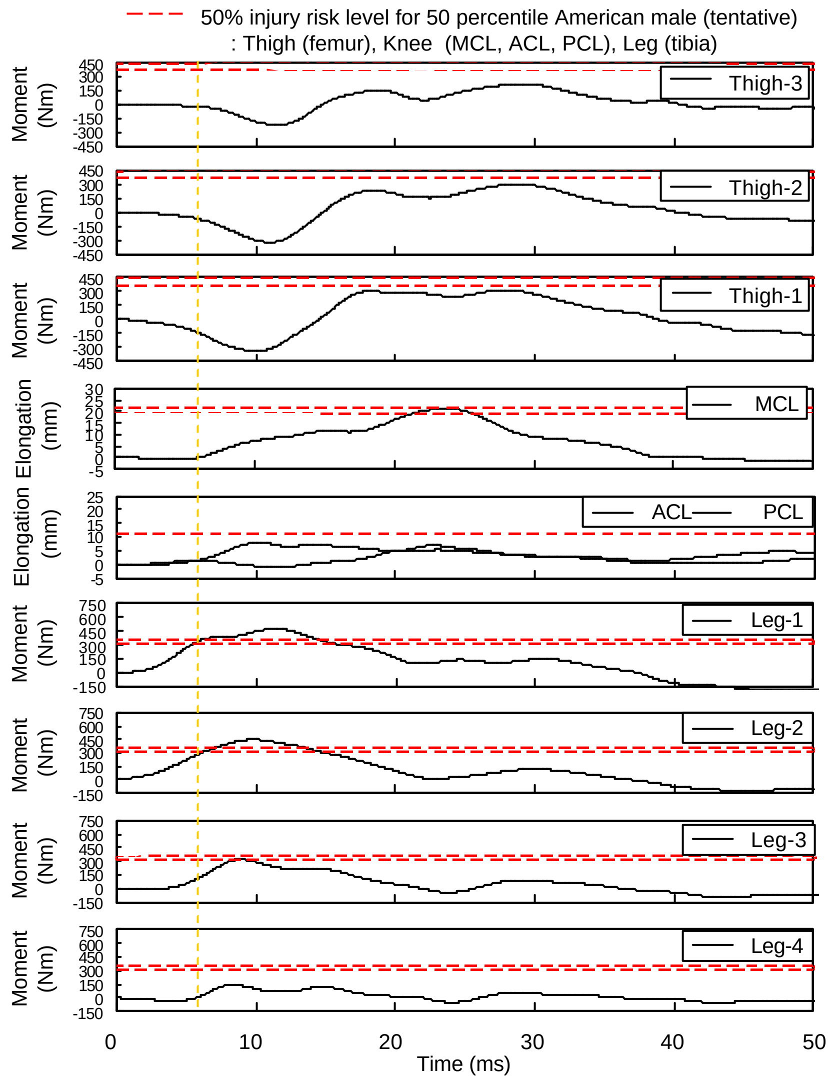
Flex-GTα



Car information			Pedestrian information						
Car	Test No.	Impact speed (m/s)	Gender	Age (year)	H_T (cm)	W_T (kg)	Lower extremity injury: Thigh	Knee	Leg
C1	T3	8.9	Male	48	170	62	-	-	FX (fibula and tibia)
	T4	8.9	Male	58	185	85	-	-	FX (fibula and tibia)

C1: Ishikawa et al. (1993)

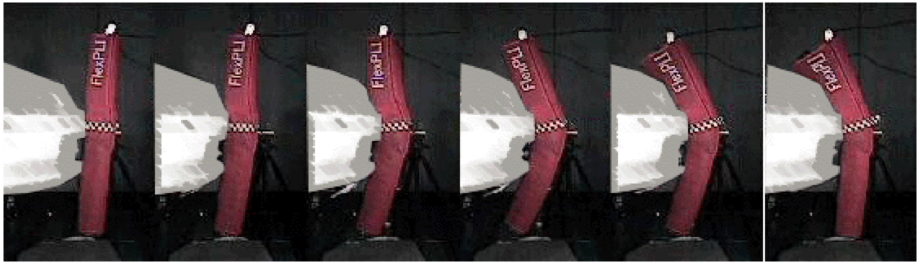
H_T: Total body height, W_T: Total body weight, FX: Fracture



- Flex-GTα recorded a high bending moment (over tibia fracture level) on its leg at around 5 ms.

Reconstruction Test Results (Car: C3)

Flex-GTα

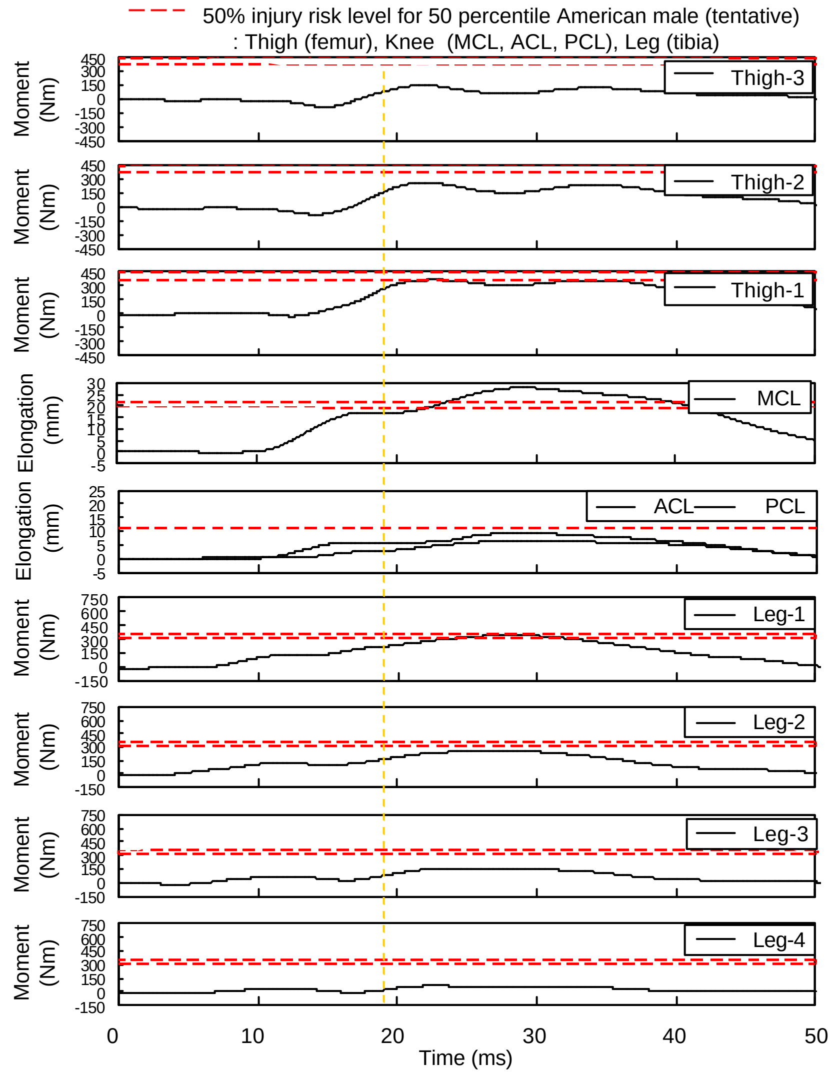


0ms | 8ms | 16ms | 24ms | 32ms | 40ms

Car Information			Pedestrian Information						
Car	Test No.	Impact speed (m/s)	Gender	Age (year)	H_T (cm)	W_T (kg)	Lower extremity injury: Thigh	Knee	Leg
C3	Y1	8.3	Male	70	167	68	-	-	FX (fibula and tibia)

C3: Schroeder et al. (2000)
H_T: Total body height, W_T: Total body weight, FX: Fracture

- Flex-GTα recorded a high loading (over/close threshold level) on its leg, knee, and thigh at around 20 ms.



Discussion and Conclusions on Part 2

- In this study, a reconstruction test on PMHS tests was conducted.
- It has a possibility that the Flex-GTα has good injury assessment ability on PMHS tests.
- However, 1) cannot change length, mass and bending stiffness of impactor for each test, besides, 2) cannot know strength of each pedestrian leg and knee, therefore, it has a high limitation on this evaluation methodology.

Evaluation Activities (Part 3)

Reconstruction Test on Car-Pedestrian Traffic Accidents Using Flex-GTa

Car-Pedestrian Traffic Accident Data

Car and Pedestrian Information

Car information				Pedestrian information						
Car No.	Model year	Impact speed (km/h)	Braking	Gender	Age (year)	H_T (cm)	W_T (kg)	Lower extremity injury Thigh	Knee	Leg
Car 2	1997	30	Activated	Male	79	150	45	FX (femur**)	-	FX (tibia*)
Car 3	1994	25	Activated	Male	76	170	48	-	-	FX (tibia*)

H_T: Total body height, W_T: Total body weight, FX: Fracture,

* First contact side of lower extremity, ** Secondary contact side of lower extremity.

Car 2

Car 3

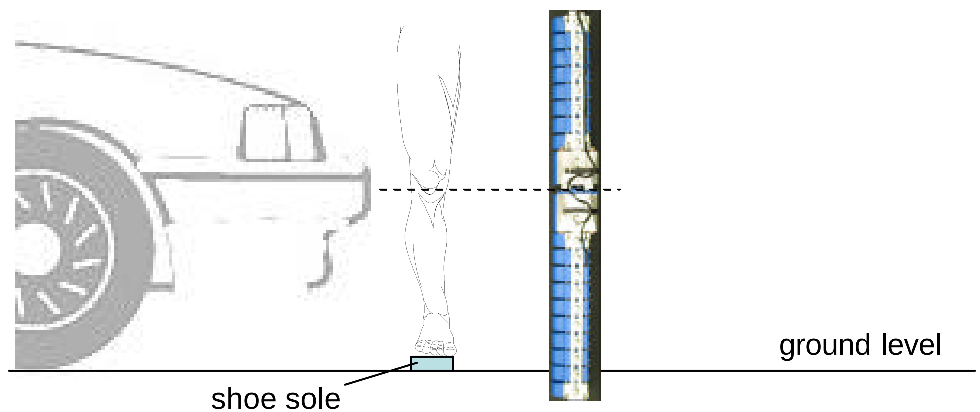
Estimation of the Car-Pedestrian Impact Location Especially for Impact Height

Estimated results

Car Information					Pedestrian Information				Statistical data				Normalization		Estimated knee height: Base	Estimated knee height: Estimation
Car No.	Model year	Impact speed	Breaking	L	Gender	Age	H_T	W_T	$H_{T\text{-}Avg.}$	SD_{HT}	$H_{K\text{-}Avg.}$	SD_{HK}	Z_{HT}	Z_{HK}	H_K	H_{KR} (H_{KB} + BHD + H_{SS})
		(m/s)		(mm)		(year)	(mm)	(kg)	(mm)	(mm)	(mm)	(mm)			(mm)	(mm)
Car 2	1997	8.3	activated	1941	Male	79	1500	45	1586	57	404	24	-1.51	-1.51	368	439
Car 3	1994	6.9	activated	1379	Male	76	1700	48	1586	57	404	24	2.00	2.00	452	510

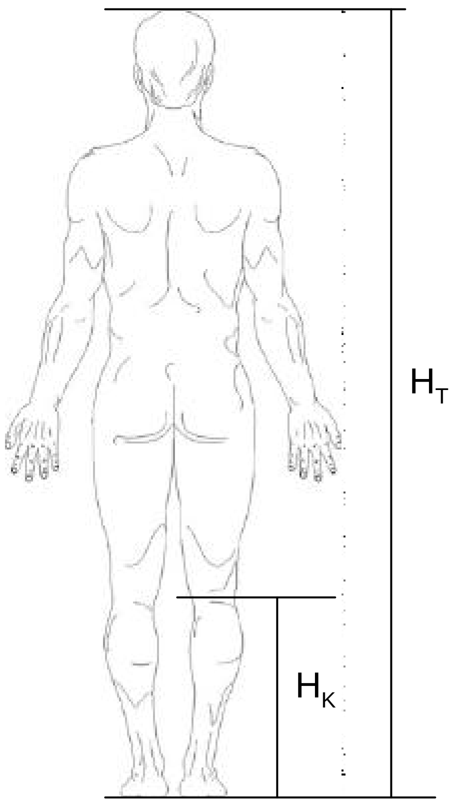
L: Horizontal length from C.G. to car front end, H_T: Total body height, W_T: Total body weight, $H_{T\text{-}Avg.}$: Average of total body height, SD_{HT}: Standard deviation of total body height, $H_{K\text{-}Avg.}$: Average of knee height, SD_{HK}: Standard deviation of knee height, Z_{HT}: Normalized total body height, Z_{HK}: Normalized knee height, H_K: Knee height, H_{KR}: Knee height relative to car, BHD: Bumper height difference by breaking (BHD = L x tan (?), ? = 1.365 degrees), H_{SS}: Shoe sole height (assumed as 25 mm).

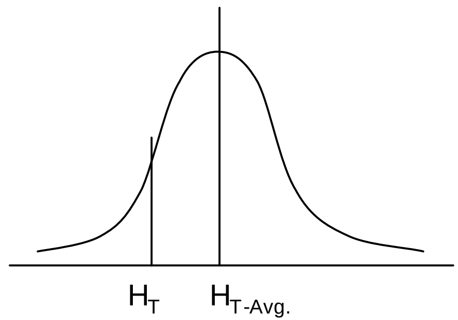
Knee height related to car is estimated.
(Considered individual pedestrian knee height, car braking effect, and shoe sole height)



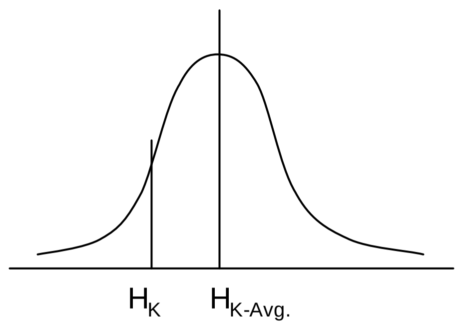
Estimation of the Car-Pedestrian Impact Location Especially for Impact Height (cont.)

Estimation method (pedestrian knee height)





a) Distribution of total body height.



b) Distribution of knee height.

$$Z_{H_T} = \frac{H_T - H_{T-Avg.}}{SD_{H_T}}$$

$$Z_{H_K} = \frac{H_K - H_{K-Avg.}}{SD_{H_K}}$$

$$Z_{H_T} = Z_{H_K} \ (assumption)$$

$$H_K = H_{K-Avg.} + Z_{H_T} \cdot SD_{H_K}$$

c) Knee height estimation.

Z_{H_T} : *Normalized total body height*

H_T : *Total body height*

$H_{T-Avg.}$: *Average of total body height*

SD_{H_T} : *Standard deviation of total body height*

Z_{H_K} : *Normalized knee height*

H_{KB} : *Knee height*

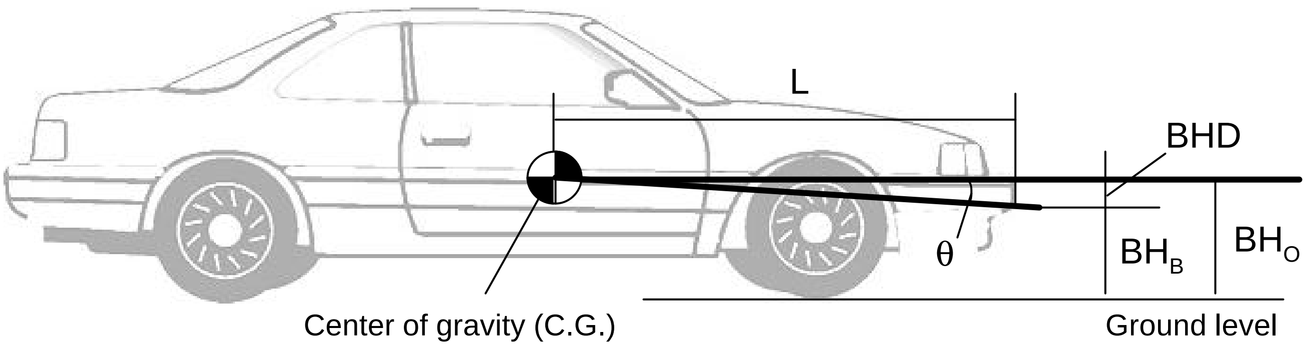
$H_{K-Avg.}$: *Average of knee height*

SD_{H_K} : *Standard deviation of knee height*

Reference: Matsui. Y., New injury reference values determined for TRL legform impactor from accident reconstruction test, IJCrash 2003.

Estimation of the Car-Pedestrian Impact Location Especially for Impact Height (cont.)

Estimation method (braking effect)



$$BHD = BH_O - BH_B = L \cdot \tan(q)$$

BHD : *Bumper height difference by braking*

BH_O : *Bumper height (original)*

BH_B : *Bumper height under braking*

L : *Horizontal length from C.G. to car front end*

q : *Car pitching angle by braking (around* 1.365 deg.)

Reference: Matsui. Y., New injury reference values determined for TRL legform impactor from accident reconstruction test, IJCrash 2003.

Estimated Test Conditions

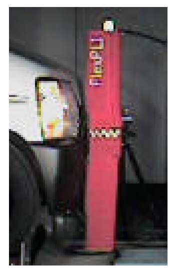
Accident Reconstruction Test conditions

Car	Impact speed (m/s)	Impactor	Impact location (mm) *	
			horizontal	vertical (H_{KR}**)
Car 2	8.3	Flex-GTα	L 100	439
Car 3	6.9	Flex-GTα	L 410	510

* Estimated from literature(ITARDA 2001, 2004).

** H_{KR}: Knee height relative to car.

Car 2



Car 3

Tentative Thresholds

Tentative Thresholds for Flex-GTα

Body regions		50% injury risk level for 50 percentile American male (tentative)	References
Leg	(Tibia)	BM (312 - 350 Nm)	BM (312 Nm): Kerrigan et al., 2004 BM (350 Nm): INF GR/PS/82
Knee	(MCL)	EL (19.5 - 21.6 mm)**	BA (18 deg).: Ivarsson et al., 2004 BA (20 deg).: INF GR/PS/82
	(ACL, PCL)	EL (11.2 mm)***	SD (10 mm): IHRA/PS/309
Thigh	(Femur)	BM (372-447 Nm)	BM (372 - 447 Nm): Kerrigan et al., 2004 BM (390 - 395 Nm): Kennedy et al., 2004

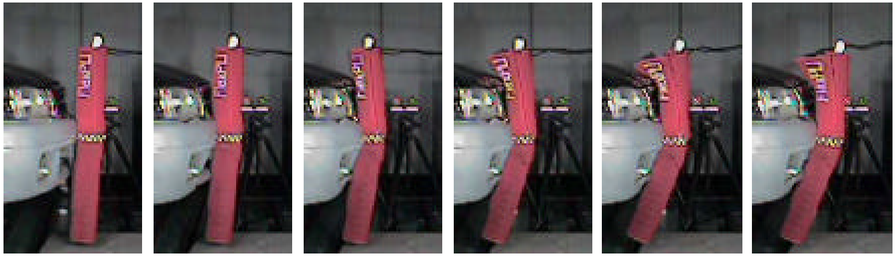
* BM: Bending moment, EL: Elongation, BA: Bending angle, SD: Shearing displacement.

** Estimated values for Flex-GTα from BA (18-20 deg.).

*** Estimated values for Flex-GTα from SD (10 mm).

Reconstruction Test Results (Car: Car2)

Flex-GTα

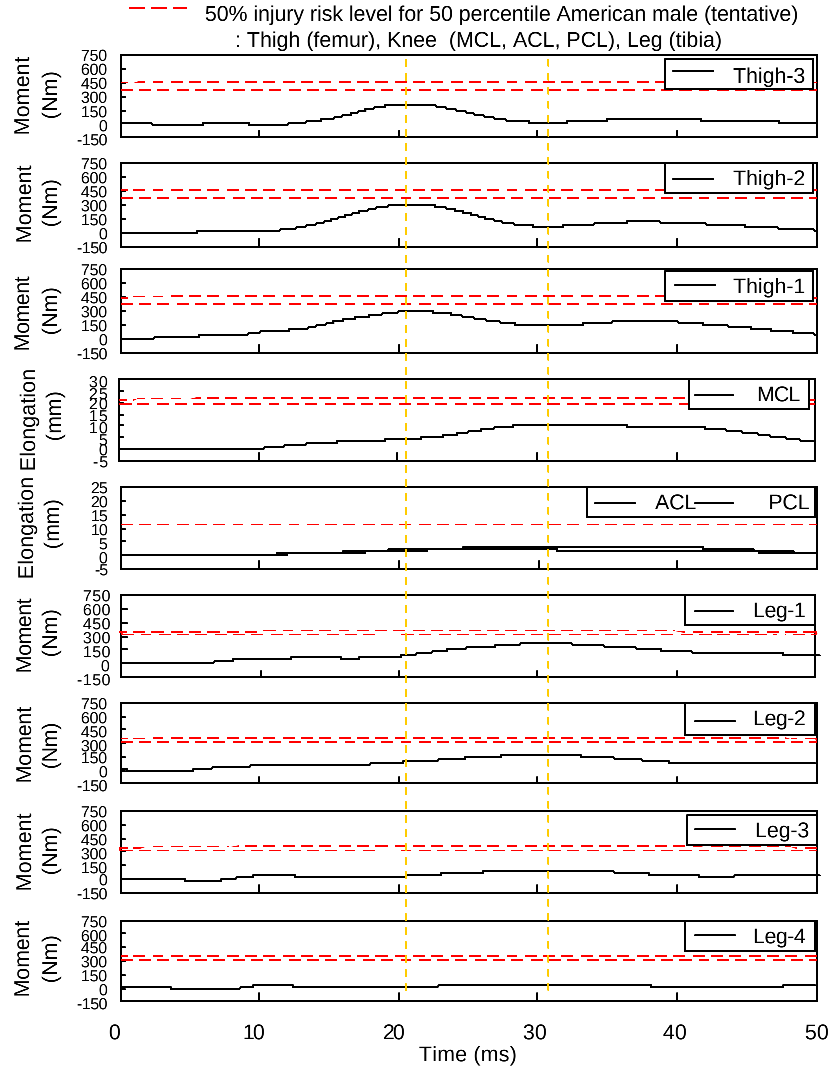


0ms 8ms 16ms 24ms 32ms 40ms

Car information				Pedestrian information						
Car No.	Model year	Impact speed (km/h)	Braking	Gender	Age (year)	H_T (cm)	W_T (kg)	Lower extremity injury: Thigh	Knee	Leg
Car 2	1997	30	Activated	Male	79	150	45	FX (femur**)	-	FX (tibia*)

H_T: Total body height, W_T: Total body weight, FX: Fracture,
* First contact side of lower extremity, ** Secondary contact side of lower extremity.

- Flex-GTα recorded a high bending moment (close to thigh fracture level) on its thigh at around 20 ms.
- Flex-GTα also recorded a high bending moment (close to leg fracture level) on its leg at around 30 ms.



Reconstruction Test Results (Car: Car3)

Flex-GTα

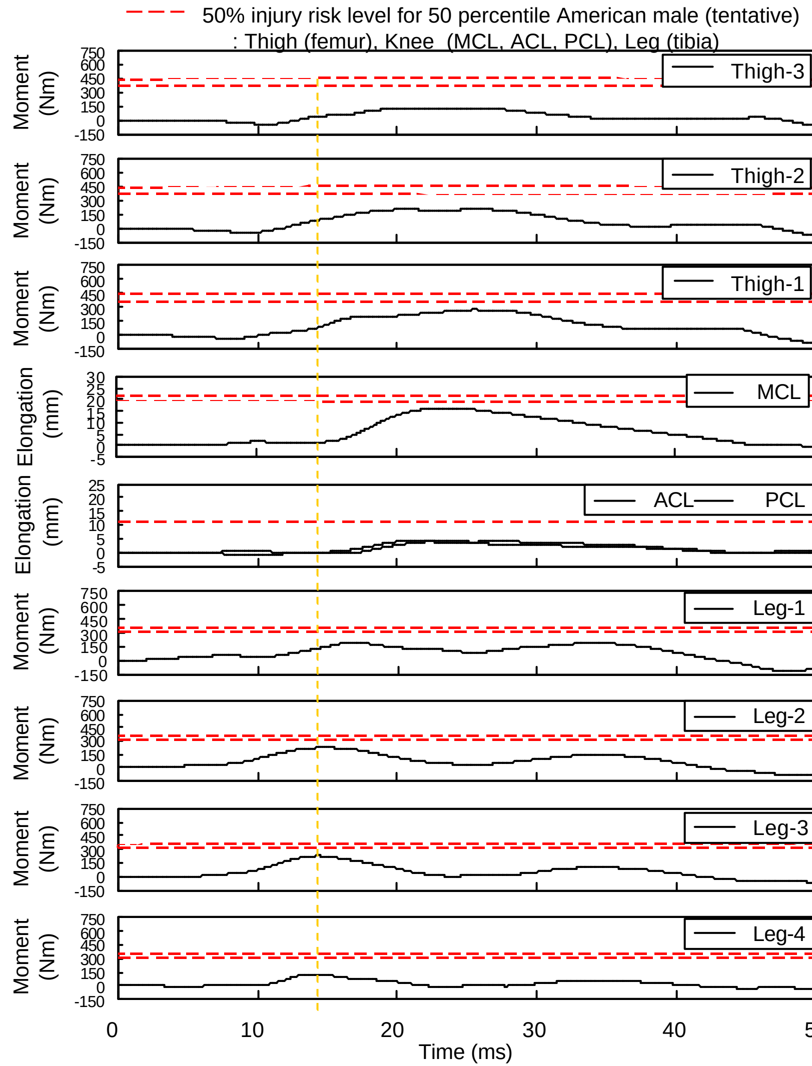
0ms 8ms 16ms 24ms 32ms 40ms

Car information				Pedestrian information						
Car No.	Model year	Impact speed (km/h)	Braking	Gender	Age (year)	H_T (cm)	W_T (kg)	Lower extremity injury: Thigh	Knee	Leg
Car 3	1994	25	Activated	Male	76	170	48	-	-	FX (tibia*)

H_T: Total body height, W_T: Total body weight, FX: Fracture,

* First contact side of lower extremity

- Flex-GTα recorded high bending moment (close to leg fracture level) on its leg at 10 to 15 ms.



Discussion and Conclusions on Part 3

- In this study, a reconstruction test on car-pedestrian traffic accidents was conducted.
- It has a possibility that the Flex-GTα has good injury assessment ability on car-pedestrian traffic accidents.
- However, 1) cannot change length, mass and bending stiffness of impactor for each test, besides, 2) cannot know strength of each pedestrian leg and knee, therefore, it has a high limitation on this evaluation methodology.

Conclusions

- In this study, evaluations were conducted on the injury assessment ability of Flex-GTα comparing with human FE model.
- Flex-GTα indicated an injury assessment ability comparable with the human FE model.
- The conditions of human FE model simulation, however, is slightly different from the those of Flex-GTα test, therefore, additional evaluations are necessary.

Conclusions, cont.

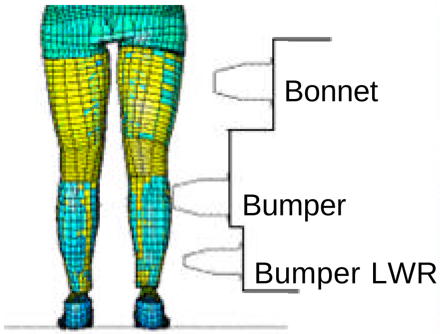
- In addition, in this study, evaluations were conducted on the injury assessment ability of Flex-GTα by conducting reconstruction tests of PMHS testing and of car-pedestrian accidents.
- Flex-GTα also indicated a possibility to have good injury assessment ability in the reconstruction tests of PMHS testing and of car-pedestrian accidents, however, the evaluation methodologies had high limitations.
- It is because, 1) cannot change length, mass and bending stiffness of impactor for each test, besides, 2) cannot know strength of each pedestrian leg and knee.

Conclusions, cont.

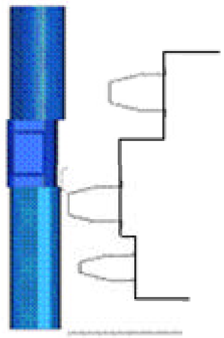
- Therefore, it is recommended that the comparison with human FE model should be main evaluation methodology, and the reconstruction tests of PMHS testing and of car-pedestrian accidents should be subsidiary evaluation methodologies.

Current Idea of Human FE Model Implementation

(1) Perform comparison CAE, using a simplified vehicle model.



Human FE model



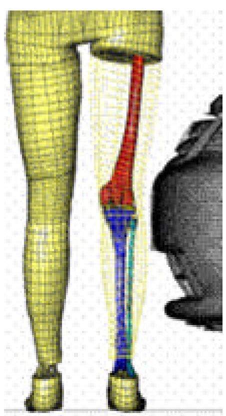
Flex-PLI FE model

A simple vehicle model is developed as a support rig having a plate on each of the bonnet, bumper and bumper-lower sections.

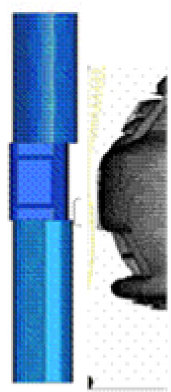
Let the human FE model and Flex-PLI FE model crash into the rig, and compare their behaviors and injury values.

Modify the impactor specifications according to the CAE results.

(2) Perform a vehicle crash CAE, applying the modified impactor specifications from (1).



Human FE model



Modified Flex-PLI FE model

Confirm the validity of the above modification.

Besides, adopt the above CAE impactor modifications into the actual impactor, and perform a car test to confirm CAE validity.

Action Plan

May '06 | June '06 | July '06 | Aug. '06 | Sep. '06

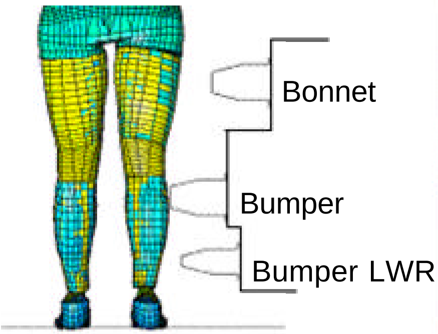
Final evaluation analysis will be conducted using computer simulation models, to finalize Flex-GT specifications.

Develop Flex-GT 1.0

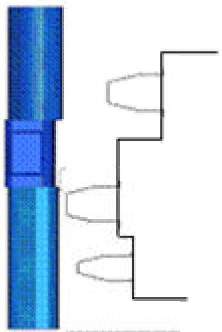
Evaluation test Flex-GT 1.0

4th Flex-TEG MT

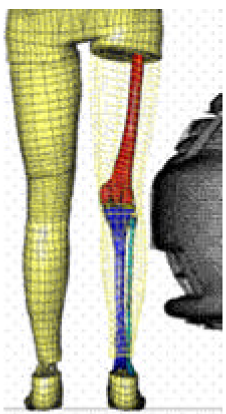
Release Flex-GT 1.0



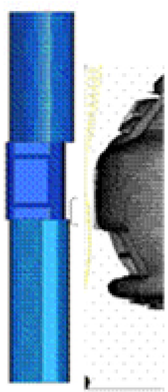
Human FE model



Flex-PLI FE model



Human FE model



Modified Flex-PLI FE model

Thank you for your attention!

References

- Takahashi, T., Kikuchi. Y., Konosu. A., Ishikawa. H. (2000) Development and Validation of the Finite Element Model for the Human Lower Limb of Pedestrians, 44th Stapp Car Crash Conference, 2000-01-SC22.
- Ivarsson, B.J., Lessley, D., Kerrigan, J.R., Bhalla, K.S., Bose, D., Crandall, J.R., Kent, R.（2004）Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities, Proc. International IRCOBI Conference on the Biomechanics of Impacts, pp. 179-191.
- Bhalla, K.S., Bose, D., Madeley, N.J., Kerrigan, J., Crandall, J., Longhitano, D., Takahashi, Y. (2003) Evaluation of the response of mechanical pedestrian knee joint impactors in bending and shear loading, Proc. 18th International Technical Conference on the Enhanced Safety of Vehicle, Paper No. 429.
- Ishikawa. H., et al. (1993) Computer Simulation of impact Response of the Human Body in Car-Pedestrian Accidents, SAE Paper No.933129.
- Schroeder. G., et al. (2000) Injury Mechanism of Pedestrians During a Front-End Collision with a Late Model Car, J-SAE Pedestrian Safety Forum 2000 Spring, No.20004255, 2000.
- Kerrigan, J.R., Drinkwater, D.C., Kam, C.Y., Murphy, D.B., Ivarsson, B.J., Crandall, J.R., Patrie, J. (2004) Tolerance of the Human Leg and Thigh in Dynamic Latero-Medial Bending, ICRASH 2004.
- ECE/TRANS/WP.29/GRSP/INF GR PS (2004) Discussion on Injury Threshold for Pedestrian Legform Test, INF/GR/PS/82, P. 2.

References, Cont

- International Harmonized Research Activity/Pedestrian Safety Working Group (2004) IHRA/PS Decisions for the IHRA/PS Legform Test Procedures, IHRA/PS/309.
- Kennedy, E.A., Hurst, W.J., Stitzel, J.D., Cormier, J.M., Hansen, G.A., Smith, E.P., Duma, S.M. (2004) Lateral and Posterior Dynamic Bending of the Mid-Shaft Femur: Fracture Risk Curves for the Adult Population, Stapp Car Crash Journal, Vol. 48, pp. 22-51.
- ITARDA, H13 Traffic Accident Investigation and Analysis Report, pp. 299 - 344.
- ITARDA, H16 Traffic Accident Reconstruction Test to Improve Car Crash Safety.
- Matsui, Y. (2003) New Injury reference values determined for TRL legform impactor from accident reconstruction test, IJ Crash 2003, Vol. 8, No. 2, pp. 179-188.