Review of the Flexible Pedestrian Legform Impactor Technical Evaluation Group (Flex-TEG) Activity

- Summary -

- ver.111021-

November 3rd, 2011
Japan

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

1. Biofidelity

◆**Component Level**
- **Leg/Thigh bending stiffness**
  - ➤ **Within the human corridor (TEG-021)**
- **Knee bending stiffness**
  - ➤ **Much closer to the human corridor compared to that of the EEVC PLI (TEG-021)**

1. Biofidelity, contd.

◆**Full Assembly Level**

- **Evaluated by Accident Reconstruction Tests**
  - **Showed possibility of good injury assessment ability of Flex-PLI. (TEG-022)**
- **Evaluated by using Human and Flex-PLI FE Model**
  - **Good correlation between Human and Flex-PLI (extended rubber spec.) was observed regarding Tibia bending moment and MCL elongation outputs. (TEG-096)**
  - **+ 50 mm higher impact height to a car, compared to human one, was selected by compensating for the lack of the human upper body part in the specification of Flex-PLI. (TEG-032)**

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

2. Performance/Injury Criteria

◆Discussions

- Detailed discussions were made in the Flex-TEG. (TEG-035, TEG-048, TEG-076, TEG-077, TEG-078, TEG-084, TEG-095, TEG-097, TEG-098, TEG-127, TEG-128, TEG-129, TEG-130)

◆Conclusions of Flex-TEG

- Finally, Flex-TEG made conclusions as follows (TEG-127):
  - Tibia: 340 Nm
  - MCL: 22 mm
  - ACL/PCL: seek guidance to GRSP
- Besides, Flex-TEG proposed to do not use rebound phase test data for car evaluation (TEG-130)

2. Performance/Injury Criteria

◆ Information: GRSP proposals

- After the GRSP discussions, following values ware proposed:
  - Tibia: 340 Nm, 380 Nm (relaxation zone)
  - MCL: 22 mm
  - ACL/PCL: 13 mm
  - Does not use rebound phase test data

Outline

3. Benefit

◆**Estimations**

- **Lower limb protection level provided by Flex-PLI was estimated by JAMA-JARI using NHTSA method (GRSP/2006/7). (TEG-049)**

◆**Results**

- **Following number of injured person can be decreased by introduction of Flex-PLI in U.S..**
  - **2,438 person (in pedestrian - passenger vehicle (PV) accidents)**
  - **359 person (in pedestrian - large truck vehicle (LTV) accidents)**

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

4. Durability

◆**Evaluations**

- **A lot of durability tests were conducted by Flex-TEG members in many countries. (TEG-037, TEG-063, TEG-112, TEG-113)**

◆**Results**

- **No serious issues occurred.**
- **NHTSA would like to conduct additional durability test against a car which has poor performance in EEVC PLI test.**

Outline

5. Reproducibility and Repeatability

◆**Evaluations**

- **A numerous revaluation tests regarding reproducibility and repeatability of Flex-PLI were conducted by Flex-TEG members in many countries. (TEG-021, TEG-034, TEG-036, TEG-038, TEG-039, TEG-043, TEG-045 Rev.1, TEG-047, TEG-051 Part1-3, TEG-063, TEG-064, TEG-071, TEG-072 Rev.1, TEG-087, TEG-089, TEG-093, TEG-094, TEG-105, TEG-112, TEG-113)**

◆**Results**

- **Repeatability and reproducibility of Flex-PLI is accepted by Flex-TEG members.**

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

6. Vehicle Countermeasures

◆**Evaluations**

- **Various comparison tests, Flex-PLI and EEVC PLI, were conducted by Flex-TEG members in many countries. (TEG-035, TEG-036, TEG-091, TEG-112, TEG-113)**

◆**Results**

- **The comparison results were not revealed concrete trend between the Flex-PLI test results and EEVC PLI test results because specifications and measurement items are differed by Flex-PLI and EEVC PLI.**

Thank you for your attention!

Appendix

Summary, results and important slides from all of the past Flex-TEG documents relevant to the agenda items of the IG PS2

November 3rd, 2011
Japan

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

1. Biofidelity

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-021	JARI	Flex-GT	- Dynamic 3-point bending test of the thigh and leg of Flex-GT - Dynamic knee bending test of the knee of Flex-GT - Comparison with human response corridors **Results** **- Flex-GT thigh and leg bending responses fell within human response corridors** **- Flex-GT knee bending stiffness was higher than human response corridor but lower than that of TRL-LFI**
TEG-022	JARI	Flex-GT	- Kinematics comparison between Flex-G, Flex-GT and human FE model - Reconstruction test of 2 full-scale PMHS tests using Flex-GT - Reconstruction test of 2 car-pedestrian accidents using Flex-GT **Results** **- Flex-GT knee response was closer to that of human compared to Flex-G** **- Reconstruction of both PMHS tests and pedestrian accidents showed a possibility that Flex-GT has a good injury assessment capability**

1. Biofidelity

- List of Relevant TEG Documents -

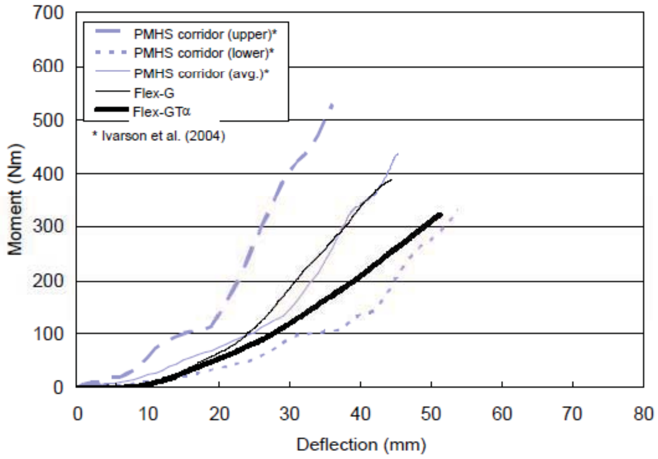
Doc. #	Affiliation	Version	Summary
TEG-032	JAMA-JARI	Flex-GT	- Correlation study using a human FE model and a Flex-GT FE model **Results** **- Impactor height of 75 mm provided best correlation by compensating for the lack of the upper body**
TEG-096	JAMA-JARI	Flex-GTR	- Development of Flex-GTR FE model - Analysis of injury measure correlations between human and Flex-GTR models **Results** **- Human-Flex-GTR correlation using 18 simplified vehicle models resulted in correlation coefficient of 0.90 for tibia and 0.55 for MCL** **- Extended rubber yielded better tibia correlation**

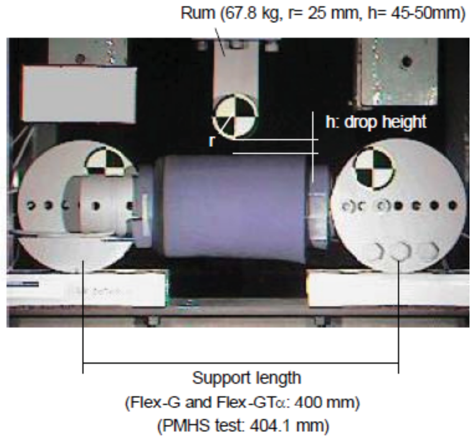
TEG-021

Long Bones

Bending characteristics (Thigh)

Flex-G and Flex-GTα





Flex-GTα (Thigh) has slightly smaller bending stiffness than that of Flex-G.

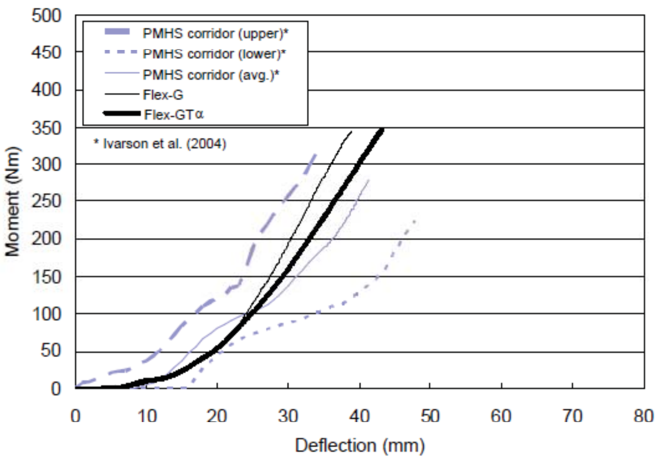
→ The difference gives Flex-GTα a better injury assessment ability than that of Flex-G.

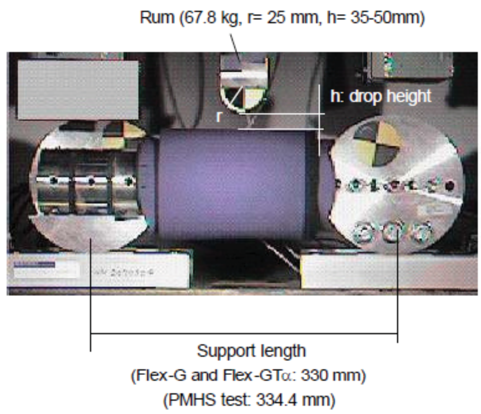
TEG-021

Long Bones

Bending characteristics (Leg)

Flex-G and Flex-GTα





Flex-GTα (Leg) has slightly smaller bending stiffness than that of Flex-G.

→ The difference gives Flex-GTα a better injury assessment ability than that of Flex-G.

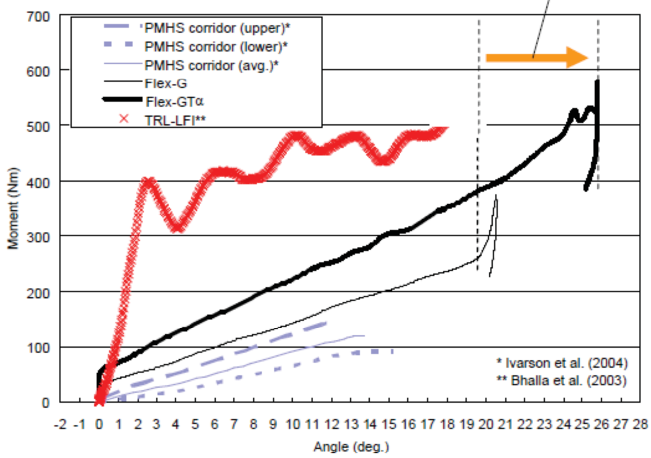
TEG-021

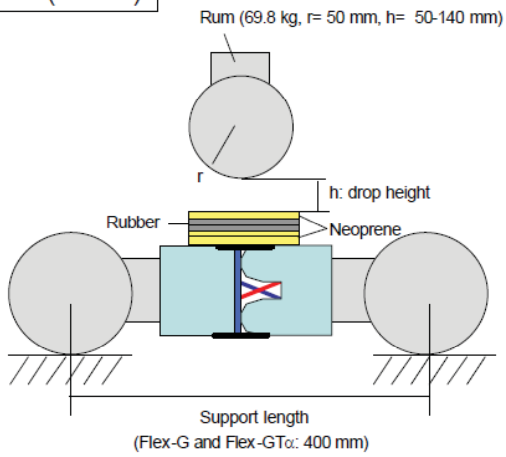
Knee

Bending characteristics (Knee)

Flex-G, Flex-GTα, and TRL-LFI

Improved knee bending limit (+30%)





Flex-GTα (Knee) has slightly greater bending stiffness than that of Flex-G
(but not stiffer than that of TRL-LFI).

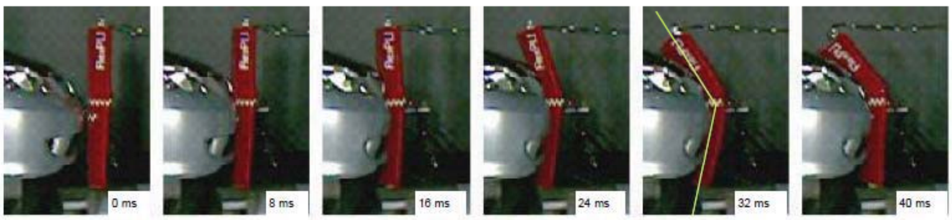
→ The difference gives Flex-GTα a better injury assessment ability than that of Flex-G.

TEG-022

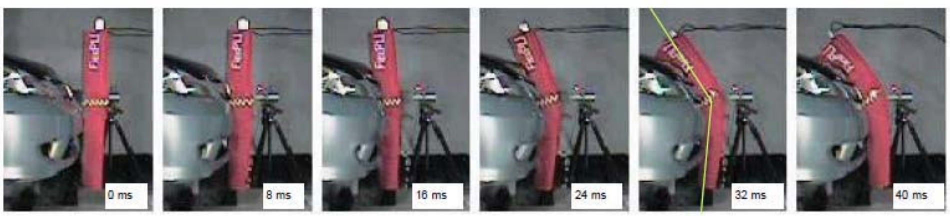
Comparison

Flex-G bending is the severest of the three.

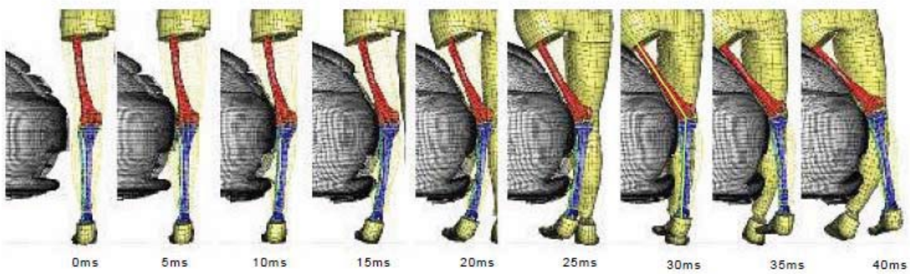
Flex-G



Flex-GTα



Human FE model



TEG-022

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: C1

Car: C3

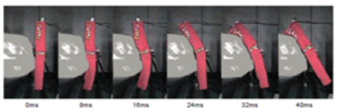
Car	Impact speed (m/s)	Impactor	Impact location (mm) *: horizontal	vertical (H_{KR}**)
C1	8.9	Flex-GTα	R 200	537
C3	8.3	Flex-GTα	R 200	bumper center height

* Estimated from literature(C1: Ishikawa (1993), C3: Schroeder (2000)).
** H_K: Knee height relative to car.

TEG-022

Reconstruction Test Results (Car: C1)

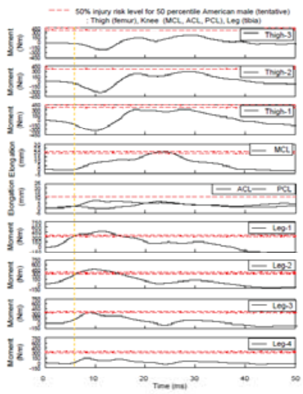
Flex-GTα



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)

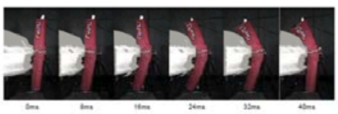
C1: Ishikawa et al. (1993)
H_T: Total body height, W_T: Total body weight, FX: Fracture

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



Reconstruction Test Results (Car: C3)

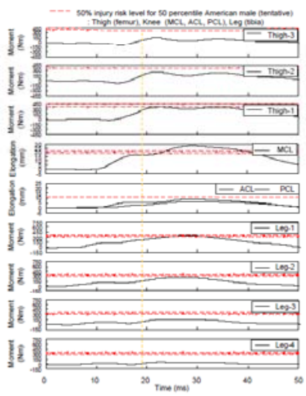
Flex-GTα



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.

TEG-022

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.

Estimated Test Conditions

Car 2

Car 3

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.

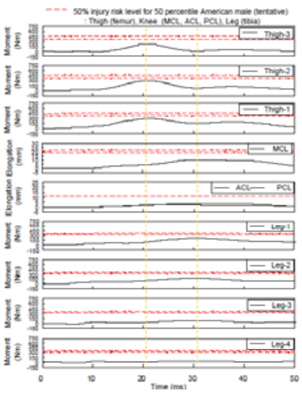
TEG-022

Reconstruction Test Results (Car: Car2)

Flex-GTα

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.



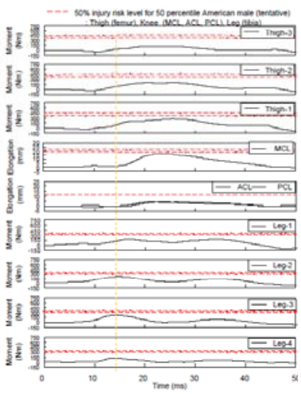
- Flex-GTα recorded a high bending moment (close to thigh fracture level) on its thigh at around 20 ms.
- Flex-GTα also recorded a high bending moment (close to leg fracture level) on its leg at around 30 ms.

Reconstruction Test Results (Car: Car3)

Flex-GTα

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.

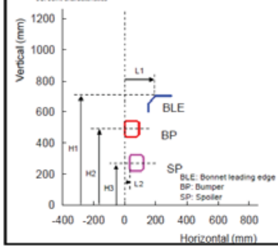
TEG-032

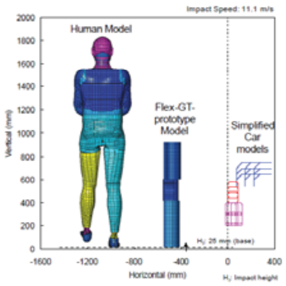
Computer simulation models

Simplified Car Model Parameters

Parameter	Unit	Level 1	Level 2	Level 3
K1 (BLE stiffness*)	mm	0.4	0.6	
K2 (BP stiffness**)	JC***	0.7	0.8	1.0
K3 (SP stiffness**)	JC***	0.6	0.8	1.0
H1 (BLE height)	mm	650	700	750
H2 (BP height)	mm	450	490	530
H3 (SP height)	mm	250	270	350
L1 (BLE lead)	mm	125	200	275
L2 (SP lead)	mm	-20	0	30

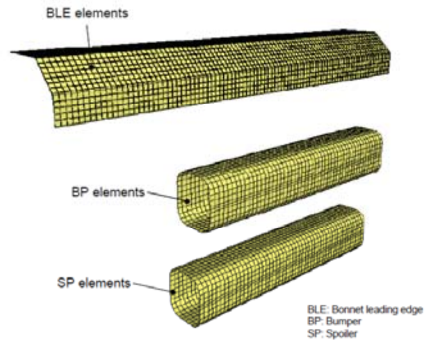
* Stiffness is changed by steel plate thickness.
** Stiffness is changed by joint characteristics.
*** JC: Joint characteristics





As for the Flex-GT-prototype model, Impact height (H_i) base + 50 mm and base + 75 mm is also calculated.

Explanation of Simplified Car Model
Over view – oblique front projection drawing



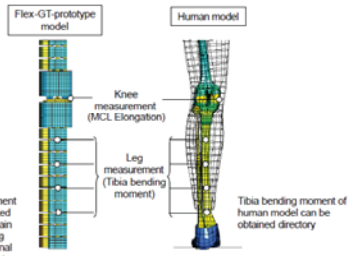
Specifications of the simplified car models (total 18 types)
Based on design of experiment method, L18 orthogonal table is utilized

Simplified Car model specifications

Simplified Car Model ID	K1 (BLE stiffness*) mm	K2 (BP stiffness**) JC***	K3 (SP stiffness**) JC***	H1 (BLE height) mm	H2 (BP height) mm	H3 (SP height) mm	L1 (BLE lead) mm	L2 (SP lead) mm
S1	0.4	0.7	0.6	650	450	250	125	-20
S2	0.4	0.7	0.8	700	490	270	200	0
S3	0.4	0.7	1.0	750	530	350	275	30
S4	0.4	0.8	0.6	650	490	270	275	30
S5	0.4	0.8	0.8	700	530	350	125	-20
S6	0.4	0.8	1.0	750	450	250	200	0
S7	0.4	1.0	0.6	700	450	350	200	30
S8	0.4	1.0	0.8	750	490	250	275	-20
S9	0.4	1.0	1.0	650	530	270	125	0
S10	0.6	0.7	0.6	750	530	270	200	-20
S11	0.6	0.7	0.8	650	450	350	275	0
S12	0.6	0.7	1.0	700	490	250	125	30
S13	0.6	0.8	0.6	700	530	250	275	0
S14	0.6	0.8	0.8	750	450	270	125	30
S15	0.6	0.8	1.0	650	490	350	200	-20
S16	0.6	1.0	0.6	750	490	350	125	0
S17	0.6	1.0	0.8	650	530	250	200	30
S18	0.6	1.0	1.0	700	450	270	275	-20

* Stiffness is changed by steel plate thickness.
** Stiffness is changed by joint characteristics.
*** JC: Joint characteristics
\# BLE: Bonnet leading edge, BP: Bumper, SP: Spoiler

Measurement points of the human model and the Flex-GT-prototype model

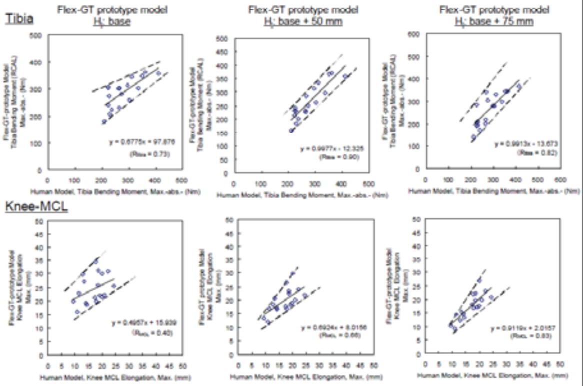


In this study, tibia bending moment of Flex-GT-prototype is estimated from each part of bone core strain using bone core 3 point bending test results not using conventional dynamic 3 point leg bending test like before (dynamic 3 point bending test include high inertia force of leg then difficult obtain appropriate conversion values).

Tibia bending moment of human model can be obtained directory

TEG-032

Results: Relationship between the Human model and Flex-GT prototype model

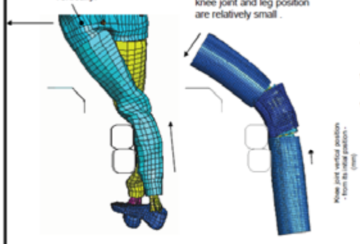


- To lift up the impact height of the Flex-GT can be obtained better correlation to the human one.

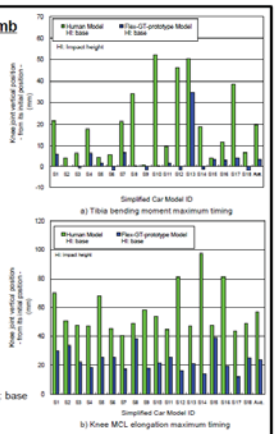
Upper body effect (1): Lifting up the lower limb

Upper body tend to stay at the initial position because of its high inertia, as a result, upper body tend to lift up the knee joint and leg positions vertically.

Impactor lift up motions of knee joint and leg position are relatively small.



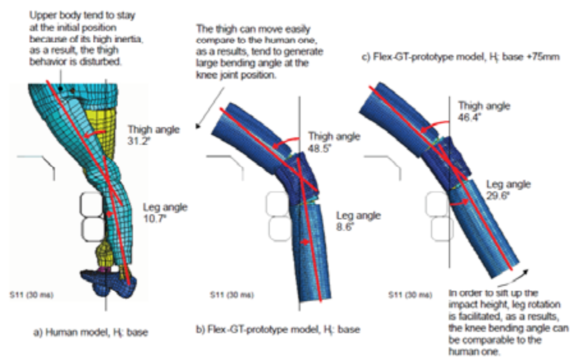
a) Human model, H_i: base b) Flex-GT-prototype model, H_i: base



a) Tibia bending moment maximum timing

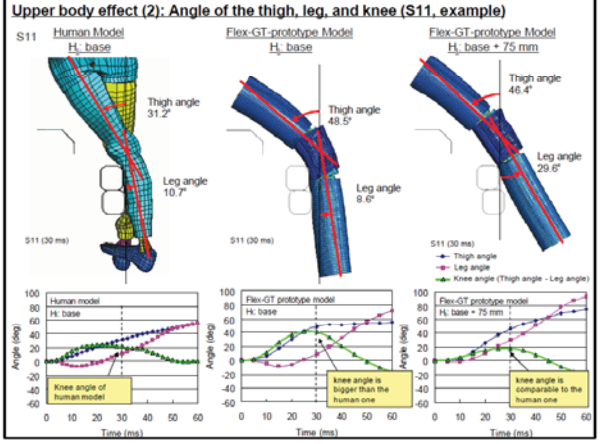
b) Knee MCL elongation maximum timing

Upper body effect (2): Inhibition of thigh behavior



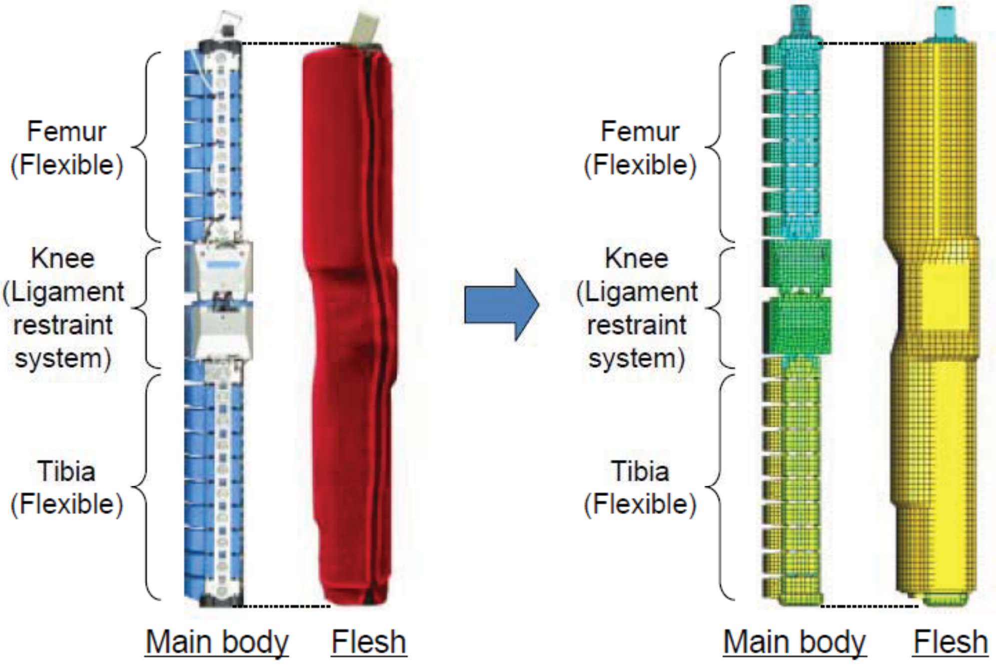
a) Human model, H_i: base b) Flex-GT-prototype model, H_i: base

Upper body effect (2): Angle of the thigh, leg, and knee (S11, example)



TEG-096

Flex-GTR-prototype and Developed FE model (Overview)

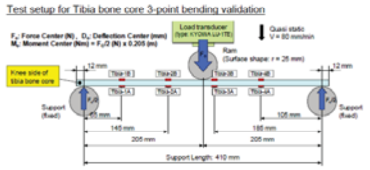


GTR9-C-05 Part 1

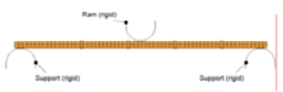
TEG-096

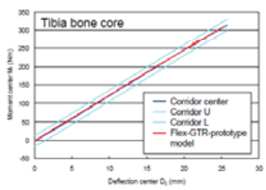
Tibia bone core 3-point bending validation

Test setup for Tibia bone core 3-point bending validation



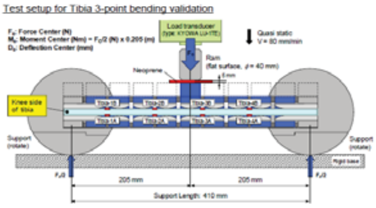
Model setup for Tibia bone core 3-point bending validation



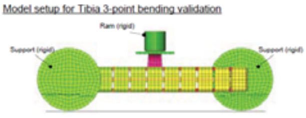


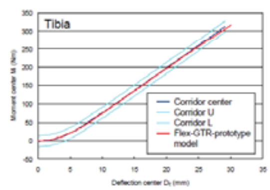
Tibia 3-point bending validation

Test setup for Tibia 3-point bending validation



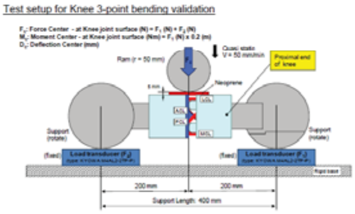
Model setup for Tibia 3-point bending validation



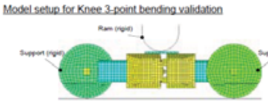


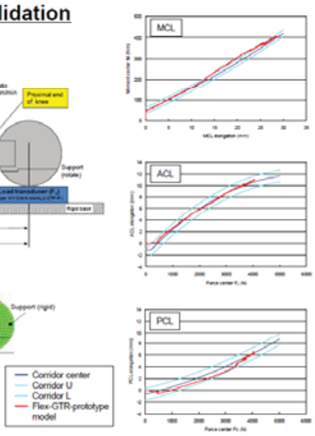
Knee 3-point bending validation

Test setup for Knee 3-point bending validation



Model setup for Knee 3-point bending validation

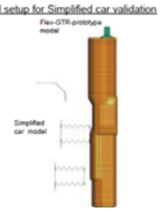


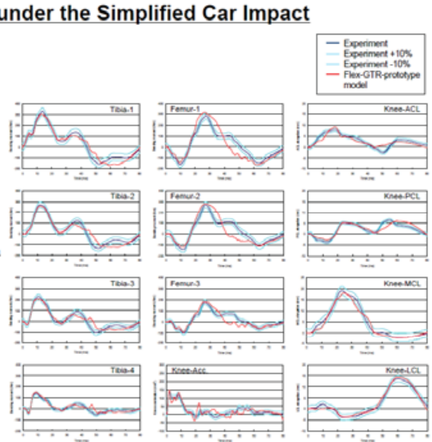


Overall validation under the Simplified Car Impact

Test setup for Simplified car validation

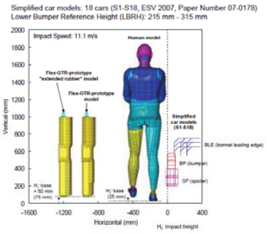
Model setup for Simplified car validation



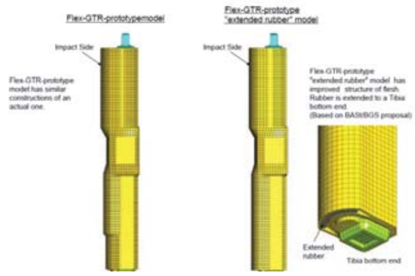


TEG-096

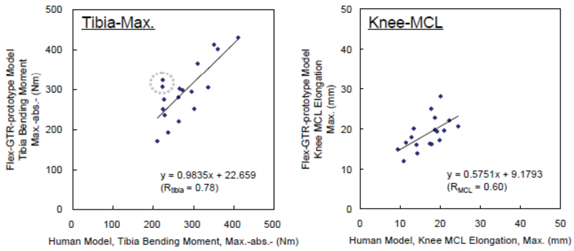
Computer simulation models



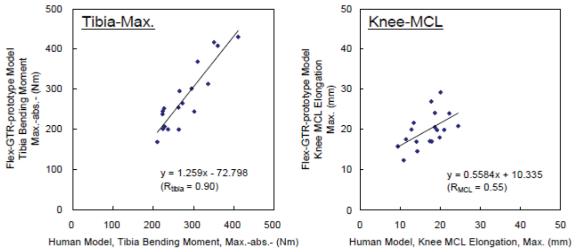
Flex-GTR-prototype models



Flex-GTR prototype model



Flex-GTR prototype "extended rubber" model



- Flex-GTR prototype model and Flex-GTR prototype "extended rubber" model show a high correlation with the human model.
- Correlation of Tibia-Max.(R_{tibia}): Flex-GTR prototype "extended rubber" model is higher than Flex-GTR prototype model.
- Correlation of Knee-MCL(R_{MCL}): Flex-GTR prototype "extended rubber" model and Flex-GTR prototype model is comparable.

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

2. Performance/Injury Criteria

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-035	JAMA	Flex-GT	-Tentative injury thresholds for Flex-GT **Results** **-Human tibia bending moment : 312 – 350 Nm, human knee bending angle : 18 – 20 deg (MCL failure) for 50% injury probability** **-Converted Flex-GT tentative threshold range : 299 – 337 Nm for tibia bending moment, 18 – 20 mm for MCL elongation**
TEG-048	JAMA-JARI	Flex-GT	- Tentative injury thresholds for Flex-GT (TEG-035) -Review of references **Results** **-Reference for tibia : Kerrigan et al. (2004), Nyquist et al. (1985)** **-Reference for MCL : Ivarsson et al. (2004), Konosu et al. (2001)**

2. Performance/Injury Criteria

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-076	JAMA	Flex-GT	- Review of proposed MCL failure threshold - Human-Flex-GTR correlation using simplified vehicle models including high bumper vehicles - Incorporation of muscle tone effect taken into account with the threshold for TRL-LFI - New proposal of 23 mm for Flex-GTR MCL elongation **Results** **- Human-Flex-GT knee response correlation analysis using FE human, Flex-GT and simplified vehicle models including high bumper vehicles** **- The correlation function converted human MCL elongation of 15-17 mm to 19.3-21.9 mm of Flex-GT MCL elongation** **- Proposed MCL elongation threshold for Flex-GT : 23 mm (taking into account 10% increase in knee stiffness due to muscle tone)**
TEG-077	JAMA	Flex-GT	- Review of proposed tibia bending moment threshold **Results** **- Average value of proposed tibia bending moment threshold is 318 Nm**

2. Performance/Injury Criteria

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-078	BASt	Flex-GT	-Correlation study between Flex-PLI and TRL-LFI showed no comparible assessment of ACL/PCL protection **Results** **- 12.7 mm ACL/PCL elongation limit for monitoring purpose only proposed based on one paper presenting 2 human data** **- First estimation of MCL elongation limit : 18-20 mm, muscle tone already taken into account**
TEG-084	JAMA	Flex-GTR	- Injury probability function for human tibia fracture - Data scaling options **Results** **- Different data scaling options resulted in the range of bending moment of 312 – 397 Nm for 50% fracture probability**
TEG-095	JAMA	Flex-GTR	-Proposal for bending angle threshold (50% probability) of human MCL failure **Results** **- For injury timing definition options from Ivarsson et al., the use of Definition B (time of maximum moment) is recommended based on the injury distribution in the experiment (1/8 complete MCL failure, 6/8 partial MCL failure, 1/8 no injury)** **- Proposed human knee bending angle threshold: 19 deg**

2. Performance/Injury Criteria

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-097	JAMA	Flex-GTR	- Proposal for Flex-GTR injury thresholds based on human thresholds for 50% injury probability and human vs Flex-GTR correlation analysis **Results** **- Estimated human threshold for 50% injury probability: Tibia bending moment = 361 Nm, MCL elongation = 15.9 mm** **- Human – Flex-GTR correlation function developed using the Flex-GTR FE model incorporating an extended rubber flesh** **- Converted Flex-GTR thresholds for 50% injury probability: Tibia bending moment = 380 Nm, MCL elongation = 21 mm**
TEG-098	BASt	Flex-GTR	- Human tibia fracture probability function using scaled data - Conversion to Flex-GTR threshold (50% risk) using human vs Flex-GT correlation analysis and Flex-GT vs Flex-GTR correlation **Results** **- 6 data from Nyquist et al. scaled to German anthropometric data, 10% increase of peak moment due to filtering, and cumulative normal distriibution method, resulted in 265 Nm for 50% probability of tibia fracture** **- Converted Flex-GTR tibia bending moment threshold: 260 – 301 Nm**

2. Performance/Injury Criteria

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-127	Flex-TEG	Flex-GTR	-Generic trace of Flex-TEG injury criteria discussion **Results** **- Different studies resulted in different threshold proposals** **- As a result of Flex-TEG discussion, a consensus was reached as to the threshold values for the Flex-GTR: Tibia bending moment = 340 Nm, MCL elongation = 22 mm** **- Seek for a guidance from GRSP as to the injury thresholds for ACL/PCL**
TEG-128	ACEA	Flex-GTR	- Example car test results (time histories of all injury measures) **Results** **- In one example test, maximum PCL elongation occurred in the rebound phase** **- Proposal to ignore injury measures during and after the rebound phase**
TEG-129	ACEA	Flex-GTR	-Review of literature on ACL/PCL injury threshold **Results** **- Bhalla et al.: Two tests, a likely ACL failure at 17.8mm and 12.7mm shear displacement, NOT ACL elongation** **- Kajzer et al.: One ACL avulsion at 23mm shear displacement** **- Teresinski et al.: ACL failure occurred after MCL rupture** **- Criteria without a sufficient data base is not advisable**

2. Performance/Injury Criteria

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-130	BASt	Flex-GTR	- Car test (1 one-box, 2 sedans, 1 SUV) and dynamic certification test - Correlation analysis between TRL-LFI and Flex-PLI - Geometric analysis of correlation between Flex-PLI shear displacement and ACL elongation -Proposal for ACL/PCL injury thresholds **Results** **- Conversion from Shear Displacement: 8 mm ACL elongation** **- Conversion from MCL elongation: 10 mm ACL elongation** **- Proposal: ACL = 13 mm (mandatory), PCL = 13 mm (monitoring)**

TEG-035

Flex-GT Tentative Threshold Values

Human value

Body regions	50% injury risk level of AM50 (tentative) Human value	References
Leg (Tibia)	BM (312 - 350 Nm)	BM (312 Nm): Kerrigan et al., 2004 BM (350 Nm): INF GR/PS/82
Knee (MCL)	BA (18 - 20 deg)	BA (18 deg).: Ivarsson et al., 2004 BA (20 deg).: INF GR/PS/82

AM50: 50 percentile of american male
BM: Bending moment, BA: Bending angle, EL: Elongation, SD: Shearing displacement.

Convert: Human value >>> Flex-GT value

Human	Human Model	Flex-GT Model	Flex-GT
Tibia bending moment	Tibia bending moment	Tibia bending moment	Tibia bending moment
H_{TBM} (Nm)	HM_{TBM} (Nm)	$FGTM_{TBM}$ (Nm)	FGT_{TBM} (Nm)
312	312	299	299
350	350	337	337

Tentative threshold values

assumption: $H_{TBM} = HM_{TBM}$, $FGT_{MTBM} = FGT_{TBM}$
$FGT_{MTBM} = 0.9977 * HM_{TBM} - 12.325$ (from reguration curve)

Human	Human Model	Human Model	Flex-GT model	Flex-GT
Knee bending angle	Knee bending angle	Knee MCL elongation	Knee MCL elongation	Knee MCL elongation
H_{KBA} (deg.)	HM_{KBA} (deg.)	HM_{MCL} (mm)	$FGTM_{MCL}$ (mm)	FGT_{MCL} (mm)
18	18	15	18	18
20	20	17	20	20

assumption: $H_{KBA} = HM_{KBA}$, $FGT_{MMCL} = FGT_{MCL}$
$HM_{MCL} = 0.835 * HM_{KBA}$ (from human model output)
$FGTM_{MCL} = 0.6924 * HM_{MCL} + 8.0156$ (from reguration curve)

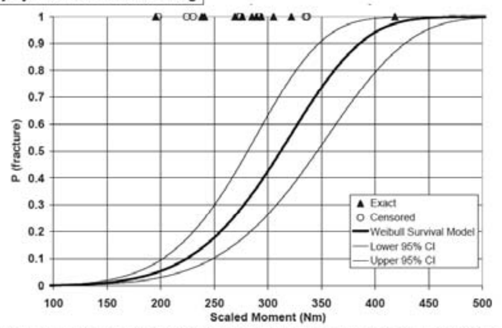
Convert human tolerance values to the Flex-GT ones (use correlation ratio/formula)

TEG-048

References (referred contents)

Human value

Injury Risk Curve for Mid-Leg



- Kerrigan, J.R., Drinkwater, D.C., Kam, C.Y., Murphy, D.B., Ivarsson, B.J., Crandall, J.R., Patrie, J. C Tolerance of the Human Leg and Thigh in Dynamic Latero-Medial Bending, ICRASH 2004.

References (referred contents)

Human value

Injury Risk Curve for Mid-Leg

Tibia Bending Strength and Response
Nyquist G. W. et al, 1985 (SAE, Paper No. 851728)

Tibia Bending: Strength and Response
Nyquist G. W. et al, 1985 (SAE 851728)

TestNo.	CadaverNo.	Sex	Age (years)	Stature (m)	Body Mass (kg)	Impact Speed (m/s)	Direction of Loading	Peak Bending Moment at Midspan (Nm) *	Ave.	10%up
118	458	M	54	1.82	68	3.5	LM	395		
124	406	M	64	1.77	82	4.2	LM	287		
126	375	M	58	1.74	73	4.2	LM	224		
127	404	M	56	1.76	79	3.7	LM	237		
129	395	M	57	1.78	99	3.7	LM	349		
132	525	M	57	1.87	45	3.8	LM	264		
147	400	M	57	1.78	84	2.9	LM	431	312.4	343.7

* The peak values were attenuated by 10 % by filtering (CFC 60) procedure.

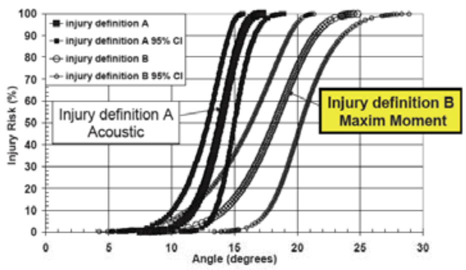
Proposed injury threshold for tibia bending: 350 Nm

- ECE/TRANS/WP.29/GRSP/INF GR PS (2004) Discussion on Injury Threshold for Pedestrian Legform Test, INF/GR/PS/82, P. 2.

References (referred contents)

Human value

Injury Risk Curve for Knee (Bending)



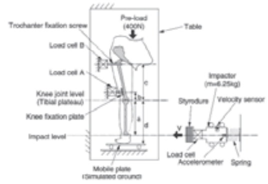
- Ivarsson, B.J., Lessley, D., Kerrigan, J.R., Bhalla, K.S., Bose, D., Crandall, J.R., Kent, R. (2004) Dy Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities, Proc. Internationa Conference on the Biomechanics of Impacts, pp. 179-191.

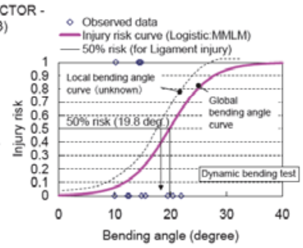
References (referred contents)

Human value

Injury Risk Curve for Knee (Bending)

RECONSIDERATION OF INJURY CRITERIA FOR PEDESTRIAN SUBSYSTEM LEGFORM TEST
- PROBLEMS OF RIGID LEGFORM IMPACTOR -
Konosu A. et al, 2001 (ESV, Paper No. 263)





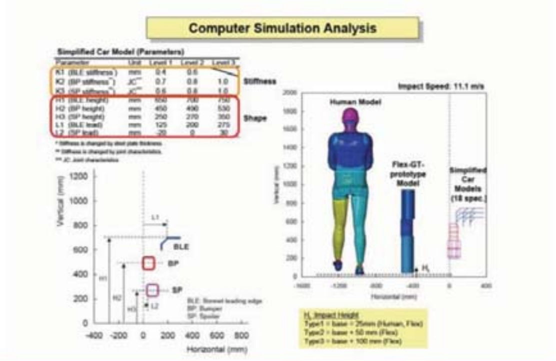
Local bending angle: Exclude Long Bone Bending Angle
Global bending angle: Include Long Bone Bending Angle

Proposed injury threshold for Knee bending: 20 deg.

- ECE/TRANS/WP.29/GRSP/INF GR PS (2004) Discussion on Injury Threshold for Pedestrian Legform Test, INF/GR/PS/82, P. 2.

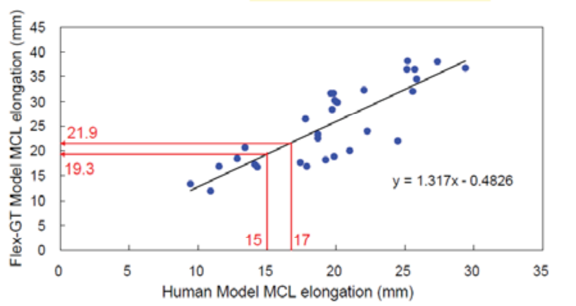
TEG-076

Current Proposal



Parameter study was carried out using simplified car models.

Estimation of MCL Failure Threshold



Flex-GT MCL elongation thresholds will be 19-22 mm when the correlation obtained using the FE simulation results with simplified vehicle models INCLUDING those representing high-bumper vehicles is used

Effect of Muscle Tone

- Lloyd and Buchanan (1996) – Muscles are activated to support about 15% of static varus-valgus loads. Muscular contribution increased with increasing magnitude of VV moments
- Lloyd and Buchanan (2001) – For volunteers, average contribution to varus is 17 ± 9.7% and to valgus is 10 ± 6.3% of externally applied moment

David G. Lloyd, Thomas S. Buchanan
Strategies of muscular support of varus and valgus isometric loads at the human knee
J. of Biomechanics 34 (2001) 1257-1267

The effect of muscle tone has been addressed in Lloyd and Buchanan (1996, 2001) from the Journal of Biomechanics

Effect of Muscle Tone

- Flex-GT MCL elongation thresholds : 19.3-21.9 mm based on the correlation obtained using the FE simulation results with simplified vehicle models INCLUDING those representing high-bumper vehicles
- Effect of muscle tone : 10% in valgus bending
- Flex-GT MCL elongation thresholds taking into account the effect of muscle tone : 21.2-24.1 mm (average : 22.7 mm)

Proposed Flex-PLI MCL elongation threshold : 23 mm

TEG-077

Current Proposal

Flex-GT Tentative Threshold Values

TEG-035

Human value

Body regions		50% injury risk level of AM50 (tentative) Human value	References
Leg	(Tibia)	BM (312 - 350 Nm)	BM (312 Nm): Kerrigan et al., 2004 BM (350 Nm): INF GR/PS/82
Knee	(MCL)	BA (18 - 20 deg)	BA (18 deg).: Ivarsson et al., 2004 BA (20 deg).: INF GR/PS/82

AM50: 50 percentile of american male
BM: Bending moment, BA: Bending angle, EL: Elongation, SD: Shearing displacement.

Convert: Human value >>> Flex-GT value

Human Tibia bending moment	Human Model Tibia bending moment	Flex-GT Model Tibia bending moment	Flex-GT Tibia bending moment
H_{TBM} (Nm)	HM_{TBM} (Nm)	$FGTM_{TBM}$ (Nm)	FGT_{TBM} (Nm)
312	312	299	299
350	350	337	337

$FGTM_{TBM} = 0.9977 * HM_{TBM} - 12.325$ (from reguration curve)

Tentative threshold values

Based on the SAE paper by Nyquist et al. and the ICRASH paper by Kerrigan et al., the threshold values ware set at 299 and 337Nm.

New Proposal

Injury threshold for Flex-PLI Tibia bending moment (JAMA proposal): **318Nm**

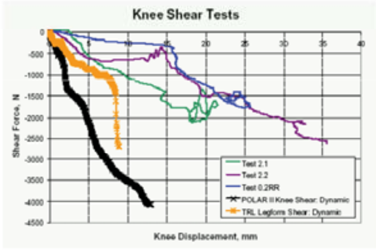
Average value of the two threshold values shown in this presentation

TEG-078

ACL/PCL injury thresholds

bast

- Therefore, it appears more appropriate to stick with PMHS knee shearing results evaluated by Bhalla et al (2003) that state a tolerance of at least 12,7 mm for knee shear displacement of the 50th male, even though the timing of injury could not be clearly identified:



Dynamic shear tests on the TRL legform and POLAR-II knee joint plotted along with two PMHS shear tests performed by UVA) [Source: Bhalla et al, 2003]

Oliver Zander | December 8th, 2008 | Slide No. 6

ACL/PCL injury thresholds

bast

Conclusions / Proposal:

1. Under the previously made observations, the following, first estimation could be done:

   Flex-GT ACL/PCL elongation upper performance limit: 12,7 mm

2. In a next step, a more detailed correlation study between shearing displacement and cruciate ligament elongation could be done, using an appropriate amount of simulations on simplified test rigs and / or real car Tests, representing the current vehicle fleets.

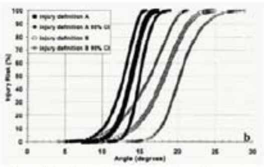
   Anyway, as the cruciate (ACL) ligament injuries are expected to occur in conjunction with other (MCL) injuries, the common injury mechanisms have to be better understood.

   Therefore, and for the comparatively low relevance within real pedestrian accidents, for the time being, a threshold of 12,7 mm ACL/PCL elongation could be proposed as performance limit for monitoring purposes only.

Oliver Zander | December 8th, 2008 | Slide No. 8

MCL injury threshold

bast



Univariate Weibull survival models predicting the risk of knee injury (MCL injury) in dynamic valgus bending of the 50th percentile male knee as function of bending angle [Source: Ivarsson et al, 2004]

Proposal for higher performance limit: 18° knee bending angle

Questions:

- Why injury definition B (injury occurence at the time of maximum moment) and not definition A (injury occurence at time of first peak) ?
- Why no use of the dynamic response corridor (16-20° / 12,5°-15°) but just the average value?

Oliver Zander | December 8th, 2008 | Slide No. 11

MCL injury threshold

bast

Conclusions / Proposal:

1. As starting point, the dynamic bending limit response corridor according to injury definition B [approx 16… 20°] and the inkury risk curve by Konosu (2001) [19,8°]for a 50% injury risk might be appropriate
2. Those bending limits could be used (as before) as human model knee bending angle and then be transformed accordingly into:
   ➔ human model knee MCL elongation
   ➔ Flex-GT model knee MCL elongation (= Flex-GT knee MCL EL)
3. Under the previously made observation (Human knee bending angle [deg] ~ Flex-GT MCL elongation [mm]) the following ,first estimation could be done:

   Flex-GT MCL elongation lower performance limit: 20 mm
   Flex-GT MCL elongation upper performance limit: 16 mm

4. Note:
   Effect of muscle tone has already been taken into account
   High bumper vehicles still have to be taken into account in an appropriate, weighted manner

Oliver Zander | December 8th, 2008 | Slide No. 17

TEG-084

2. Scaling Factor used in Kerrigan et al. (2004)

Data Scaling Procedure used by Kerrigan et al.

Data Scaling

Equation 1 shows that the stress arising in a bone (modeled as a linearly elastic beam) is proportional to the moment applied and the cross sectional geometry of the bone. To provide a basis for comparing specimen responses, it is common to assume that specimens are geometrically similar and thus can be scaled to a reference geometry. Thus the bones in this study are scaled to a reference geometry using a scale factor ($\lambda_L = L_{ref}/L$) based on the length of the bone specimen.

from Kerrigan et al. (2004)

- Assume geometric similarity between the leg specimens
- Tibia bending moment was scaled using the following equations

$$\lambda_L = L_{ref} / L$$
$$M_{scaled} = \lambda_L^{\ 3} M$$

where

L_{ref} : Reference tibia length
M : Measured tibia bending moment
L : Tibia length of specimen
M_{scaled} : Scaled tibia bending moment

2. Scaling Factor used in Kerrigan et al. (2004)

Options for More Reasonable Length Scale Factor

Option 1

- Determine reference length such that the average length scale factor coincides with the average height scale factor
  - Assumption: overall tibia length distribution should correlate well with overall height distribution
  - Assume the same ratio of tibial plateau height to tibia length as that used by Kerrigan et al. (1.22)
  - Reference tibia length (for scaling Kerrigan data) : 397.4 cm
  - Reference tibial plateau height (for scaling Nyquist data) : 483.5 cm

Option 2

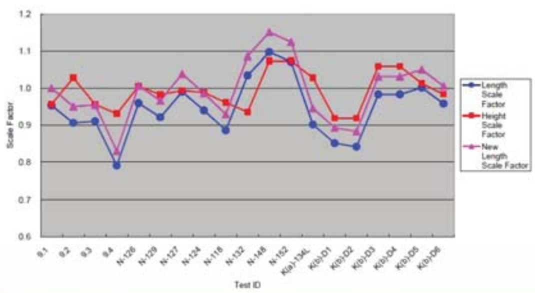
- Use unscaled data
  - Average height of the specimens (176.6 cm) is close to 50th percentile

Reanalyze injury risk curves using the same statistical procedures as those used by Kerrigan et al. under these two options

2. Scaling Factor used in Kerrigan et al. (2004)

Scale Factors for Option-1

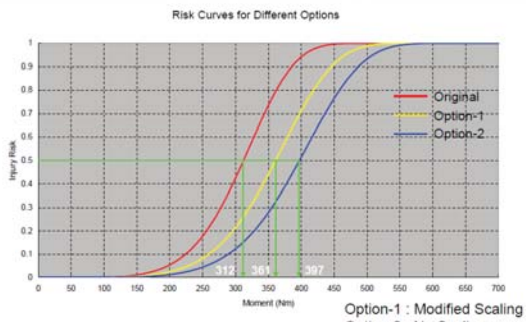
Length Scale Factor Comparison



Option-1 yields average scale factor identical to average height scale factor while allowing individual variation

2. Scaling Factor used in Kerrigan et al. (2004)

Injury Risk Curves for Original, Option-1 and Option-2 Datasets



Option-1 : Modified Scaling
Option-2 : No Scaling

TEG-095

Original Proposal (TEG-035)

2

Flex-GT Tentative Threshold Values

TEG-035

Human value

Body regions	50% injury risk level of AM50 (tentative) Human value	References
Leg (Tibia)	BM (312 - 350 Nm)	BM (312 Nm): Kerrigan et al., 2004; BM (350 Nm): INF GR/PS/82
Knee (MCL)	BA (18 - 20 deg)	BA (18 deg): Ivarsson et al., 2004; BA (20 deg): INF GR/PS/82

AM50: 50 percentile of american male
BM: Bending moment, BA: Bending angle, EL: Elongation, SD: Shearing displacement

Based on Konosu et al. (2001)

Originally proposed threshold for human MCL (TEG-035)

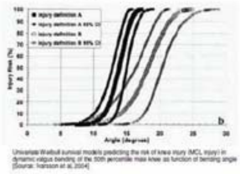
- 18 deg based on Ivarsson et al. (2004)
- 20 deg based on Konosu et al. (2001)
- No single value proposal

Questions Raised at 7th Flex-TEG

9

MCL injury threshold

bast



Proposal for higher performance limit: 18° knee bending angle

Questions:

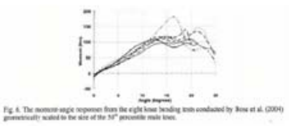
- Why injury definition B (injury occurence at the time of maximum moment) and not definition A (injury occurence at time of first peak) ?
- Why no use of the dynamic response corridor (16-20° / 12,5°-15°) but just the average value?

Oliver Zander — December 8th, 2008 — Slide No. 11

Questions Raised at 7th Flex-TEG

11

Scaled moment-angle curves in Ivarsson et al.



Injuries sustained by each specimen in Bose et al.

Table 3: Injuries observed in each tested specimen

Test #	Specimen #	Aspect	Test	ACL	PCL	MCL	LCL
Bend 1	51000044-004	Right	4 pt	v	v	P	v
Bend 2	2002-FRM-150	Right	4 pt	v	v	P	v
Bend 3	2001-FRM-141	Left	4 pt	v	v	P	v
Bend 4	2002-FRM-179	Right	4 pt	v	v	P	v
Bend 5	2002-FRM-179	Left	4 pt	v	v	C	v
Bend 6	2001-FRM-141	Right	4 pt	v	v	P	v
Bend 7	2003-FRM-167	Left	4 pt	v	v	v	v
Bend 8	2001-FRM-152	Left	4 pt	v	v	P	v
Comb 8	2001-FRM-152	Right	3 pt	v	v	P	v

4 pt: 4 point bending, 3pt: 3 point combined Loading
v: No injury, P: Partial avulsion, C: Complete avulsion
B: Bony Avulsion, L: Slight bodly

- Time of first local moment peak is not always different from time of maximum moment : No consistency
- Acoustic emission burst would work with bone fractures, but not with ligament failure : May have detected vibration from other phenomenon than MCL failure
- Most of the specimens sustained only partial failure of MCL : Use of first peak is likely to introduce minor failure of other knee components
- For above reasons, use of Definition B (Maximum moment) is recommended

Proposal for Human MCL Threshold

14

- No data duplication between Konosu et al. (2001) and Ivarsson et al. (2004) : simple average can be justified to take into account as many data as possible
- Data scaling does not affect injury risk functions for the MCL (bending angle) in both Konosu et al. and Ivarsson et al.
- Use of Injury Definition B in Ivarsson et al. is more appropriate to reasonably represent failure of the MCL
- 95% CI curves in Ivarsson et al. should not be used because the estimated risk function provide the best fit to the data

- Proposed bending angle threshold for human MCL : **19 deg** (virtually the same as previously proposed value)
- Flex-GTR MCL elongation threshold needs to be investigated based on the response correlation between the Flex-GTR and human lower limb

TEG-097

Proposed Human Thresholds

2

Proposal for Human MCL Threshold

- No data duplication between Konosu et al. (2001) and Ivarsson et al. (2004) : simple average can be justified to take into account as many data as possible
- Data scaling does not affect injury risk functions for the MCL (bending angle) in both Konosu et al. and Ivarsson et al.
- Use of Injury Definition B in Ivarsson et al. is more appropriate to reasonably represent failure of the MCL
- 95% CI curves in Ivarsson et al. should not be used because the estimated risk function provide the best fit to the data
- Proposed bending angle threshold for human MCL : 19 deg (virtually the same as previously proposed value)
- Flex-GTR MCL elongation threshold needs to be investigated based on the response correlation between the Flex-GTR and human lower limb

Proposed Thresholdfor Human MCL
Knee Bending Angle **19 deg**

Proposal for Human Tibia Moment Threshold

- Only data used by Kerrigan et al. (2004) were used in order to avoid duplicated data entry
- Unscaled data resulted in different injury risk curve from that obtained using modified scale factors with the average scale factor identical to the average height scale factor
- Although the average height of the specimens was close to that of 50th percentile male, data scaling should allow more appropriate threshold for the Flex-PLI that represents 50th percentile male anthropometry
- Proposed bending moment threshold for human tibia : 361 Nm
- Flex-GTR tibia bending moment threshold needs to be investigated based on the response correlation between the Flex-GTR and human lower limb

Proposed Thresholdfor Human Tibia
Tibia Bending Moment **361 Nm**

MCL Injury Measure Conversion

3

Convert: Human value >>> Flex-GT value

TEG-035

Human Tibia bending moment H_{TBM} (Nm)	Human Model Tibia bending moment HM_{TBM} (Nm)	Flex-GT Model Tibia bending moment $FGTM_{TBM}$ (Nm)	Flex-GT Tibia bending moment FGT_{TBM} (Nm)
312	312	289	289
350	350	337	337

assumption: $H_{TBM} = HM_{TBM}$, $FGT_{MTBM} = FGT_{TBM}$
$FGT_{MTBM} = 0.9077 * HM_{TBM} - 12.325$ (from regression curve)

Tentative threshold values

Human Knee bending angle H_{KBA} (deg.)	Human Model Knee bending angle HM_{KBA} (deg.)	Human Model Knee MCL elongation HM_{MCL} (mm)	Flex-GT model Knee MCL elongation $FGTM_{MCL}$ (mm)	Flex-GT Knee MCL elongation FGT_{MCL} (mm)
18	18	15	18	18
20	20	17	20	20

assumption: $H_{MCL} = HM_{MCL}$, $FGT_{MMCL} = FGT_{MCL}$
$HM_{MCL} = 0.835 * HM_{KBA}$ (from human model output)
$FGTM_{MCL} = 0.6924 * HM_{MCL} + 8.0156$ (from regression curve)

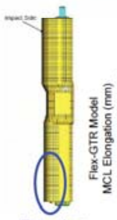
Convert human tolerance values to the Flex-GT ones (use correlation ratio/formula)

- Tibia Bending Moment for Human Model : **361 Nm**
- MCL Elongation for Human Model : 0.835*19 deg = **15.9 mm**

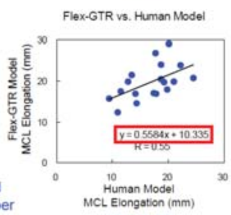
Human - Flex-GTR Response Correlation

8

Flex-GTR Prototype w/Extended Flesh Rubber

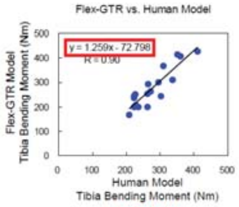


MCL



R = 0.55

Tibia

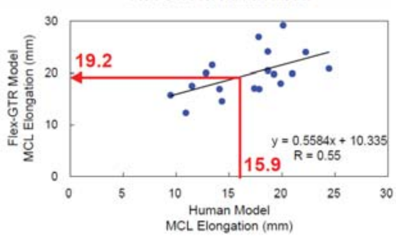


R = 0.90

- Better correlation for tibia bending moment with extended flesh rubber
- Use results for extended flesh rubber to convert injury thresholds from human to Flex-GTR

MCL Threshold Conversion

9



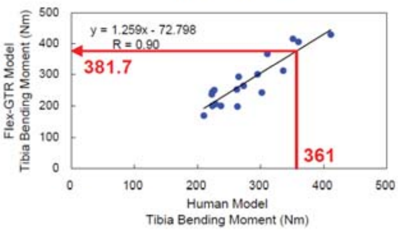
Converted Flex-GTR MCL Elongation : **19.2 mm**

TEG-097

Tibia Threshold Conversion

10

Flex-GTR vs. Human Model



Converted Flex-GTR Tibia Bending Moment : **381.7 Nm**

Effect of Muscle Tone

12

gtr9 Preamble (TEG-076)

110. These studies suggest a bending limit in the range of 15° to 21° for knee protection. The informal group determined that a value close to the upper limit (21°) of this range should be considered, and not the average. The absence of muscle tone in the PMHS tests reduced the knee stiffness of the subjects, and the high rigidity of the impactor bones transferred to the knee joint a part of the impact energy normally absorbed by the deformation of human long bones. For these reasons, a bending limit of 19° was selected for this gtr.

Lloyd and Buchanan (2001)

David G. Lloyd, Thomas S. Buchanan
Strategies of muscular support of varus and valgus isometric loads at the human knee
J. of Biomechanics 34 (2001) 1257-1267

- For volunteers, average contribution to varus is 17 ± 9.7% and **to valgus is 10 ± 6.3%** of externally applied moment
- Flex-GTR MCL threshold incorporating effect of muscle tone : 19.2 mm * 1.1 = **21.1 mm**

Proposal for Flex-GTR Injury Threshold

13

- Correlation functions derived from data NOT INCLUDING high bumper vehicles were used for threshold conversion
- Correlation functions with an extended flesh rubber were used for significantly improved correlation for the tibia bending moment
- Converted thresholds were 19.2 mm for MCL, and 381.7 Nm for Tibia
- Incorporation of muscle tone effect yielded the MCL elongation threshold of 21.1 mm

- Proposed elongation threshold for Flex-GTR MCL : **21 mm**
- Proposed bending moment threshold for Flex-GTR tibia : **380 Nm**

TEG-098

PMHS Data

Test	Source	Gender	Age	Stature (cm)	Body Mass (kg)	Impact Speed (m/s)	Loading Direction	Peak BM at Midspan (CFC 60) [Nm]	Peak BM at Midspan M_{Max} [Nm]	Anatomical Measurement (Heel to Tibial Plateau) L [mm]	Standardized tibia height (DIN 33402-2) L_{ref} [mm]	Scaled Fracture Moment M_{scaled} [Nm]
118	Nyquist et. al.	M	54	182	68	3,5	LM*	395	434,5	520	455	291,1
124	Nyquist et. al.	M	64	177	82	4,2	LM*	287	315,7	490	450	244,5
126	Nyquist et. al.	M	58	174	73	4,2	LM*	224	246,4	480	455	209,9
127	Nyquist et. al.	M	56	176	79	3,7	LM*	237	260,7	465	455	244,2
129	Nyquist et. al.	M	57	178	99	3,7	LM*	349	383,9	500	455	289,3
132	Nyquist et. al.	M	57	187	45	3,8	LM*	264	290,4	445	455	310,4

*: Lateral to Medial
Source: Nyquist et al. (1985)

- Consideration of six male tibia specimen tested by Nyquist et al. (1985) with known heel to tibia plateau heights
- Acquisition of Bending Moment to fracture at Midspan
- Due to attenuation of peak values by CFC 60 filtering: increase of bending moment values by 10% (→ M_{max})
- Calculation of scaled Fracture Bending Moments according to the formula: $M_{scaled}=[(L_{ref}/L)^3]*M_{max}$

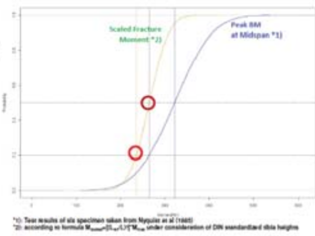
Oliver Zander | May 19th, 2009 | Slide No. 6

Injury Risk Curve

Shapiro Wilk Normality Test results in Gaussian distribution of both the Peak BM at Midspan as well as the Scaled Fracture Moment results (P>95%).

Scaled Fracture Moment results take into account the standardized tibia heights of DIN.

Therefore, the injury risk thresholds are to be derived from this risk curve.



Source: Pastor C. (2006)

20% risk of tibia fracture: $P_{0,2} = \sum_{1}^{6} M_{Max} / 6 = 235{,}7 Nm$

50% risk of tibia fracture: $P_{0,5} = \sum_{1}^{6} M_{Scaled} / 6 = 264{,}9 Nm$

Oliver Zander | May 19th, 2009 | Slide No. 8

Calculation of Maximum Tibia BM

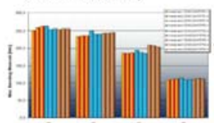
Flex-GT Tibia Bending Moment = [...] = 0,9977 * Human Tibia Bending Moment – 12,325

assumption: $H_{TBM} = HM_{TBM}$, $FGT_{MTBM} = FGT_{TBM}$
$FGT_{MTBM} = 0.9977 * HM_{TBM} - 12.325$ (from reguration curve)
Source: TEG-048

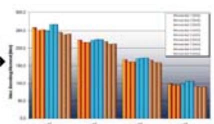
Flex-GT BM_{Tibia} = 0,9977 * 264,9 – 12,325 = 252 Nm

Increase of Flex-GTR BM_{Tibia} values compared to Flex-GT BM_{Tibia} :
A1: +1,83%, A2: +10,18%, A3: +17,04%, A4: +14,58%

→ Mean increase of Flex-GTR BM_{Tibia} compared to Flex-GT BM_{Tibia} in idealised tests: 11% (Flex-GT and Flex-GTR readings within ACEA/BASt joint projects on Flex-GT/GTR evaluation)



←Flex-GTR
Flex-GT →



Source: TEG-001

Oliver Zander | May 19th, 2009 | Slide No. 10

Calculation of Maximum Tibia BM

Flex-GTR Tibia Bending Moment = 1,11 * (0,9977 * Human Tibia Bending Moment – 12,325)

Flex-GTR BM_{Tibia} = 1,11 * (0,9977 * 264,9 – 12,325) = 279,7 Nm

Maximum deviation of tibia value from mean value within inverse tests: 7,66 % (measured at Tibia A3)

Nine inverse tests with Flex-GTR, three with SN01, SN02, SN03 each, at 40 km/h

Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4
inverse test 1 [SN01]	251,4	234,3	186,2	108,9
inverse test 2 [SN01]	257,9	236,6	184,9	111,8
inverse test 3 [SN01]	262,0	236,1	186,8	112,7
inverse test 4 [SN02]	262,7	251,3	194,9	114,5
inverse test 5 [SN02]	254,0	241,2	188,4	108,9
inverse test 6 [SN02]	256,1	240,9	185,1	110,5
inverse test 7 [SN03]	254,2	243,2	209,0	111,5
inverse test 8 [SN03]	255,8	243,7	207,9	113,6
inverse test 9 [SN03]	255,6	245,8	204,0	112,6
MV	256,63	241,46	194,13	111,67
CV	1,44	2,21	5,23	1,75
Max	262,70	251,30	209,00	114,50
Min	251,40	234,30	184,90	108,90
max. Dev. from MV [%]	2,36	4,08	7,66	2,54

Upper Performance Limit (UPL) = Flex-GTR BM_{Tibia} / 1,0766 = 259,8 Nm
Lower Performance Limit (LPL) = Flex-GTR BM_{Tibia} * 1,0766 = 301,1 Nm

As type approval requires pass-/fail threshold:
Proposed Threshold Value for Flex-GTR Max. Tibia Bending Moment: 302 Nm

Oliver Zander | May 19th, 2009 | Slide No. 11

TEG-127

Technical Background Information Document for the UN-ECE GRSP explaining the Derivation of Threshold Values and Impactor Certification methods for the FlexPLI version GTR agreed by the FlexPLI-TEG at their 9th Meeting

Drafted by: Atsuhiro Konosu (JARI/J-MLIT) and Oliver Zander (BASt) on behalf of the GRSP FlexPLI Technical Evaluation Group (TEG)

1) Tibia Threshold Value: 340 Nm

At the 8th GRSP Flex-TEG meeting on May 19th, 2009, two proposals for the tibia threshold value of the FlexPLI version GTR (also called Flex-GTR) were made by JAMA and BASt, coming to different conclusions.

a) 380 Nm (JAMA)

JAMA derived the Flex-GTR tibia bending moment threshold using a linear transition equation between human and Flex-GTR Finite Element (FE) models derived from computer simulation results. The average human tibia bending moment threshold value was taken from an injury risk curve of the 50th percentile male for tibia fracture, taking into account scaled male and female PMHS data from Nyquist et al. (1985) and Kerrigan et al. (2004) under modification of the standard tibia length and standard tibia plateau height, making the assumption that the height scale factor and length scale factor should correlate to each other. The Weibull Survival Model was used to develop the injury probability function. The proposed final threshold value resulted in 380 Nm.

b) 302 Nm (BASt)

BASt derived the Flex-GTR tibia bending moment threshold also using the corresponding transition equation between human and Flex-GTR FE models. The average human tibia bending moment threshold value was taken from an injury risk curve of the 50th percentile male for tibia fracture, taking into account scaled male PMHS data from Nyquist et al. (1985) using the standard tibia plateau height provided by DIN 33402-2 German anthropometrical database. The cumulative Gaussian distribution was used to develop the injury probability function. The calculated threshold value under consideration of possible scatter of test results and of a reproducibility corridor derived from inverse certification test results was 302 Nm.

A comparison of both approaches revealed that the calculated threshold values mainly depend on

- the underlying set of PMHS data
- the consideration of female and / or male data
- the use of scaled or unscaled data
- the particular anthropometrical database based on which human data are scaled
- the injury risk to be covered
- the statistical procedure to develop an injury probability function

As consensus for both approaches BASt proposed a rounded average value of 340 Nm for maximum tibia bending moment threshold.

In parallel to BASt proposing a rounded average value, JAMA conducted a correlation study on the EEVC WG 17 PLI tibia acceleration and FlexPLI tibia bending moment. As a result, they found that the 170 g EEVC WG 17 PLI tibia acceleration in gtr 9 was correlated to 343 Nm Flex-GTR tibia bending moment

As this was almost the value proposed by BASt as average value between the BASt and former JAMA proposals, the group agreed at the 9th TEG meeting on September 3rd – 4th, 2009, on a consensus of the rounded value of 340 Nm.

2) MCL Elongation Threshold Value: 22 mm

a) 22 mm (JAMA)

JAMA developed an MCL injury risk function as average function between the risk functions from Ivarsson et al. (2004) and Konosu et al. (2001), latter one revised using the Weibull Survival Model. In this function, a 50% risk of knee injury in terms of MCL rupture corresponded to a human knee bending angle of 19 degrees. This value was converted to 19.1 mm MCL elongation, using a corresponding transition equation from computer simulation. After incorporating the effect of muscle tone the threshold value was calculated at 21 mm. As this value was converted to 16.9 degrees of EEVC WG 17 PLI knee bending angle by using a corresponding transition equation which would be by 11 % more conservative than the currently defined GTR threshold value of 19 deg, a 5% more conservative approach, equal to 18 deg EEVC WG 17 PLI knee bending angle was proposed and transformed to 22 mm MCL elongation, using the same transition equation as before.

b) 22 mm (BASt)

As BASt is not in the position to validate or double-check those results, they investigated a direct correlation between the EEVC WG 17 PLI knee bending angle and the FlexPLI MCL elongation as verification of the JAMA results. A transition equation was developed, based on hardware test results of different vehicle categories and idealized tests. Thus, a knee bending angle of 19 degrees would correspond to 22.7 mm MCL elongation. In order to provide at least the same level of protection as the current GTR, a threshold value of 22 mm was proposed which was in line with the JAMA proposal

At the 9th GRSP Flex-TEG meeting on September 3rd - 4th, 2009, the group agreed on a Flex-GTR threshold value for MCL elongation of 22 mm.

3) ACL/PCL Elongation Threshold Value

a) Mandatory with a threshold of 13 mm (BASt)

Currently, no injury risk curve for cruciate ligament injuries is available. BASt proposed to therefore use the results of PMHS tests described by Bhalla et al. (2003), stating that below a shear displacement of 12.7 mm sufficient protection is provided to the cruciate ligaments. Thus, and in the absence of more data but having in mind that the FlexPLI should provide at least the same level of protection as the EEVC WG 17 PLI, BASt proposed a mandatory threshold value of 13 mm for ACL/PCL.

b) Monitoring against a threshold of 13 mm (JAMA)

In contrast, JAMA stated that the percentage of isolated ACL/PCL injuries in real world data is low (less than 3%) and the biomechanical data is limited (only 2 data are available from Bhalla et al. (2003), which does not allow development of an injury probability function. Therefore, the tentative threshold value should be set for monitoring, subject to future modification to the tentative threshold based on additional biomechanical data.

c) No consideration (ACEA)

TEG-127

As pointed out by both, BASt and JAMA, the biomechanical data available to define an injury risk curve is limited. In addition, it is felt that ACL/PCL elongation usually corresponds to MCL elongation. In addition, the gtr concept does not provide for the monitoring of certain criteria. ACEA therefore proposes to abstain from defining an injury threshold for ACL and PCL.

At the 9th GRSP Flex-TEG meeting on September 3rd - 4th, 2009, the group could not agree an injury threshold for ACL/PCL elongation.

➔ GRSP is requested to either come to a conclusion or to provide guidance on this.

4) Certification methods

Two different FlexPLI certification methods have been developed in the course of the last years.

a) Pendulum test (JAMA/JARI)

From the beginning, JARI developed the pendulum test as an easily applicable, highly reproducible and repeatable test enabling the test lab to make a quick check up of the impactor's general functionality before each test series. The current manufacturer of the legform, FTSS, modified the pendulum test by hanging the legform upside down and applying an additional mass to the thigh to generate loading levels similar to those of real vehicle tests. JAMA/JARI also showed that essentially no rate sensitive materials are used for the major structures of the Flex-GTR and thus, in their point of view, as a certification test there should be no concern as to the difference in timings between the pendulum test and real vehicle test.

b) Inverse certification test (BASt)

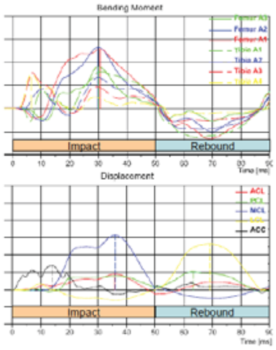
On the other hand, BASt saw the need for a certification test with impactor loadings and test conditions similar to those during real vehicle tests. Therefore, the inverse certification test was developed, providing realistic impact conditions in terms of loadings, kinematics and timings, enabling the test lab to ensure that the impactor works as intended under the impact conditions occurring in real vehicle tests. The proposed test setup is in line with the recommendations of EEVC Working Group 17 who refused for the same reasons as BASt a pendulum test with their impactor for certification purposes.

At the 9th GRSP Flex-TEG meeting on September 3rd - 4th, 2009, the group agreed on a hybrid approach, using the inverse certification tests before each homologation test series and after every 30 tests while the pendulum function test needs to be carried out after every 10 tests in case the certification is not been done by using the inverse certification.

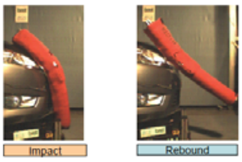
TEG-128

ACEA TEG-128

Current situation – injury values : impact vs rebound (one example)



- Bending moments :
  - Highest values occur during the impact
- ACL/PCL :
  - Maximal PCL value occurs during the rebound – (slightly) higher value than during the impact



ACEA TEG-128

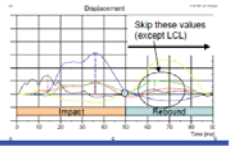
Conclusion & Recommendation

Summary/Conclusion :

- In the rebound phase of the Flex GTR (vehicle impact), higher ACL/PCL elongation values can occur than during the impact itself
- Legform Kinematics are biofidelic up until rebound

Recommendation :

- All maxima occurring during and after the rebound phase shall be ignored. (The rebound phase usually starts around 50 milliseconds but must be determined from film analysis)



TEG-129

ACEA TEG-129

EVALUATION OF THE RESPONSE OF MECHANICAL PEDESTRIAN KNEE JOINT IMPACTORS IN BENDING AND SHEAR LOADING

Kavi Bhalla, Dipan Bose, N. Jane Madeley, Jason Kerrigan, Jeff Crandall
University of Virginia, USA
Douglas Longhitano
Honda R&D Americas, Inc., USA
Yukou Takahashi
Honda R&D Co., Ltd., Japan
Paper Number 429

1 hypothesized ACL failure at 0.69kN and 12.7mm shear displacement
1 hypothesized ACL failure at 1.8kN and 17.8mm shear displacement

In comparison with bending tests, the relative timing of knee damage in shear tests is difficult to evaluate. The knee shear forces are seen to have a steadily increasing trend with shear displacement. Since tibial-spine gouging/plowing is likely an ongoing process, a drop in forces is likely due to ACL damage. Thus, it is hypothesized that the early peak in shear forces (at 12.7 mm of shear displacement, 693N shear force) in Test 2.2 is due to ACL failure. Similarly, ACL failure in Test 2.1 occurs at a shear force of 1839N and a shear displacement of 17.8 mm.

injury in the PMHS shear tests. Nevertheless, it is clear that the tolerance for shear displacement is at least 12.7mm (PMHS test 2.2) and possibly much higher, as

ACEA TEG-129

Table 3.1 Ligament avulsion as initial damage in shearing tests.

Relevant injury mechanism

TEST #	Time [ms]	Shear Force [kN]	Shear Disp [mm]	Time [ms]	Bend Mom [Nm]	Bend Angle [°]	Ligaments ACL	PCL	MCL	LCL	Dia. or Meta.* Femur	Tibia	Epiphysis Femur	Tibia
[illegible]	4.3	2.7	23	4.3	[illegible]	-4.9	●							

* : Diaphysis or Metaphysis ● : Ligament avulsion

Table 3.2 Diaphysis or metaphysis fracture as initial damage in shearing tests.

TEST #	Time [ms]	Shear Force [kN]	Shear Disp [mm]	Time [ms]	Bend Mom [Nm]	Bend Angle [°]	Ligaments ACL	PCL	MCL	LCL	Dia. or Meta.* Femur	Tibia	Epiphysis Femur	Tibia
4S	6.6	2.9	28	5.0	398	-1.9					■1			
5S	7.0	N.A	31	7.0	N.A	-4.5								
17S	5.9	2.5	26	5.3	511	-1.1								
20S	6.5	3.1	N.A	6.2	503	N.A								
Ave	6.5	2.9	28	5.9	501	2.5								
SD	0.5	0.7	2	0.9	98	1.8								

* : Diaphysis or Metaphysis ■1 : Comminuted supracondylar fracture ■2 : Transverse fracture

23mm shear displacement before ACL failure

Table 3.3 Epiphysis fracture as initial damage in shearing tests.

TEST #	Time [ms]	Shear Force [kN]	Shear Disp [mm]	Time [ms]	Bend Mom [Nm]	Bend Angle [°]	Ligaments ACL	PCL	MCL	LCL	Dia. or Meta.* Femur	Tibia	Epiphysis Femur	Tibia
8S	5.0	2.4	12	4.4	321	-1.5	(●)							▲
9S	6.1	3.3	27	6.5	422	-4.6							▲	
[illegible]	3.1	1.6	13	3.1	[illegible]	4.1	(●)		●					▲
13S	3.7	2.3	14	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]					

Kajzer et al., Shearing and bending at the knee joint at high speed lateral loading SAE paper 973326 (1997)

ACEA TEG-129

EVALUATION OF THE RESPONSE OF MECHANICAL PEDESTRIAN KNEE JOINT IMPACTORS IN BENDING AND SHEAR LOADING

REVIEW OF REAL WORLD PEDESTRIAN KNEE INJURIES

Isolated injuries to the ACL were also rare (in 2 cases out of 165) in lateral impacts.

The described knee injury mechanism in the defined lateral car-to-pedestrian accidents leads to the assumption that ACL rupture occurs after MCL rupture (but before PCL rupture) (Teresinski et al, 2001) *)

Isolated ACL avulsion seems to be difficult to replicate in PMHS tests.
A injury-risk function is currently not known.

*) unpublished BASt information, 10. TEG meeting, December 2010

ACEA TEG-129

Recommendations

ACL/PCL threshold:

- Abstain from supporting a mandatory criterion for the FlexGTR
- Risk curves should be the basis to underline any FlexGTR threshold
- More scientific information is needed which is addressed to a sophisticated knee element like the FlexGTR
- Criteria without a sufficient data base is absolutely not advisable

A requirement for ACL/PCL cannot be supported by ACEA

Relaxation zone:

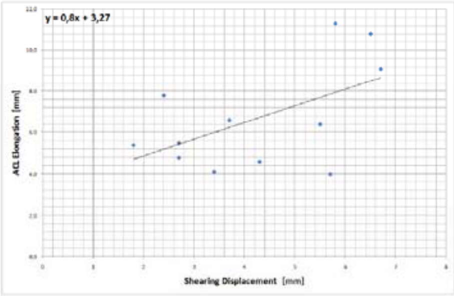
- The relaxation zone must be kept in the gtr 9 independent of test tool
- The criterion of the tibia bending moment in the relaxation zone should be modified
- For pragmatic reasons an increase of around 10% is proposed

The relaxation criterion of the tibia bending moment should be set to 380Nm

TEG-130

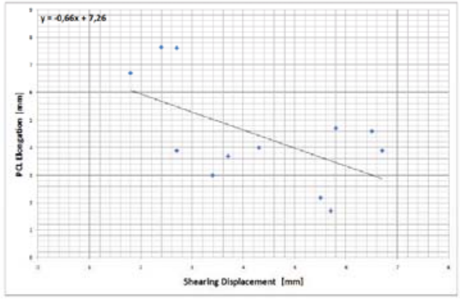
Correlation: EEVC WG 17 PLI and FlexPLI

2)SD versus ACL:



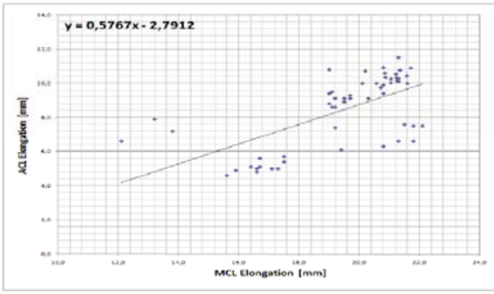
Correlation: EEVC WG 17 PLI and FlexPLI

3)SD versus PCL:



Correlation: MCL and ACL/PCL

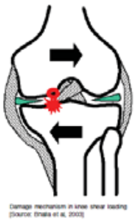
Test results:

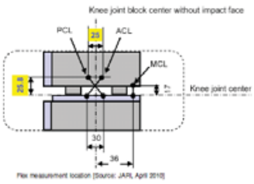


TEG-130

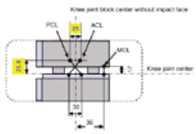
Correlation: FlexPLI SD and ACL EL

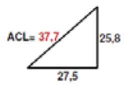
- Bhalla et al (2003) found tolerance of 12,7 mm and 17,8 mm for human knee shear displacement of the 50th male
- The knee shear displacement can be transformed to FlexPLI ACL /PCL elongation, taking into account the knee measurement locations





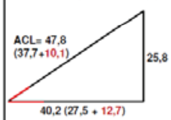
Correlation: FlexPLI SD and ACL EL



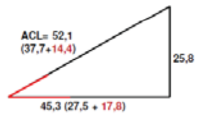


ACL length in unloaded condition @ approx. 37,7 mm

Shearing of 12,7 mm causes ACL elongation of approx. 10,1 mm



Shearing of 17,8 mm causes ACL elongation of approx. 14,4 mm



Proposal for ACL/PCL injury thresholds

Conclusions / Proposal:

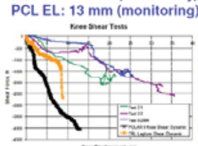
1. Under the previously made observations, the following, first estimation was made:

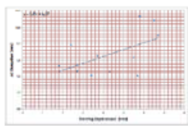
   Flex-GTR ACL elongation performance limit: 8 mm (SD transition)
   Flex-GTR ACL elongation performance limit: 10 mm (MCL transition)
2. In absence of injury risk functions for the cruciate ligaments and lacking information on transition between human and Flex-GTR ACL/PCL elongation a threshold value of 13 mm ACL/PCL elongation is proposed as performance limit.
3. German In-depth accident data gives evidence of clearly defined cruciate ligament ruptures.
4. ACL was proved to be the more critical because under the defined impact conditions less protected ligament. Therefore, the threshold value regarding PCL may be set as monitoring.
5. Anyway, as the FlexPLI should provide at least the same level of protection when being compared to the EEVC WG 17 PLI, the ACL limit should be set mandatorily.

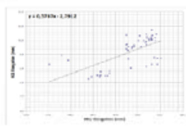
Proposal for ACL/PCL injury thresholds

BASt-Proposal for Flex-GTR:

- ACL EL: 13 mm (mandatory)
- PCL EL: 13 mm (monitoring)







Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

3. Benefit

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-049	JAMA-JARI	Flex-PLI	- Estimation of lower limb protection level provided by Flex-PLI - Follow NHTSA methodology (GRSP/2006/7), based on PCDS data **Results** **- Estimated number of injury-prevented pedestrians by PV: 2,438** **- Estimated number of injury-prevented pedestrians by LTV: 359**

TEG-049

Evaluation Method for Flex-PLI (for discussion)

Base: NHTSA Method (TRANS/WP.29/GRSP/2006/7)

Base data: PCDS

Number of pedestrians with AIS 2+ lower extremity (LE) injuries as most serious injury

Number of annual injured pedestrians	68,000 persons
Percentage at MIS 2-6 level	x56%
Percentage where LE most serious	x42%
total	15,994 persons

Estimated number of pedestrians with AIS2+ LE injuries addressed by regulation caused by vehicles covered by regulation

	PV	LTV
Number of annual LE MAIS 2+ injured pedestrians	15,994 persons	
Percentage to knee and lower leg injuries	x 56%	
Percentage sustained by vehicle type	x 84%	x 16%
Percentage of vehicle type covered by regulation	x100%	x 87%
Percentage attributed to bumper contact by vehicle	x 81%	x 72%
total	6,094 persons	898 persons

Same as the NHTSA Method

MAIS 2+ knee and lower leg injuries prevented (by PV)

Target population: 6,094 persons

Separated by injured parts*

Treatment of primary zone and relaxation zone will be discussed in the Flex-TEG Meeting (now just set 50% injury level for each).

	Lower leg: Primary zone	Lower leg: Relaxation zone	Knee: Primary zone	Knee: Relaxation zone
Persentage of injury type	x71.5%		x28.5%	
Persentage of no injury ratio	x 50%	x50%	x 50%	x 50%
Persentage of test zone	x 65%	x15%	x 65%	x 15%
	1,416 persons	327 persons	564 persons	130 persons
total	2,438 persons			

Number of Injury Prevented Persons (by PV)

MAIS 2+ knee and lower leg injuries prevented (by LTV)

Target population: 898 persons

	Lower leg: Primary zone	Lower leg: Relaxation zone	Knee: Primary zone	Knee: Relaxation zone
Persentage of injury type	x71.5%		x28.5%	
Persentage of no injury ratio	x 50%	x50%	x 50%	x 50%
Persentage of test zone	x 65%	x15%	x 65%	x 15%
	209 persons	48 persons	83 persons	19 persons
total	359 persons			

Separated by car type

Number of Injury Prevented Persons (by LTV)
(in case of LTV made a countermeasure for the Flex-PLI)

* Data Source: SAE 2006-01-0683

Outline

1. Biofidelity
2. Performance/Injury Criteria
3. Benefit
4. Durability
5. Reproducibility and Repeatability
6. Vehicle Countermeasures

4. Durability

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-037	BGS	Flex-GT	- Dec 2006 - Apr 2007 BASt test programme - 70 tests at 40 km/h using Flex-GT - Durability check **Results** **- Flex-GTα withstood more than 70 tests @ 40 km/h** **- No major mechanical defect** **- Cable defects outside the impactor** **- Minor design and wiring modifications required**
TEG-063	NHTSA	Flex-GT	- Car test using Flex-GT : 2 cars, 1 location for one car, 2 locations for another car, 2 impactor heights per location - 2 additional car tests : same car, same location, same impactor height for repeatability - Durability check **Results** **- Several minor issues but no catastrophic damage** **- Need to test more aggressive vehicles to evaluate durability for US fleet**

4. Durability

- List of Relevant TEG Documents -

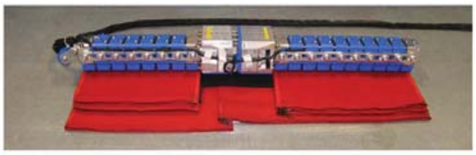
Doc. #	Affiliation	Version	Summary
TEG-112	NHTSA	Flex-GTR	- Flex-GTR car test (2005 Honda CR-V, 2002 Mazda Miata, 2006 Infiniti M35, 2006 VW Passat, 2001 Honda Civic) -Durability comparison between Flex-GT and Flex-GTR **Results** **- Improved durability** **- Poor performers in TRL legform tests have not been tested**
TEG-113	KATRI	Flex-GTR	- Flex-GTR car test (1 car) -Durability check **Results** **- No serious issues on durability**

TEG-037

Inspection after test

BGS

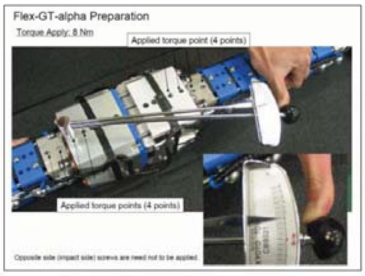
- Visual inspection of the impactor components and the cabling



Inspection after test

BGS

- Verification of the torque of 8 screws

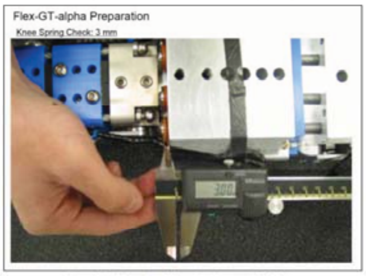


(Flex GTα Handling Manual, Konosu, 2006)

Inspection after test

BGS

- Check of the length of the 20 knee spring ends

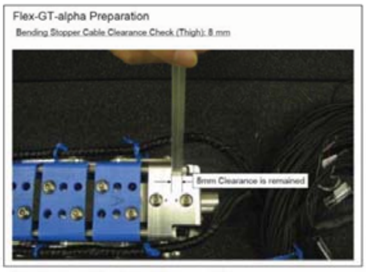


(Flex GTα Handling Manual, Konosu, 2006)

Inspection after test

BGS

- Check of the length of the 4 upper leg bending stopper cable ends



(Flex GTα Handling Manual, Konosu, 2006)

TEG-037

Inspection after test

BGS

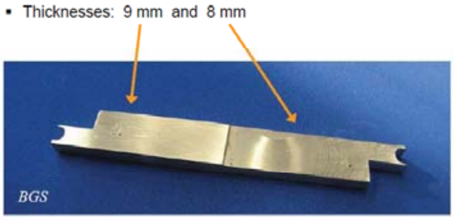
- Check of the length of the 4 lower leg bending stopper cable ends

(Flex GTα Handling Manual, Konosu, 2006)

Inspection after test

BGS

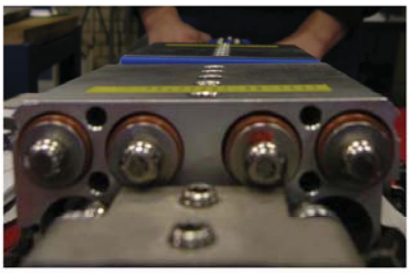
- New tool for cable clearance checks:
  - Thicknesses: 9 mm and 8 mm



Inspection after test

BGS

- Check for distortion



TEG-037

Summary

BGS

- Flex GTα withstood more than 70 impact tests at 40 km/h
- No greater mechanical defect
- Cable defects outside the impactor lead to measurement faults and time-intensive repairs
- Improvement of endurance through minor design and wiring modifications required
- Preparations for the test laboratory are comparatively negligible
- Handling effort comparable with EEVC legform
- Significantly more measurement channels than in other pedestrian protection impactor tests
- The necessity of a certification test after every single impact test should be reconsidered

April 2nd, 2007 Dirk-Uwe Gehring Slide 25

TEG-063 (Flex-GT Damage)

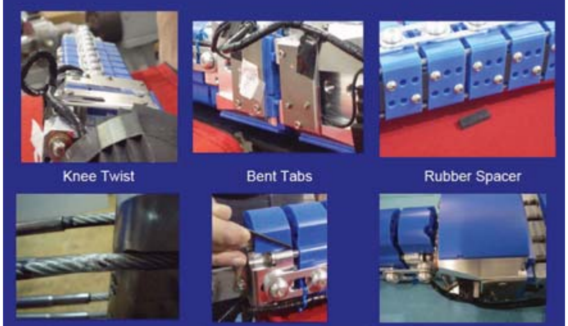
Tests Performed

2002 Mazda Miata

2005 Honda CR-V

- Each location: 25 mm / 75 mm above ground reference level
- Two additional tests performed on Miata at 75 mm for repeatability

Mechanical



Knee Twist | Bent Tabs | Rubber Spacer

Damaged Casings | Seized Bolt/Sleeve | Tibia Plate Damage/Rotation

Mechanical (cont.)

- Zippers need to be made more durable
  - Broken pull rings due to repeated high tension when assembling leg
- Slices and cuts were common
  - When does accumulated damage require replacement of flesh?
- Addition of threaded holes in standard location for accelerometer attachment at knee
  - Recommended for impact speed redundancy & comparison to TRL-measured tibia acceleration

Electrical

- We had 10 – 12 instances of a broken cable in our testing
- Improvements needed:
  - Better routing scheme
  - Dull sharp edges on knee structure
  - Stronger wire covers
  - Smaller bundle (can redundant gauges be coupled somehow to reduce the number of wires?)
  - Onboard DAS is a very good solution!

TEG-063

Summary

- Test experience and repeatability
  - Improved axial rotation with new roller support
  - Excellent repeatability
- Injury evaluation
  - Flex GT results ranked severity of impacts similarly to TRL testing but indicated higher injury severity
  - At least one Flex GT proposed injury limit exceeded for all three impact locations for 25 mm impact height
  - Effect of raising impact height to 75 mm varied
- Damage and durability
  - Several minor issues but no catastrophic damage
  - Need to test more aggressive vehicles to evaluate durability for US fleet

TEG-112

Test Matrix

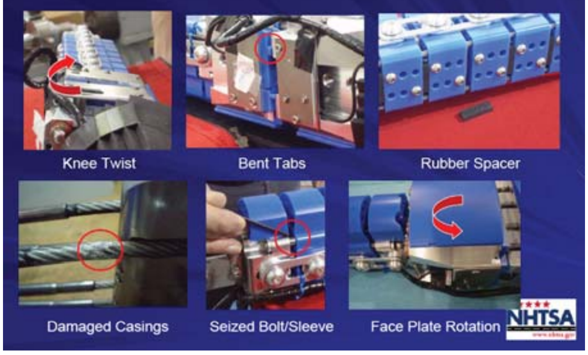
- Selection Criteria
  - Vehicle location did reasonably well in TRL tests (Mallory, ESV 2009 & more recent testing)

Vehicle	Tibia Acceleration (GTR: 170 g)	Bending Angle (GTR: 19 deg)	Shear Displacement (GTR: 6 mm)
2005 Honda CR-V	Pass	Pass	Pass
2002 Mazda Miata	Pass	Pass	Pass
2006 Infiniti M35 (with Nissan Fuga bumper)	Pass	Pass	Pass
2006 Volkswagen Passat	Pass	Fail	Pass
2001 Honda Civic	Fail (marginal)	Fail (marginal)	Fail (marginal)

NHTSA

Durability

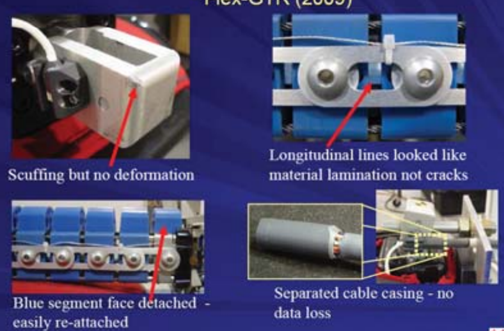
Flex-GT (2008)



NHTSA

Durability

Flex-GTR (2009)



No Functional Damage

NHTSA

Durability Comparison

Flex-GT vs. Flex-GTR

	Flex-GT (2008)	Flex-GTR (2009)
Knee Twist (Needed Manual Fix)	X	
Bent Tabs	X	
Rubber Spacer Fell Out	X	
Damaged Cable Casings	X	
Seized Bolt Sleeves	X	
Broken Zipper Ring	X	
Cut/Pulled Instrumentation Cables	X (sensors)	X (SLICE)
Scuffing of Support Piece		X
Blue Cap Came Off	X (easily replaced)	X (easily replaced)
Longitudinal Lamination Lines on Bone?		Not considered damage (?)

NHTSA

TEG-112

Summary

- Very good repeatability
  - In two repeat tests, center impact, 5 vehicles
- Improved durability
  - But we have not tested vehicles that were poor performers in TRL legform tests
- SLICE is functional & improvement over conventional DAS
  - But does have some bugs that need to be worked out

NHTSA www.nhtsa.gov

TEG-113

Introduction of Test Vehicle and Test Method

- Test Vehicle
  - Vehicle meets the criteria of the TRL-LFI to test according to existing legislation
  - Vehicle was rated completely green in the TRL-LFI to tests of Euro-NCAP
  - Vehicle is considered to be pedestrian friendly in this area
- Test Method

Impactor type	Flex-PLi-GTR Prototype
Impact velocity	11.1±0.2m/s
Impact zone	EEVC WG17 LFI by EURO NCAP (Green zone)
Impact point	Same point 2 Same vehicles
Impact times	3 Impact per 1 Vehicle
Impact Height	75mm (From ground level)

MLTM TS Korea Transportation Safety Authority

3

Conclusion

KATRI have conducted the round robin test for Flex-PLi-GTR and as the result.

- Comparison between EEVC WG17 LFI and Flex-PLi-GTR for same vehicle
  - ✓ Vehicle meets the criteria of EEVC WG17 LFI is also to meet Flex-PLi-GTR
  - ✓ In spite of meeting regulation, The margin of Flex-PLi is shorter than EEVC WG17 LFI
  - ✓ This result should not apply for every vehicle, it is only applicable to our tested vehicle
- Repeatability
  - ✓ Almost Good(62%) and Acceptable(24%) but some happened not acceptable level(9%)
- Durability and Usability
  - ✓ No serious issues on the durability and usability
- Some improvements are needed
  - ✓ As for Design and Durability : No sharp edges and No fracture especially zipper
  - ✓ As for Usability : More convenient and automatic control program
  - ✓ As for stability : Better data download and electrical ground connection
  - ※ More consideration is necessary to unexpected and without-control rebound phenomenon

MLTM TS Korea Transportation Safety Authority

Outline

5. Reproducibility and Repeatability

- List of Relevant TEG Documents -

Doc. #	Affiliation	Version	Summary
TEG-021	JARI	Flex-GT	- Dynamic certification test (pendulum) **Results** **- Comparison of 36 tests for femur and tibia** **- Comparison of 18 tests for MCL, ACL and PCL**
TEG-034	J-MLIT /NTSEL	Flex-GT	- Bending test of femur, tibia, knee of Flex-GT - Dynamic certification test (Pendulum) using Flex-GT - Car test using Flex-GT (two impactors) - R&R evaluation **Results** **- Flex-GT test results were repeatable in 3-point bending tests and pendulum tests** **- Flex-GT test results were reproducible in car tests** **- No evaluation of Coefficient of Variation**
TEG-036	BASt	Flex-GT	- Car test (2 cars) using Flex-G and Flex-GT - Dynamic certification test (Pendulum) - Repeatability evaluation **Results** **- Maximum tibia bending moments: SD between good and acceptable at all impact locations** **- Knee elongation: SD still acceptable in 5/12 cases**