#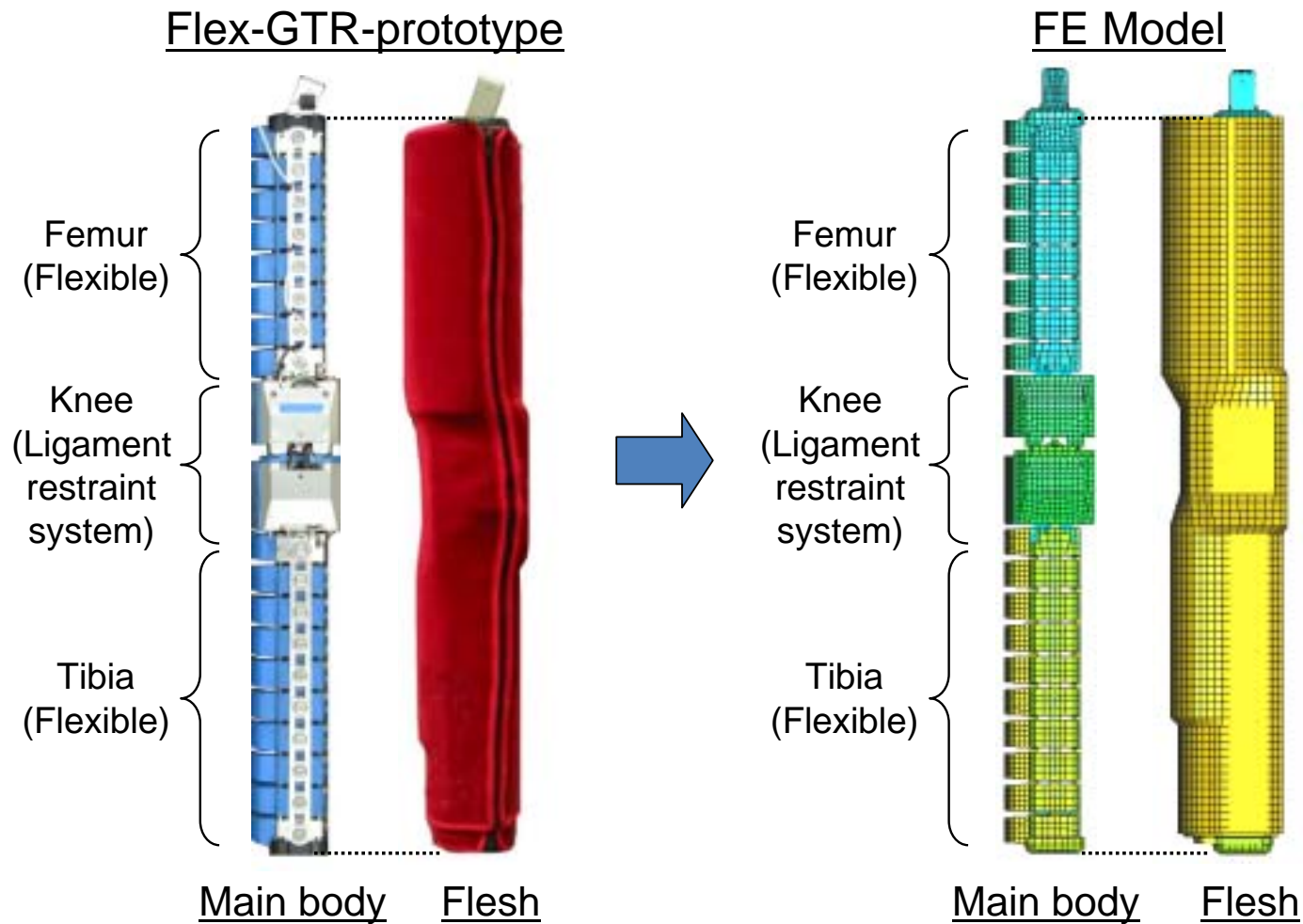 Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models

Back Grounds

- Flex-GTR-prototype was developed in Nov. 2008.
- Flex-GTR-prototype and its previous version, Flex-GT, are not exactly the same (e.g. knee joint construction).
- It is therefore required to reanalyze the correlation between the Flex-GTR-prototype and Human lower limb.
- JAMA/JARI therefore developed a FE Flex-GTR-prototype model, and then analyzed the correlation between the Flex-GTR-prototype and Human Lower Limb outputs using computer simulation models.
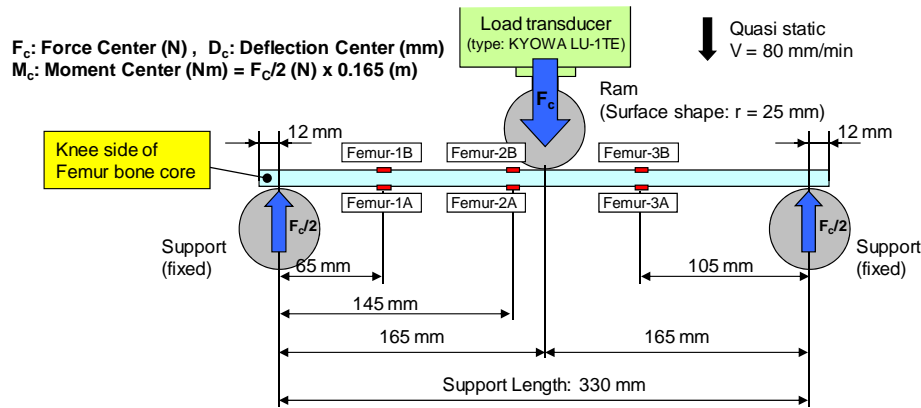
Development of a Flex-GTR-prototype model

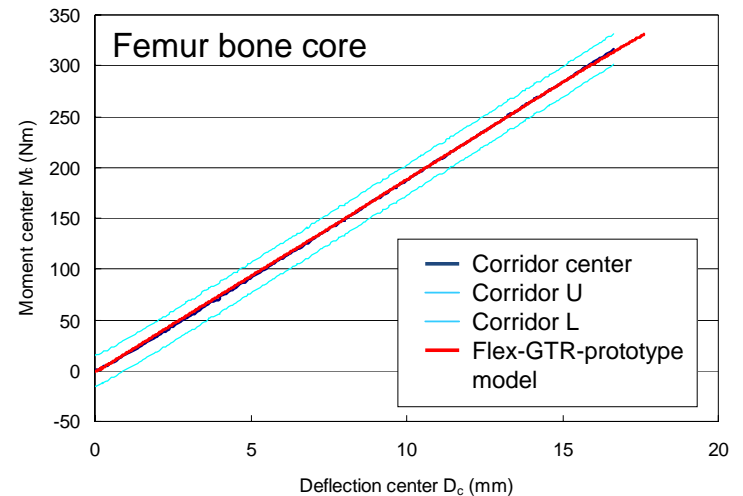# Flex-GTR-prototype and Developed FE model (Overview)
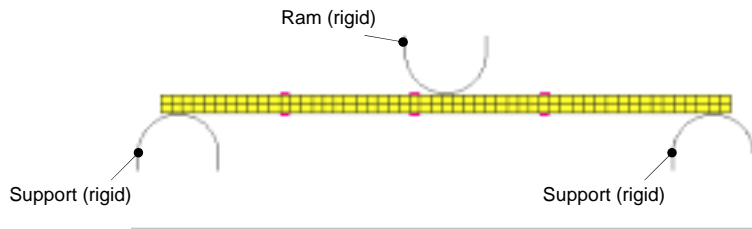
Flex-GTR-prototype

FE Model

Femur
(Flexible)

Knee
(Ligament
restraint
system)

Tibia
(Flexible)

Main body   Flesh

Femur
(Flexible)

Knee
(Ligament
restraint
system)

Tibia
(Flexible)

Main body   Flesh

Femur bone core 3-point bending validation

Test setup for Femur bone core 3-point bending validation

F_c: Force Center (N) , D_c: Deflection Center (mm)
M_c: Moment Center (Nm) = $F_C/2$ (N) x 0.165 (m)

Load transducer (type: KYOWA LU-1TE)

Quasi static
V = 80 mm/min

F_c

Ram (Surface shape: r = 25 mm)

12 mm

Knee side of Femur bone core

Femur-1B | Femur-2B | Femur-3B
Femur-1A | Femur-2A | Femur-3A

12 mm

$F_c/2$

$F_c/2$

Support (fixed)

Support (fixed)

65 mm

105 mm

145 mm

165 mm

165 mm

Support Length: 330 mm

Model setup for Femur bone core 3-point bending validation

Ram (rigid)

Support (rigid)

Support (rigid)

Femur bone core

Moment center M_c (Nm)

Deflection center D_c (mm)

- Corridor center
- Corridor U
- Corridor L
- Flex-GTR-prototype model

Tibia bone core 3-point bending validation

Test setup for Tibia bone core 3-point bending validation

F_c: Force Center (N) , D_c: Deflection Center (mm)
M_c: Moment Center (Nm) = $F_C/2$ (N) x 0.205 (m)

Load transducer
(type: KYOWA LU-1TE)

Quasi static
V = 80 mm/min

F_c

Ram
(Surface shape: r = 25 mm)

12 mm

Knee side of
tibia bone core

Tibia-1B   Tibia-2B   Tibia-3B   Tibia-4B

Tibia-1A   Tibia-2A   Tibia-3A   Tibia-4A

12 mm

$F_c/2$

$F_c/2$

Support
(fixed)

Support
(fixed)

65 mm

105 mm

145 mm

185 mm

205 mm

205 mm

Support Length: 410 mm

Model setup for Tibia bone core 3-point bending validation

Ram (rigid)

Support (rigid)

Support (rigid)

Tibia bone core

Moment center Mc (Nm)

Deflection center D_c (mm)

— Corridor center
— Corridor U
— Corridor L
— Flex-GTR-prototype model

Femur 3-point bending validation

Test setup for Femur 3-point bending validation

F_c: Force Center (N)
M_c: Moment Center (Nm) = $F_C/2$ (N) x 0.165 (m)
D_c: Deflection Center (mm)

Load transducer
(type: KYOWA LU-1TE)

Quasi static
V = 80 mm/min

F_c

Ram
(flat surface, ϕ = 40 mm)

Neoprene

5 mm

Knee side of femur

Femur-1B Femur-2B Femur-3B

Femur-1A Femur-2A Femur-3A

Support (rotate)

Support (rotate)

Rigid base

$F_c/2$

$F_c/2$

165 mm

165 mm

Support Length: 330 mm

Model setup for Femur 3-point bending validation

Ram (rigid)

Support (rigid)

Support (rigid)

Femur

Moment center M_c (Nm)

Deflection center D_c (mm)

— Corridor center
— Corridor U
— Corridor L
— Flex-GTR-prototype model

Tibia 3-point bending validation

Test setup for Tibia 3-point bending validation

F_c: Force Center (N)
M_c: Moment Center (Nm) = $F_C/2$ (N) x 0.205 (m)
D_c: Deflection Center (mm)

Load transducer
(type: KYOWA LU-1TE)

Quasi static
V = 80 mm/min

F_c

Ram
(flat surface, ϕ = 40 mm)

Neoprene

5 mm

Knee side of tibia

| Tibia-1B | Tibia-2B | Tibia-3B | Tibia-4B |

| Tibia-1A | Tibia-2A | Tibia-3A | Tibia-4A |

Support
(rotate)

Support
(rotate)

Rigid base

$F_c/2$

205 mm

205 mm

$F_c/2$

Support Length: 410 mm

Model setup for Tibia 3-point bending validation

Ram (rigid)

Support (rigid)

Support (rigid)

Tibia

- Corridor center
- Corridor U
- Corridor L
- Flex-GTR-prototype model

Moment center Mℓ (Nm)

Deflection center D_c (mm)

Knee 3-point bending validation

Test setup for Knee 3-point bending validation

F_c: Force Center - at Knee joint surface (N) = F_1 (N) + F_2 (N)
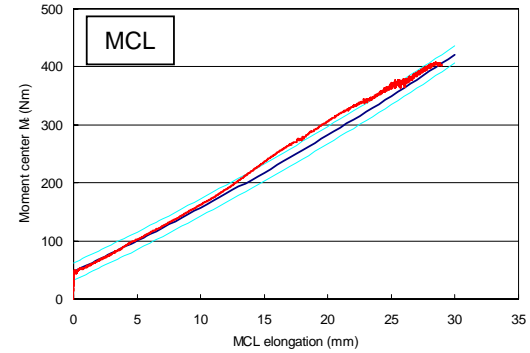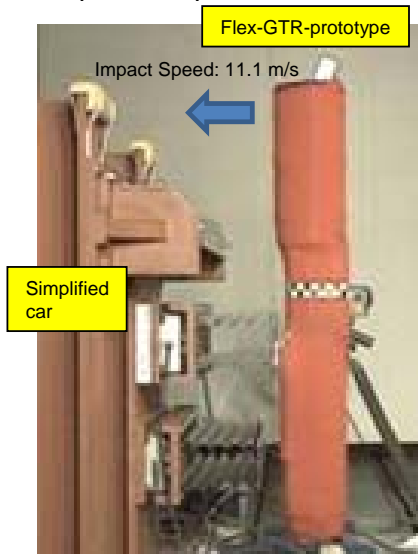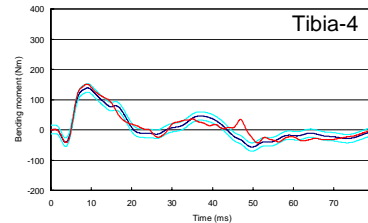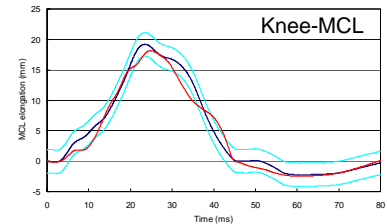M_c: Moment Center - at Knee joint surface (Nm) = F_1 (N) x 0.2 (m)
D_c: Deflection Center (mm)
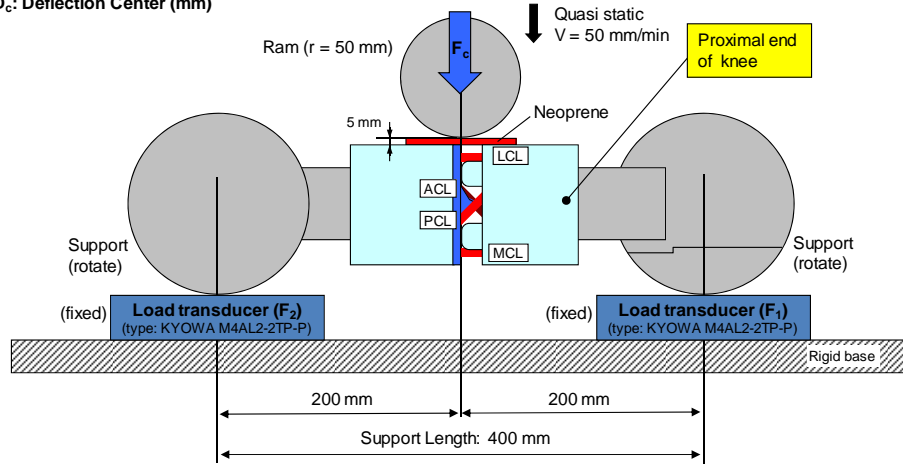
Quasi static
V = 50 mm/min

Ram (r = 50 mm)

F_c

Proximal end
of knee

5 mm

Neoprene

LCL

ACL

PCL

MCL

Support
(rotate)

Support
(rotate)

(fixed)   **Load transducer (F_2)**
(type: KYOWA M4AL2-2TP-P)

(fixed)   **Load transducer (F_1)**
(type: KYOWA M4AL2-2TP-P)

Rigid base

200 mm

200 mm

Support Length: 400 mm

Model setup for Knee 3-point bending validation

Ram (rigid)

Support (rigid)

Support (rigid)

— Corridor center
— Corridor U
— Corridor L
— Flex-GTR-prototype
model

MCL — Moment center M (Nm) vs MCL elongation (mm)

ACL — ACL elongation (mm) vs Force center F_c (N)

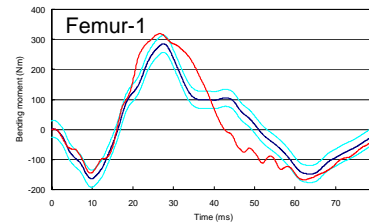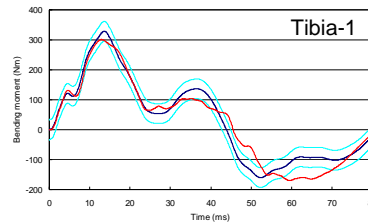PCL — PCL elongation (mm) vs Force center Fc (N)
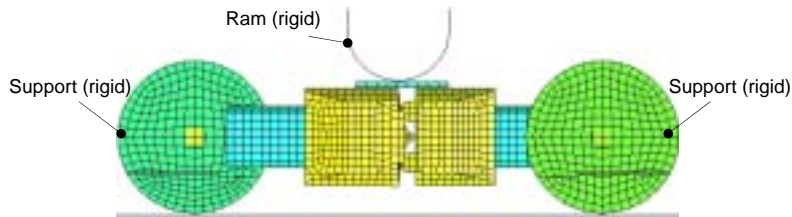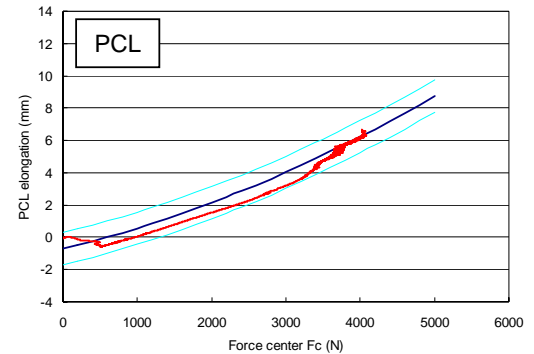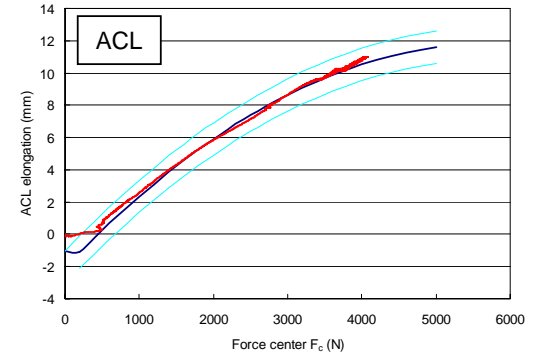
Overall validation under the Simplified Car Impact

Test setup for Simplified car validation

Flex-GTR-prototype

Impact Speed: 11.1 m/s

Simplified car

Model setup for Simplified car validation

Flex-GTR-prototype model

Simplified car model

Legend:
— Experiment
— Experiment +10%
— Experiment -10%
— Flex-GTR-prototype model

Tibia-1, Tibia-2, Tibia-3, Tibia-4, Femur-1, Femur-2, Femur-3, Knee-Acc., Knee-ACL, Knee-PCL, Knee-MCL, Knee-LCL
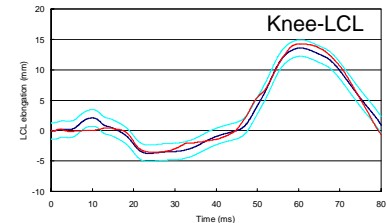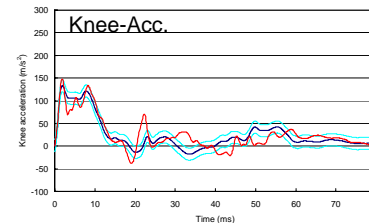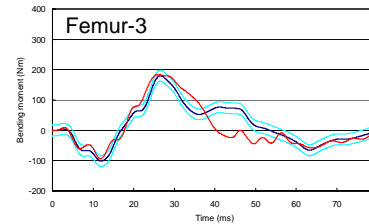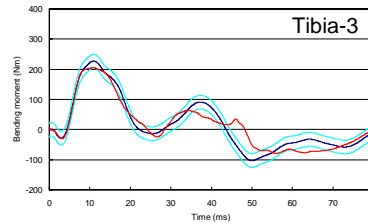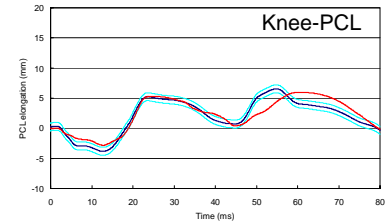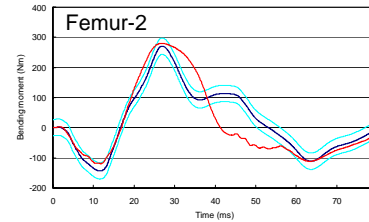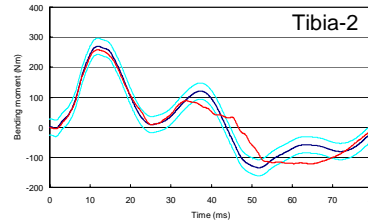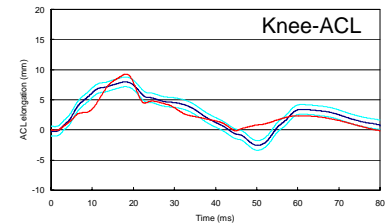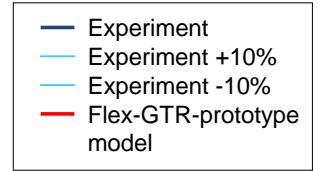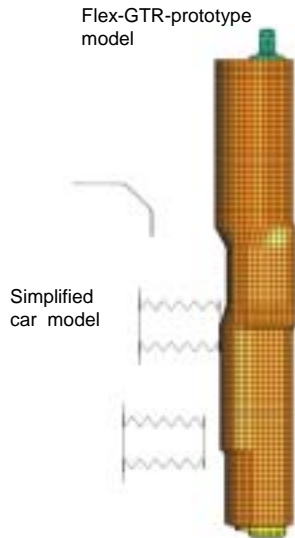
Analysis of Correlation between
the Flex-GTR-prototype and Human Lower Limb
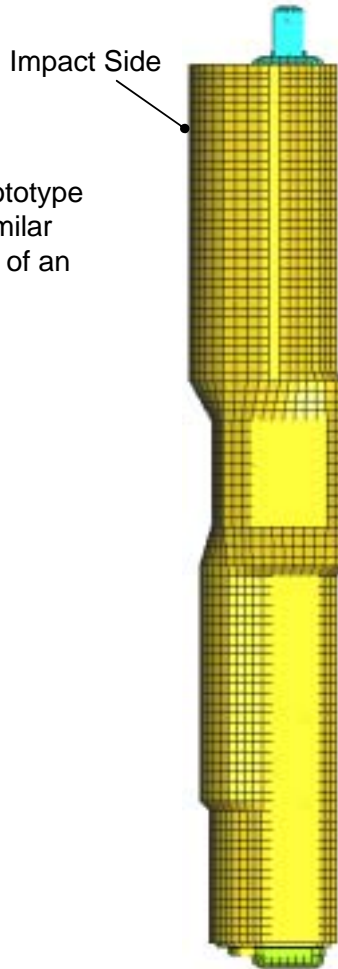# outputs using Computer Simulation Models

Computer simulation models

Simplified car models: 18 cars (S1-S18, ESV 2007, Paper Number 07-0178)
Lower Bumper Reference Height (LBRH): 215 mm - 315 mm
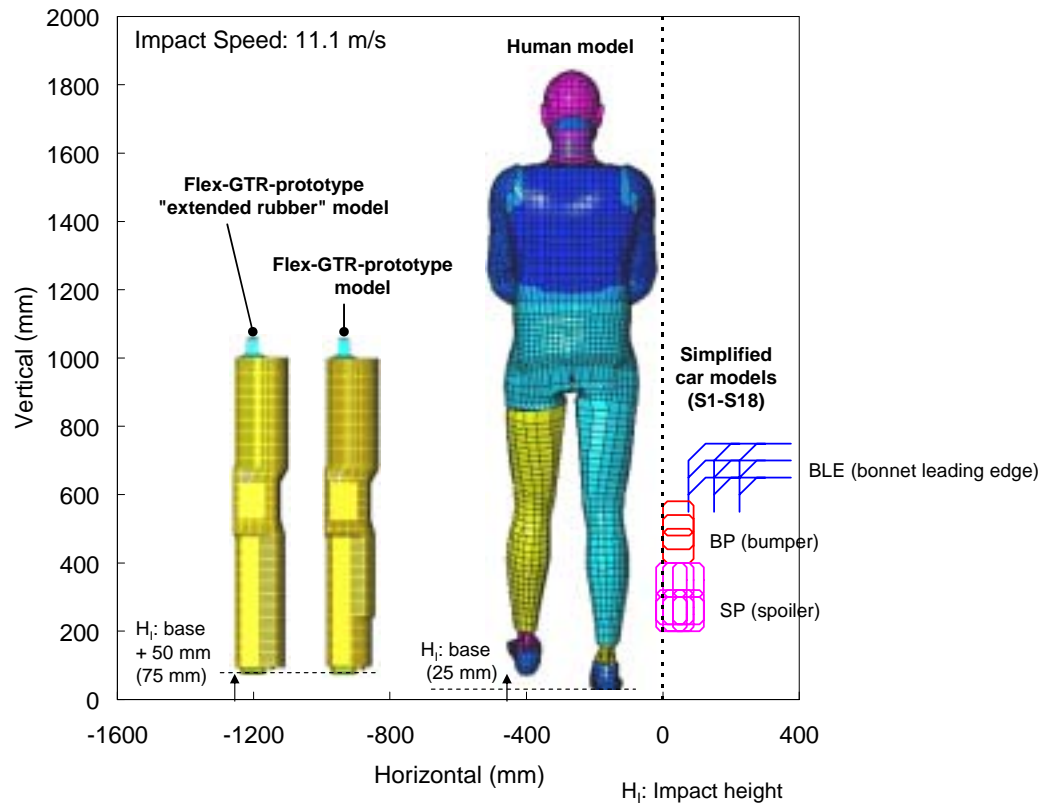
Flex-GTR-prototype models

Flex-GTR-prototypemodel

Flex-GTR-prototype
"extended rubber" model

Impact Side

Impact Side
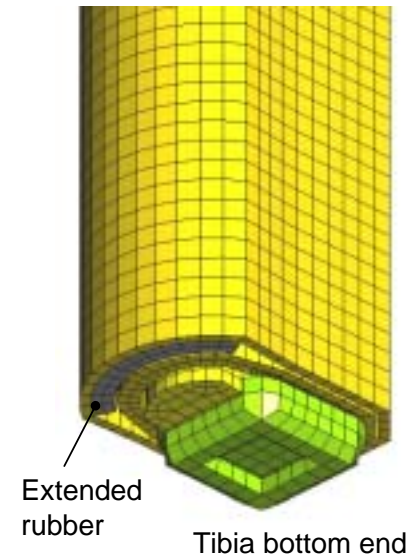
Flex-GTR-prototype
model has similar
constructions of an
actual one.
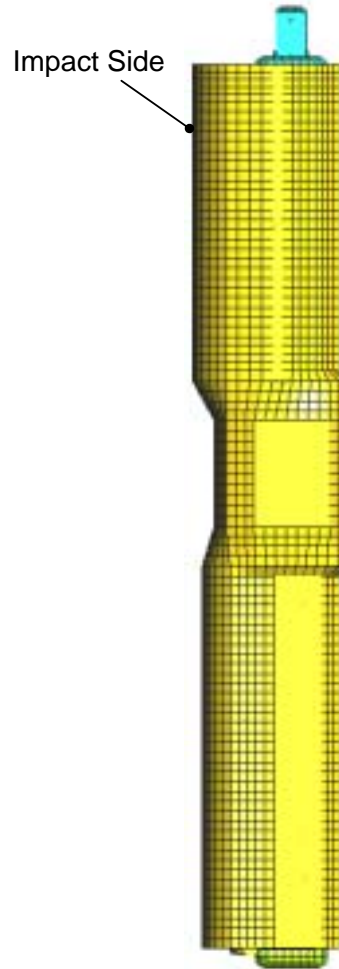
Flex-GTR-prototype
"extended rubber" model has
improved structure of flesh.
Rubber is extended to a Tibia
bottom end.
(Based on BASt/BGS proposal)

Extended
rubber

Tibia bottom end

Flex-GTR prototype model

Tibia-Max.

$y = 0.9835x + 22.659$
$(R_{tibia} = 0.78)$

Flex-GTR-prototype Model Tibia Bending Moment Max.-abs.- (Nm)

Human Model, Tibia Bending Moment, Max.-abs.- (Nm)

Knee-MCL

$y = 0.5751x + 9.1793$
$(R_{MCL} = 0.60)$

Flex-GTR-prototype Model Knee MCL Elongation Max. (mm)

Human Model, Knee MCL Elongation, Max. (mm)

Flex-GTR prototype "extended rubber" model

Tibia-Max.

$y = 1.259x - 72.798$
$(R_{tibia} = 0.90)$

Flex-GTR-prototype Model Tibia Bending Moment Max.-abs.- (Nm)

Human Model, Tibia Bending Moment, Max.-abs.- (Nm)

Knee-MCL

$y = 0.5584x + 10.335$
$(R_{MCL} = 0.55)$

Flex-GTR-prototype Model Knee MCL Elongation Max. (mm)

Human Model, Knee MCL Elongation, Max. (mm)

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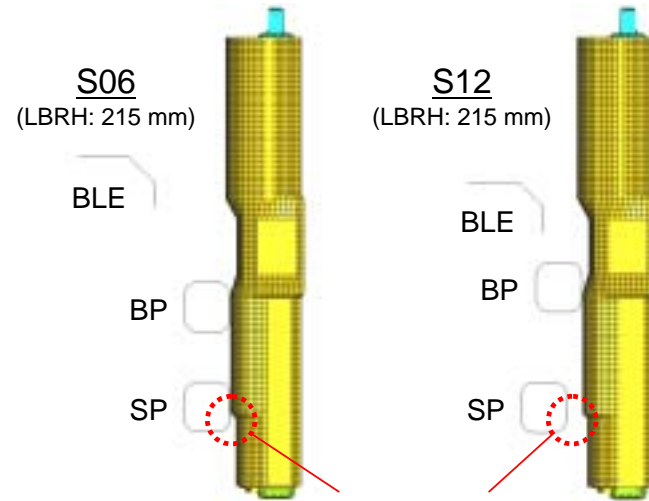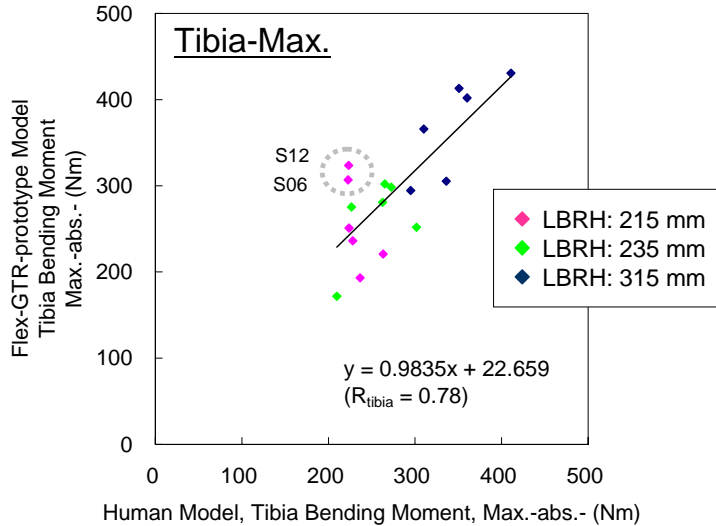
· Correlation of Tibia-Max.(R_{tibia}): Flex-GTR prototype "extended rubber" model is higher than Flex-GTR prototype model.
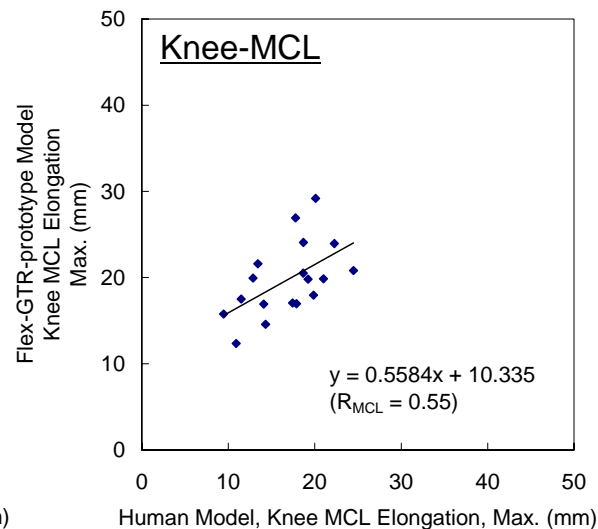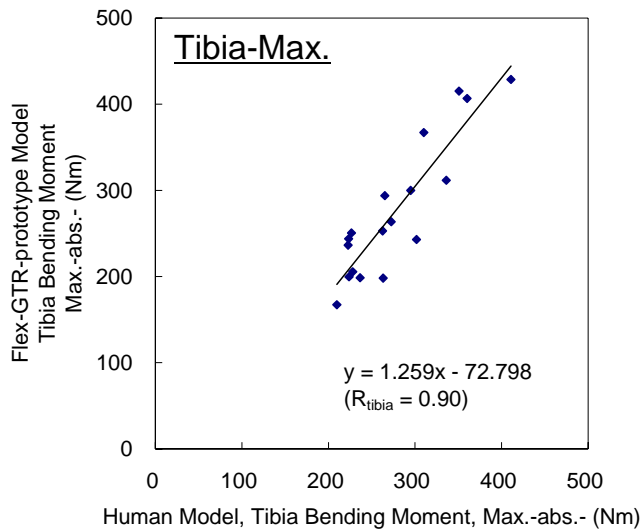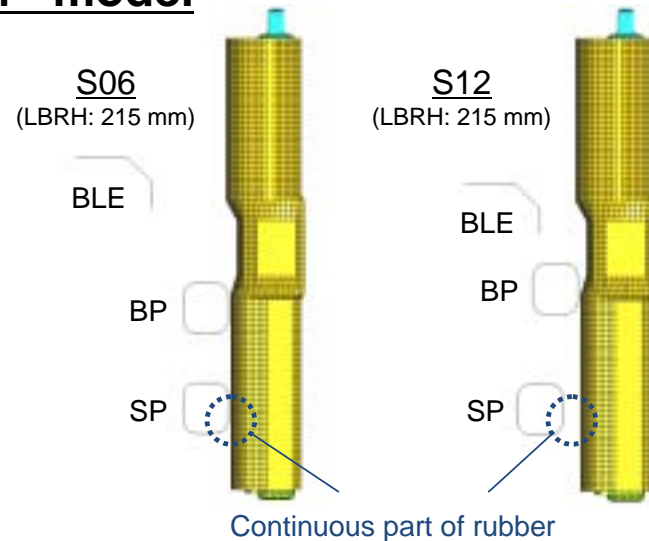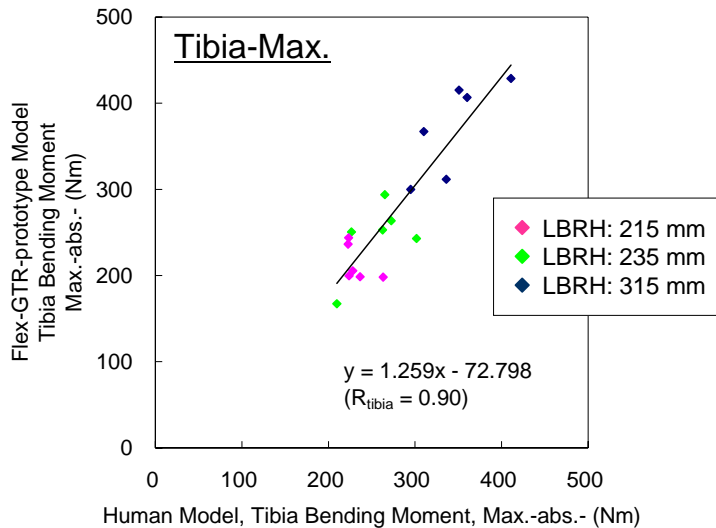
· Correlation of Knee-MCL(R_{MCL}): Flex-GTR prototype "extended rubber" model and Flex-GTR prototype model is comparable.

Flex-GTR prototype model

Tibia-Max.

y = 0.9835x + 22.659
(R_{tibia} = 0.78)

Flex-GTR-prototype Model Tibia Bending Moment Max.-abs.- (Nm)

Human Model, Tibia Bending Moment, Max.-abs.- (Nm)

◆ LBRH: 215 mm
◆ LBRH: 235 mm
◆ LBRH: 315 mm

S12
S06

S06 (LBRH: 215 mm)   S12 (LBRH: 215 mm)

BLE   BLE
BP   BP
SP   SP

In case of that the Car spoiler height is low, discontinuous part of rubber Impact to the Car spoiler.
⇒ Load to tibia become higher compare to the human one.

Flex-GTR prototype "extended rubber" model

Tibia-Max.

y = 1.259x - 72.798
(R_{tibia} = 0.90)

Flex-GTR-prototype Model Tibia Bending Moment Max.-abs.- (Nm)

Human Model, Tibia Bending Moment, Max.-abs.- (Nm)

◆ LBRH: 215 mm
◆ LBRH: 235 mm
◆ LBRH: 315 mm

S06 (LBRH: 215 mm)   S12 (LBRH: 215 mm)

BLE   BLE
BP   BP
SP   SP

Continuous part of rubber

⇒ Load to tibia become comparable to the human one.

Conclusions

- Well validated FE Flex-GTR-prototype model was developed in this study.
- When we analyzed the correlation between the Flex-GTR-prototype and Human Lower Limb outputs, we obtained following findings,
  - ✓ Flex-GTR prototype model outputs show a high correlation with the human lower limb outputs.
  - ✓ Besides, in order to extend the rubber of the flesh to the tibia bottom shows higher correlation with human lower limb especially for the Tibia outputs.
    - Correlation of Tibia (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.
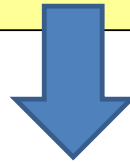
In order to obtain higher correlation between the Flex-GTR-prototype and Human Lower Limb outputs, JAMA-JARI recommend to extend the Rubber sheets of the Flesh of Flex-PLI until to the bottom of Tibia.