HONDA
The Power of Dreams

Validation of Pedestrian Lower Limb Injury Assessment using Subsystem Impactors

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IRCOBI
International Research Council on Biomechanics of Injury

Outline

- Background
- Objective
- Predictor of Tibia Fracture
- Development and Validation of Legform Models
- Correlation of Injury Measures between Human and Legform Models
- Factors for Difference in Tibia Fracture Measure Correlation
- Discussion
- Conclusions

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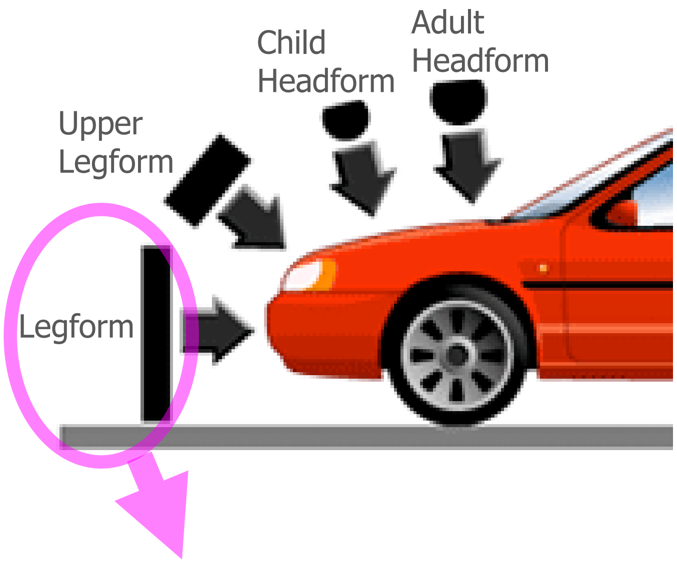
Pedestrian Test Procedure

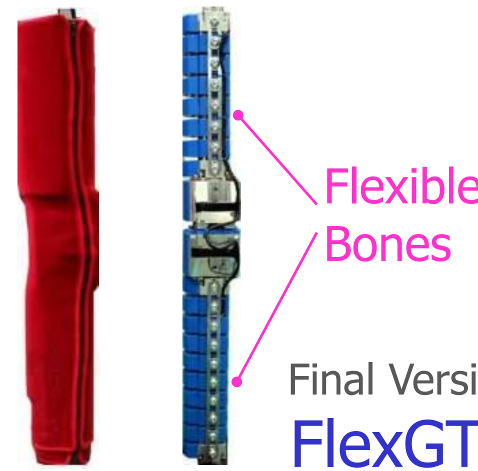
EEVC
Subsystem Impactors



EEVC Legform

FlexPLI

Flexible Pedestrian Legform Impactor



Jointly developed by JARI and JAMA

Past Studies

- Matsui et al. (2001)
  - ✓ Comparison of time histories of impact force, knee shear displacement and knee bending angle between EEVC legform tests and PMHS tests by Kajzer et al.
  - ✓ EEVC legform does not have sufficient biofidelity

- Konosu et al. (2009)
  - ✓ Impact simulations using EEVC legform and human FE models against multiple simplified vehicle models
  - ✓ No correlation between EEVC legform upper tibia acceleration and human tibia bending moment (R=0.01)

- JAMA and JARI (2009)
  - ✓ Impact simulations using FlexPLI and human FE models against multiple simplified vehicle models
  - ✓ Good correlation between FlexPLI tibia bending moment and human tibia bending moment (R=0.90)

Past Studies

- Validity of the use of tibia bending moment as a predictor of human tibia fracture needs further clarifications
- No comprehensive comparison has been made as to the correlation of all injury measures
- Factors for the difference in the correlation have not been clarified

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Objective

- Investigate difference of correlation with human body between EEVC legform and FlexPLI for all injury measures
- Clarify factors for difference in correlation from a viewpoint of stiffness of tibia and injury measures used

Identification of Predictor of Human Tibia Fracture

- Impact simulations using a human FE model against multiple simplified vehicle models

Correlation Analysis of Human and Legform Measures

- Impact simulations using EEVC legform and FlexPLI FE models against multiple simplified vehicle models
- Comparison of correlation for all injury measures

Clarification of factors for correlation difference

- Tibia fracture measures
- Additional simulations using simplified vehicle models and leg component model

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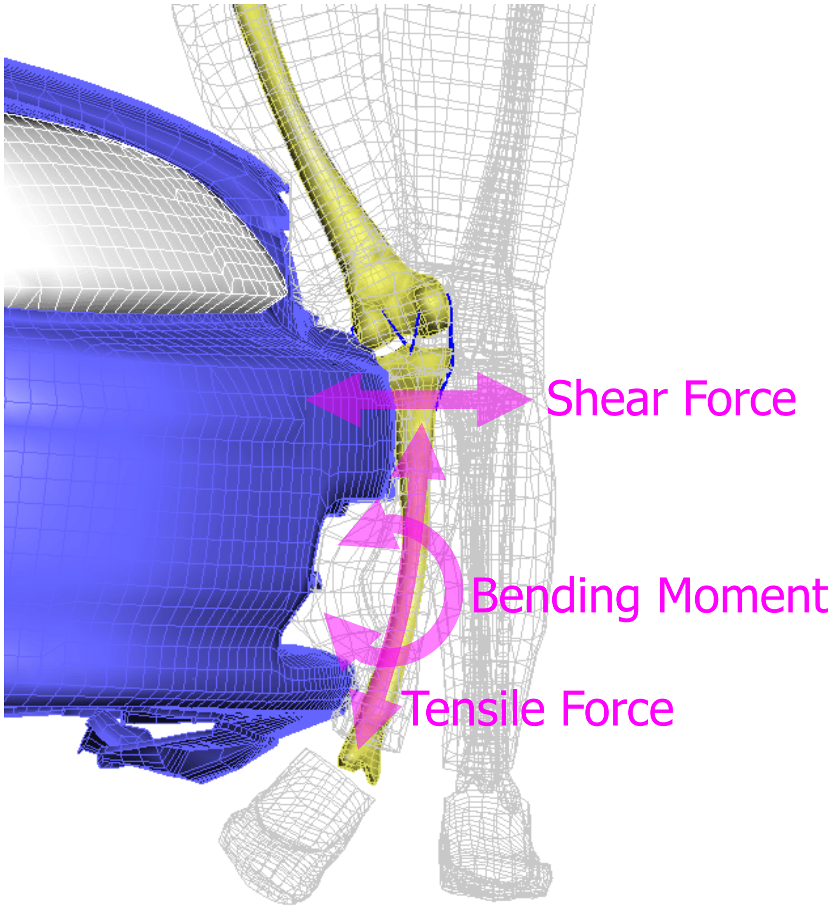
Candidate Predictors



Candidate Predictors

- Shear force, tensile force, bending moment
- Acceleration

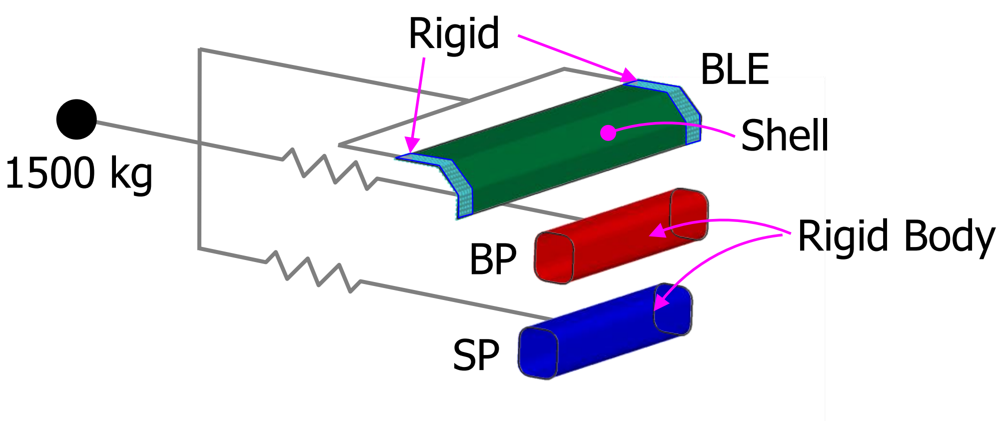
Assumption

- Bone fails when maximum von Mises stress exceeds the limit

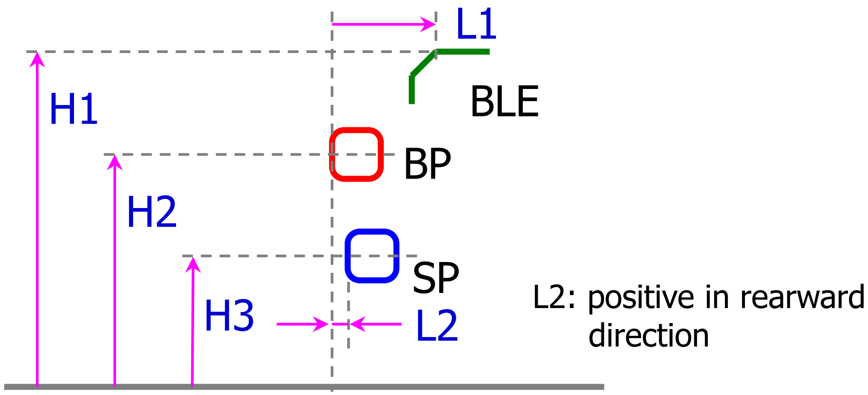
Investigate correlation between maximum von Mises stress and maximum candidate predictors

Simplified Vehicle Model

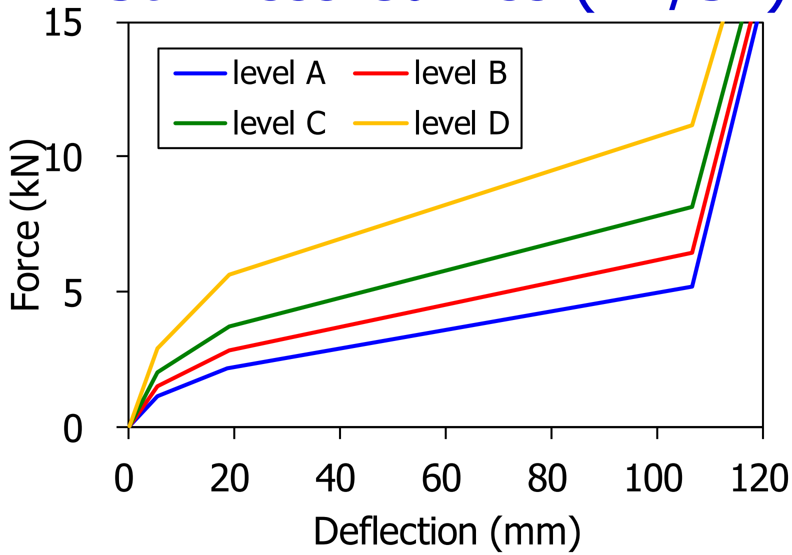
Structure



Geometric Parameters



Stiffness Curves (BP/SP)



Levels of Parameters

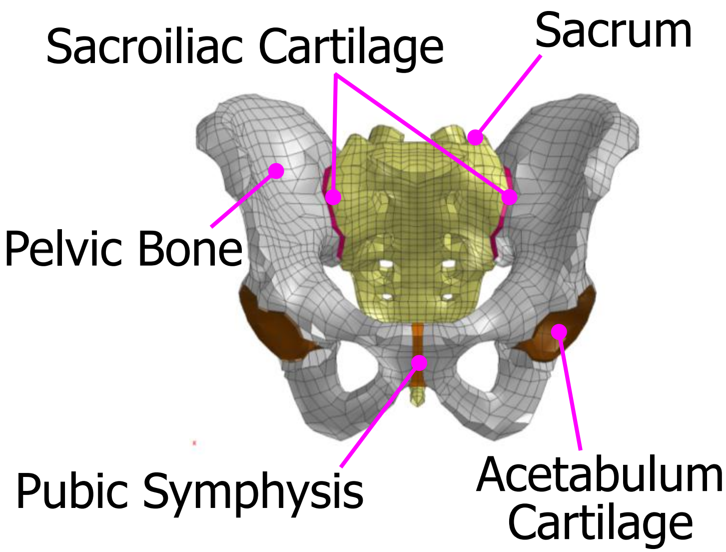
Parameter	Unit	Level 1	Level 2	Level 3
K1 (BLE thickness)	mm	0.4	0.6	-
K2 (BP stiffness)	-	B	C	D
K3 (SP stiffness)	-	A	C	D
H1 (BLE height)	mm	650	700	750
H2 (BP height)	mm	450	490	530
H3 (SP height)	mm	250	270	350
L1 (BLE lead)	mm	125	200	275
L2 (SP lead)	mm	-20	0	30

Simplified Vehicle Model

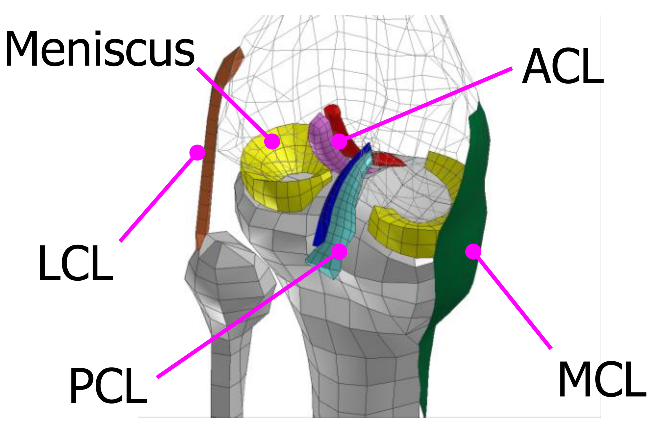
Model	K1	K2	K3	H1	H2	H3	L1	L2
S1	0.4	B	A	650	450	250	125	-20
S2	0.4	B	C	700	490	270	200	0
S3	0.4	B	D	750	530	350	275	30
S4	0.4	C	A	650	490	270	275	30
S5	0.4	C	C	700	530	350	125	-20
S6	0.4	C	D	750	450	250	200	0
S7	0.4	D	A	700	450	350	200	30
S8	0.4	D	C	750	490	250	275	-20
S9	0.4	D	D	650	530	270	125	0
S10	0.6	B	A	750	530	270	200	-20
S11	0.6	B	C	650	450	350	275	0
S12	0.6	B	D	700	490	250	125	30
S13	0.6	C	A	700	530	250	275	0
S14	0.6	C	C	750	450	270	125	30
S15	0.6	C	D	650	490	350	200	-20
S16	0.6	D	A	750	490	350	125	0
S17	0.6	D	C	650	530	250	200	30
S18	0.6	D	D	700	450	270	275	-20

Pedestrian Model

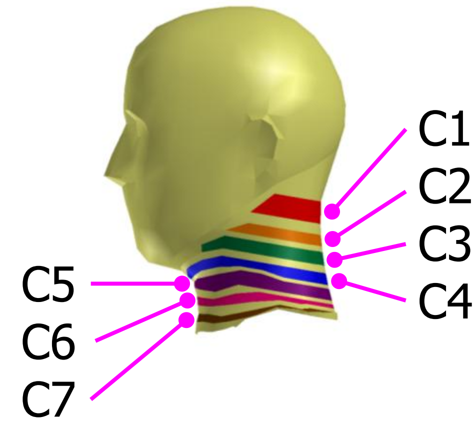
Pelvis Model



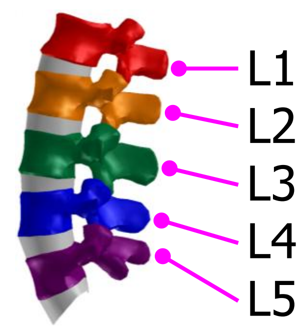
Knee Model



Neck Model



Lumber Model

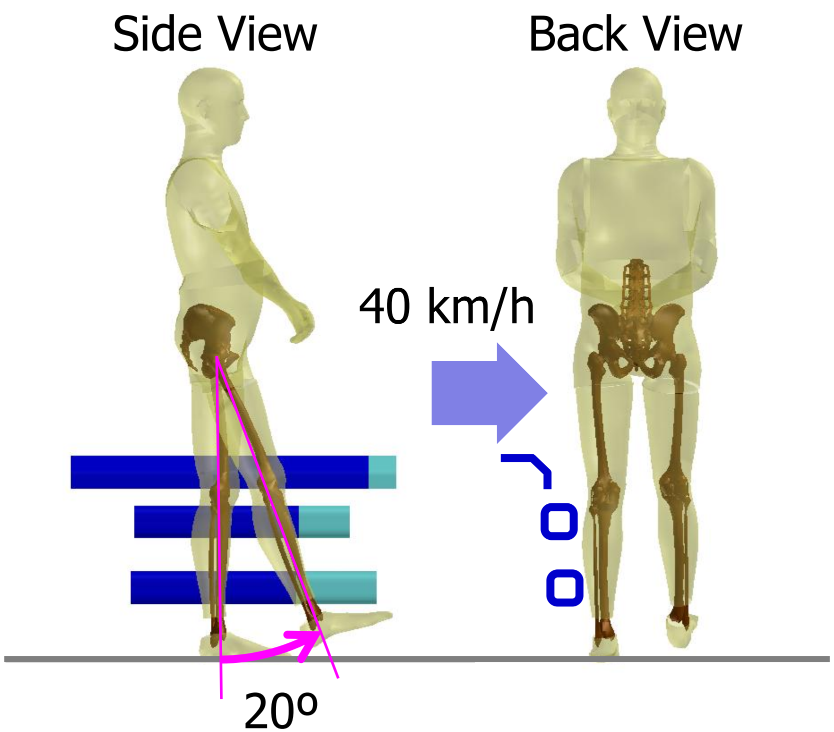


Pedestrian Model Validation

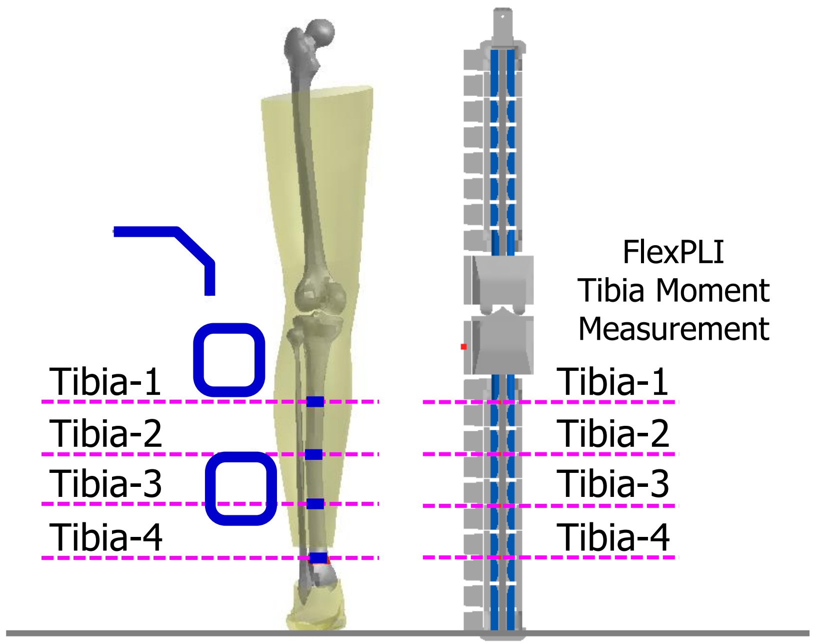
Body Region /Tissue		Loading Rate	Loading Configuration	Properties
Pelvis	Isolated pelvis	• Quasi-static • Dynamic, 1 rate	• Lateral compression • Iliac / acetabulum loadings	• Force-deflection
Thigh	Isolated femur	• Quasi-static • Dynamic, 1 rate	• 3-point bending	• Force-deflection • Moment-deflection
	Femur+flesh	• Quasi-static • Dynamic, 1 rate	• 3-point bending	• Force-deflection • Moment-deflection
Knee	Isolated ligament	• Quasi-static • Dynamic, 3 rates	• Tension	• Force-deflection
	Isolated knee joint	• Dynamic, 1 rate	• 4-point bending • 3-point bending	• Moment-angle
Leg	Isolated tibia	• Quasi-static • Dynamic, 1 rate	• 3-point bending	• Force-deflection • Moment-deflection
	Isolated fibula	• Quasi-static • Dynamic, 1 rate	• 3-point bending	• Force-deflection • Moment-deflection
	Tibia+fibula+ flesh	• Quasi-static • Dynamic, 1 rate	• 3-point bending	• Force-deflection • Moment-deflection
Whole body		• 40 km/h impact	• Lateral impact • 1 small sedan, 1 large SUV	• Head, T1, T8, pelvis trajectories • Pelvis and lower limb injury distribution

Impact Simulation Setup

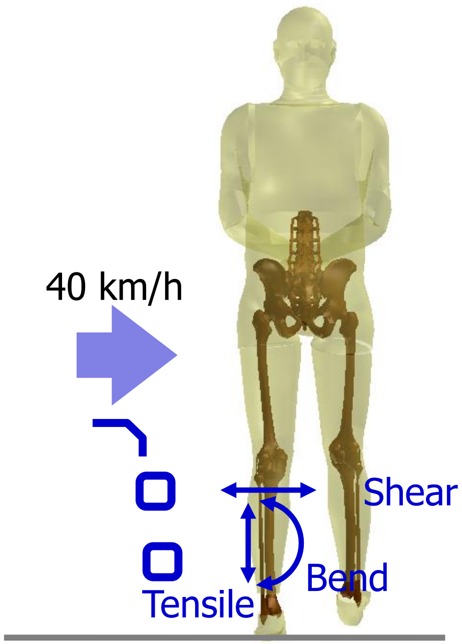
Model Setup



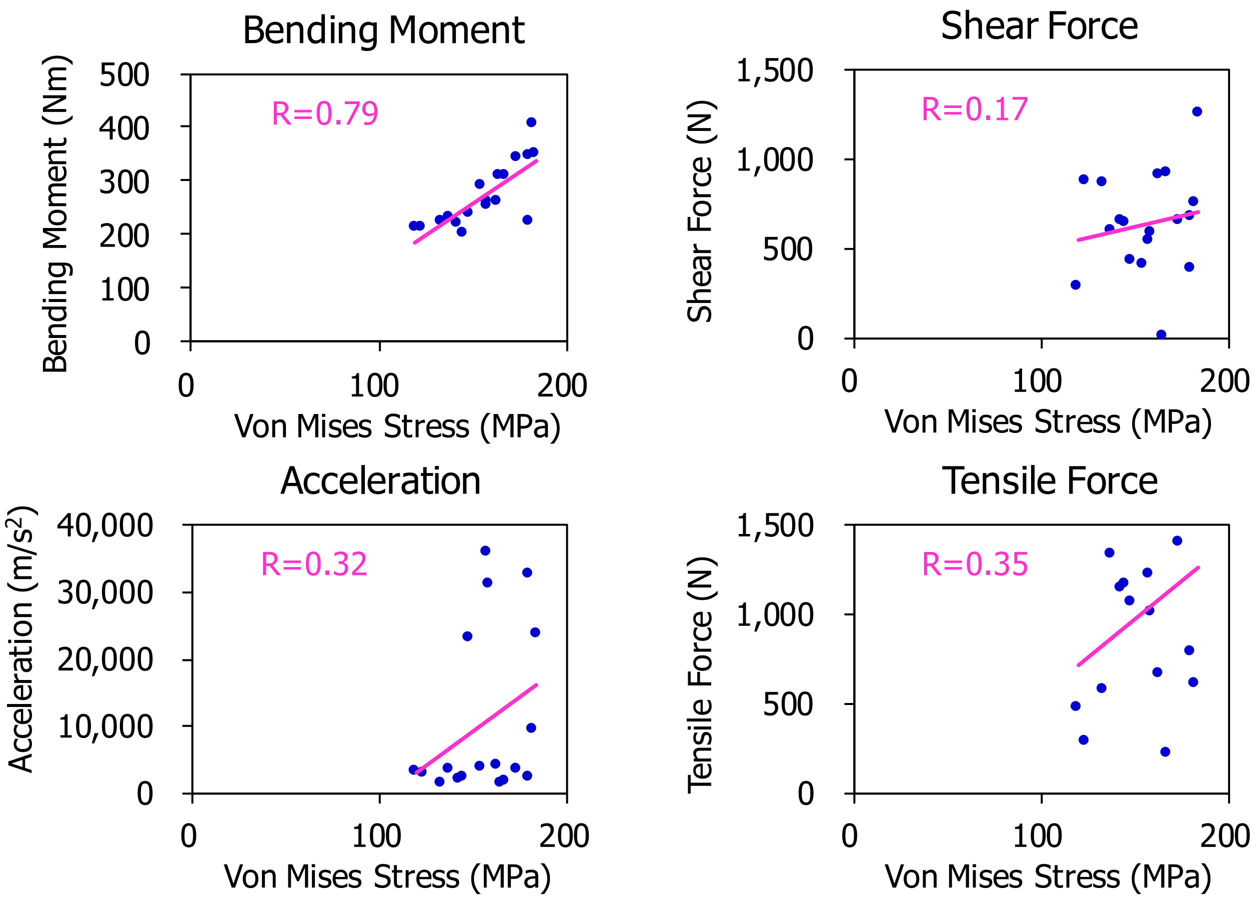
Measurement Location



Results of Correlation Analysis



18 different simplified vehicle models



Maximum tibia bending moment best correlates with maximum local von Mises stress of tibia

Maximum tibia acceleration poorly correlates with maximum von Mises stress of tibia

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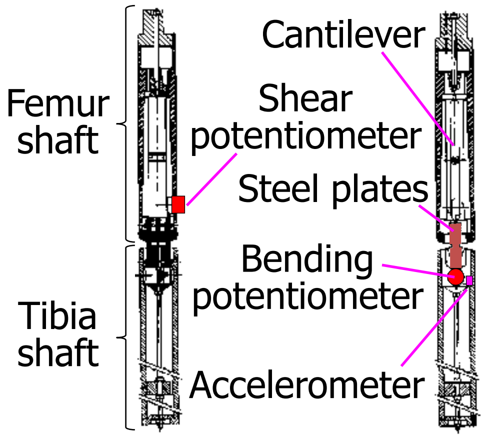
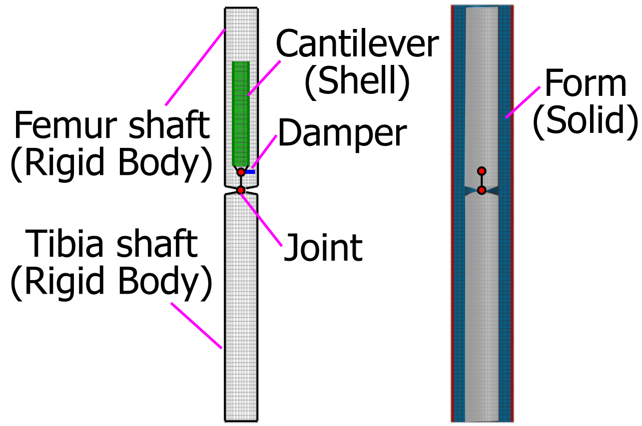
Legform Models

EEVC Legform

Structure



Model

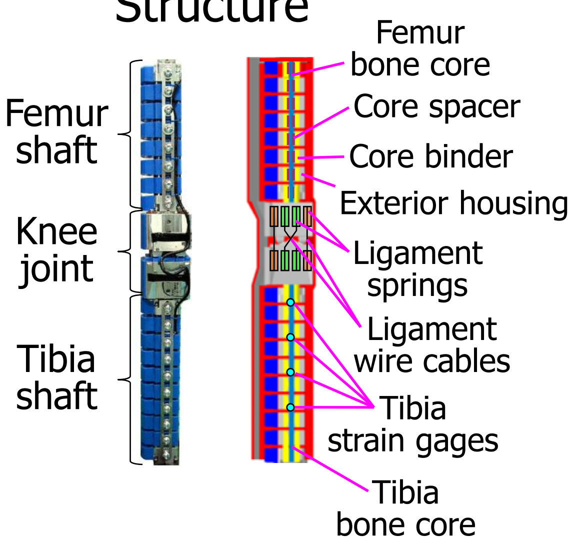


Validation Matrix

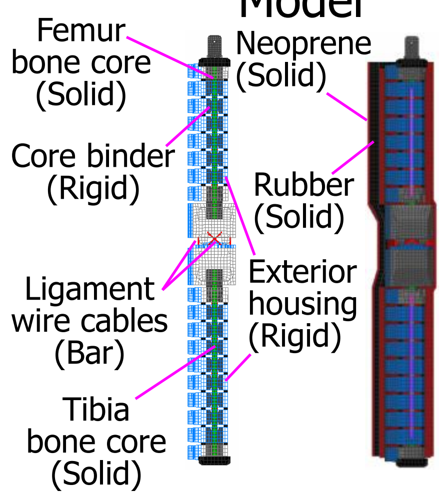
Component	Assembly
• Quasi-static knee bending • Quasi-static knee shearing	• Dynamic certification test • Vehicle test

FlexPLI

Structure



Model

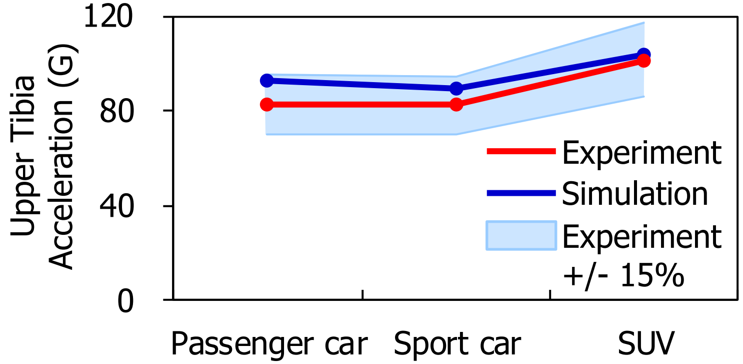


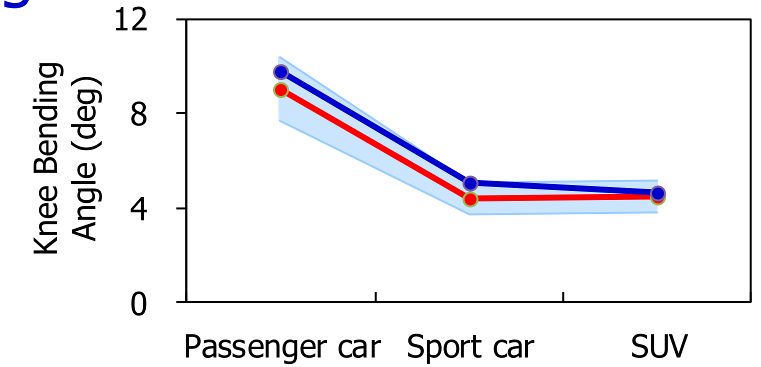
Validation Matrix

Component	Assembly
• Bone core 3-pt bending • Femur 3-pt bending • Knee 3-pt bending • Tibia 3-pt bending	• Pendulum test • Simplified vehicle test • Vehicle test

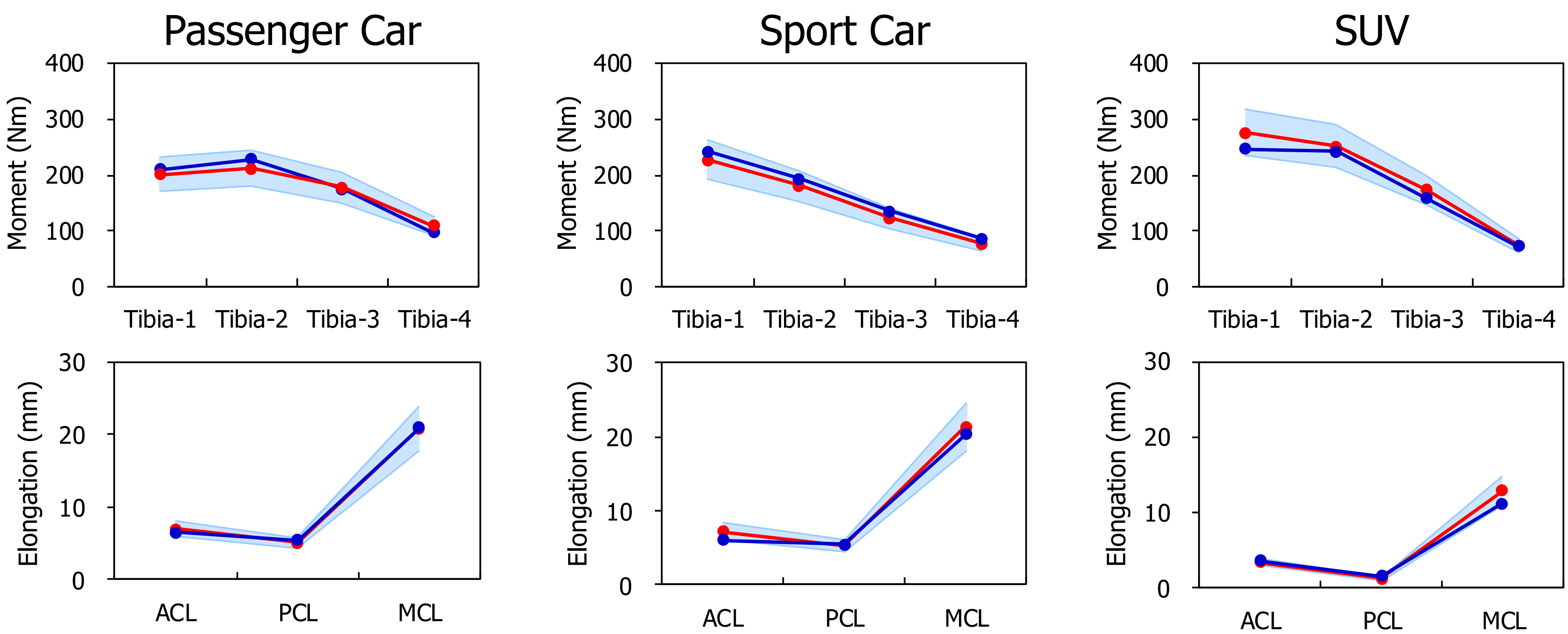
Validation against Car Test

EEVC Legform





FlexPLI



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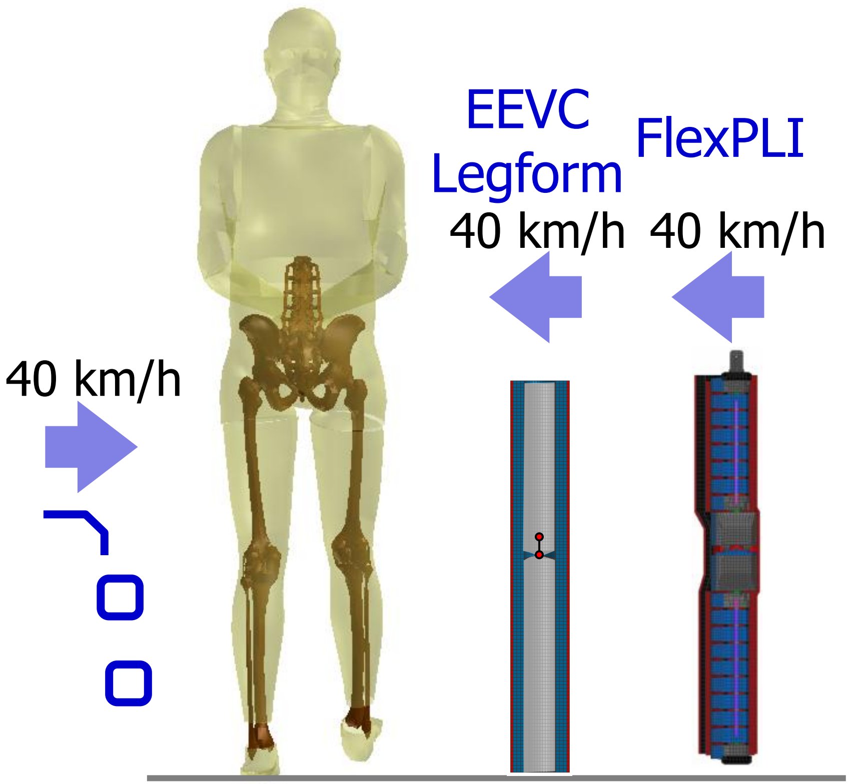
Impact Simulations

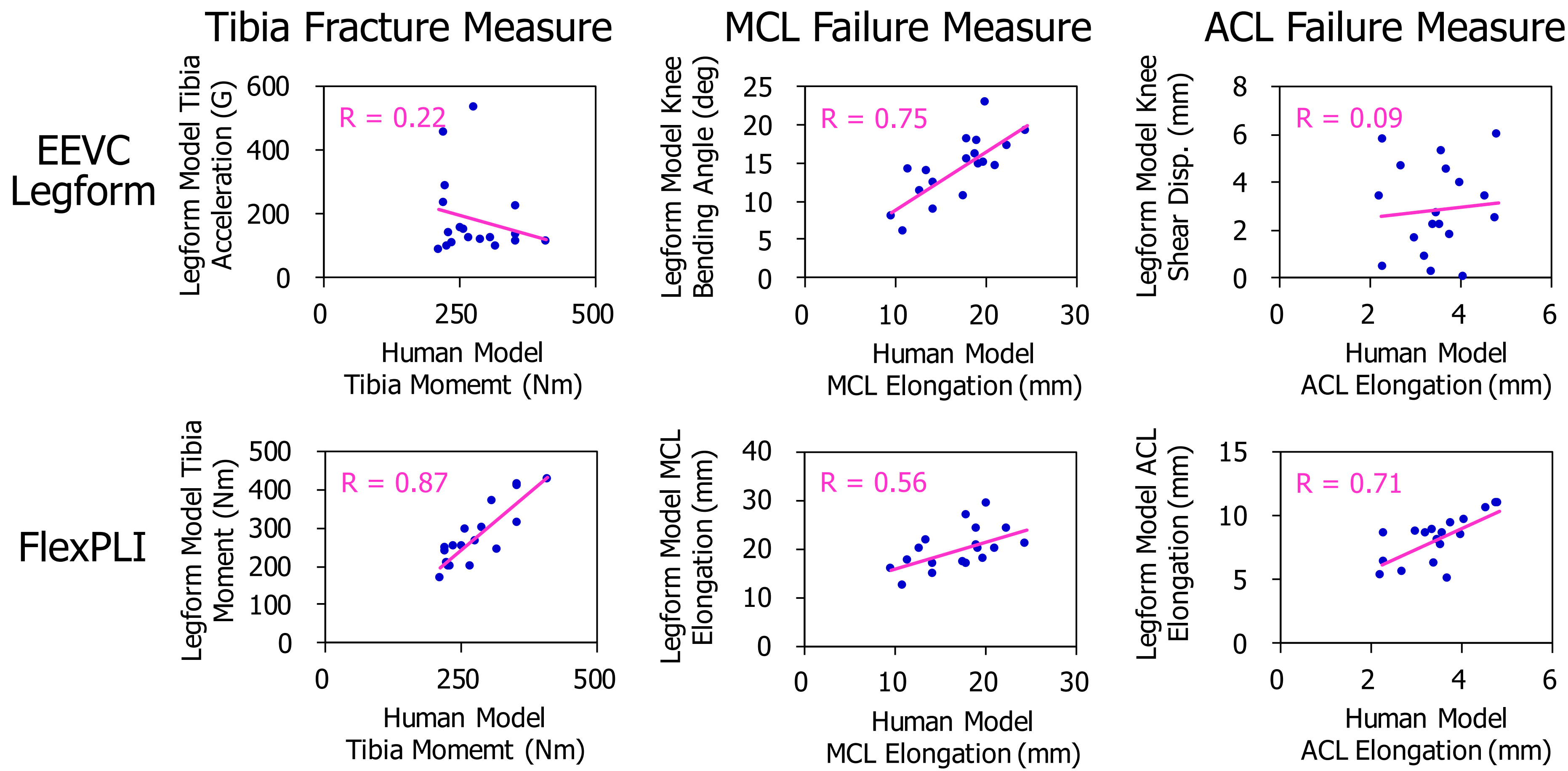


18 simplified
vehicle models

Injury	Measure		
	Human	EEVC Legform	FlexPLI
Tibia Fracture	Tibia Bending Moment	Upper Tibia Acceleration	Tibia Bending Moment
MCL Failure	MCL Elongation	Knee Bending Angle	MCL Elongation
ACL Failure	ACL Elongation	Knee Shear Displacement	ACL Elongation

Investigate correlation of tibia and knee injury measures with human model for both EEVC legform and FlexPLI models

Results of Correlation Analysis



- FlexPLI showed much better correlation than EEVC legform for tibia fracture and ACL failure measures
- EEVC legform tibia fracture measure showed a negative correlation

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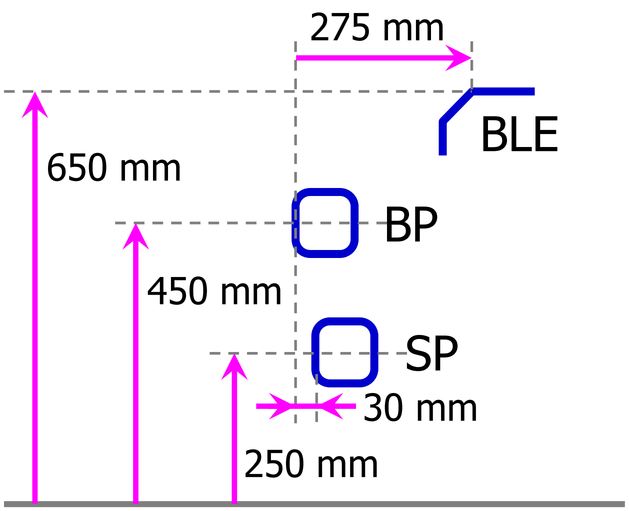
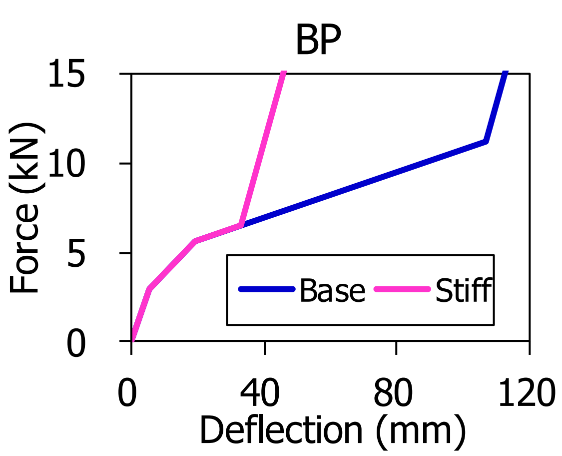
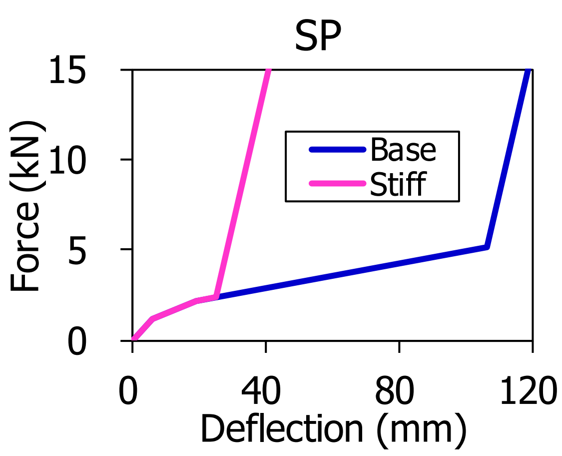
Simplified Vehicle Impact Simulation

Baseline Model

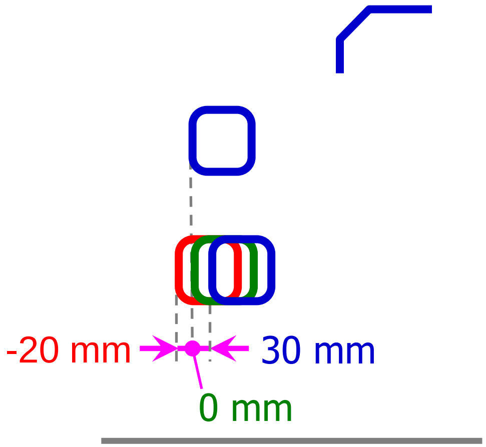


BP/SP Stiffness



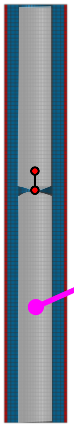


SP Location



Simplified Vehicle Impact Simulation

EEVC Legform Model



Stiffness of Tibia

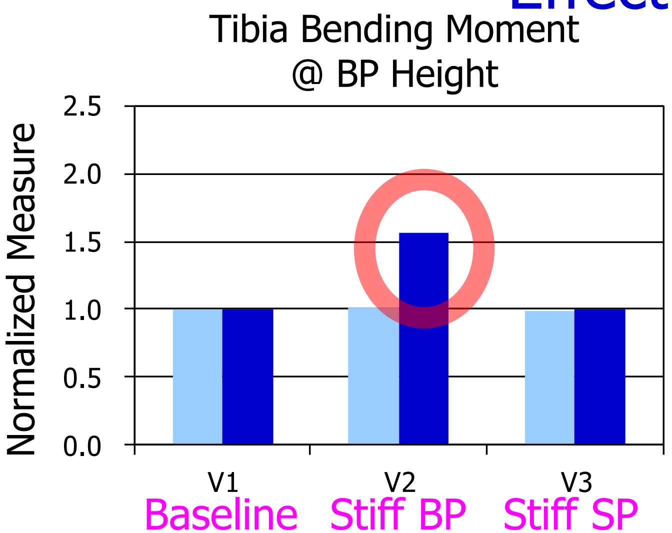
Case	Stiffness
Steel	Material parameters of steel
Bone	Flexural rigidity = 555.6 Nm^2

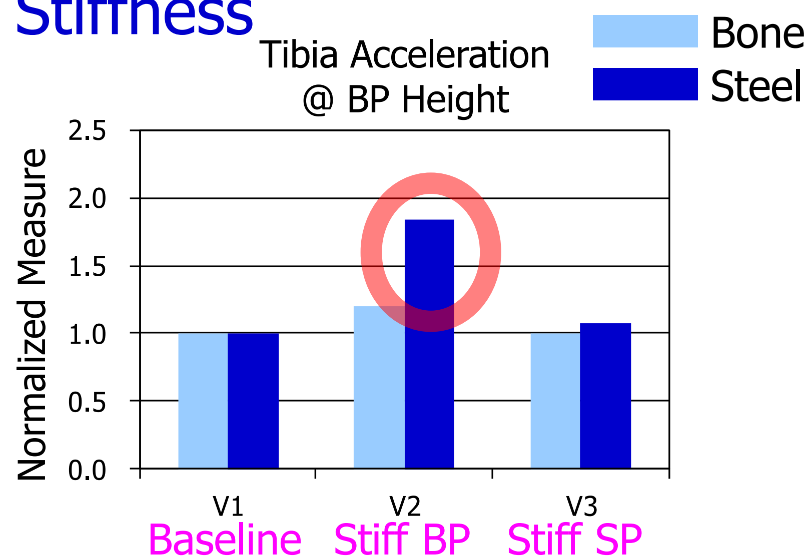
Simulation Matrix

Case	Stiffness			SP Location (L2 in mm)	Case	Stiffness			SP Location (L2 in mm)
	BP	SP	Tibia			BP	SP	Tibia	
V1-B	Base	Base	Bone	30	V1-S	Base	Base	Steel	30
V2-B	Stiff	Base	Bone	30	V2-S	Stiff	Base	Steel	30
V3-B	Base	Stiff	Bone	30	V3-S	Base	Stiff	Steel	30
V4-B	Base	Stiff	Bone	0	V4-S	Base	Stiff	Steel	0
V5-B	Base	Stiff	Bone	-20	V5-S	Base	Stiff	Steel	-20

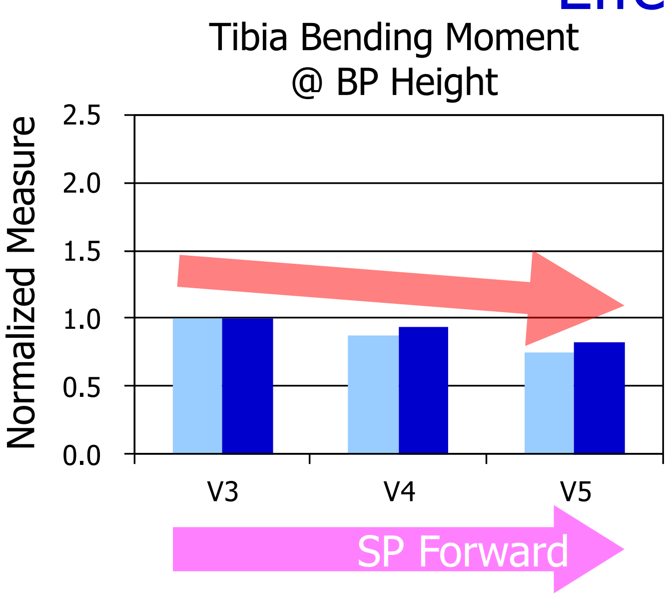
Results

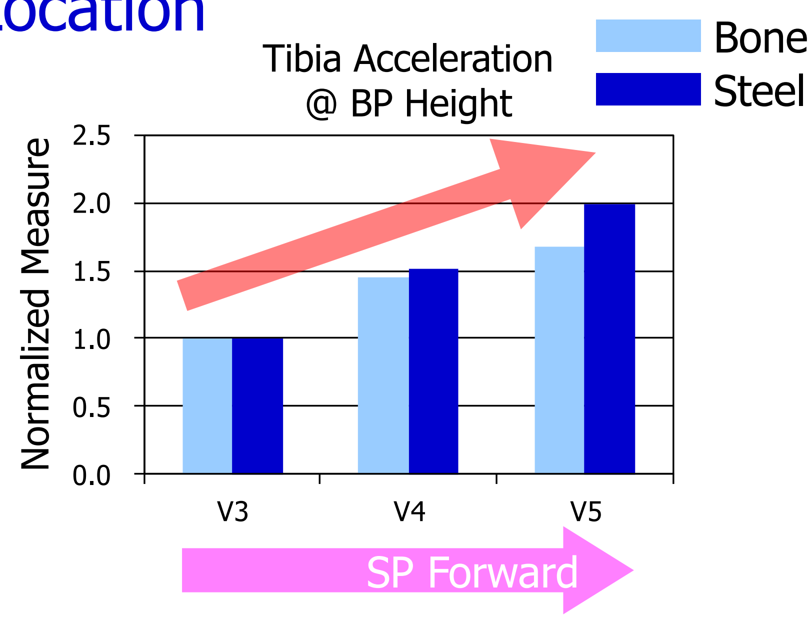
Effect of BP/SP Stiffness





Effect of SP Location

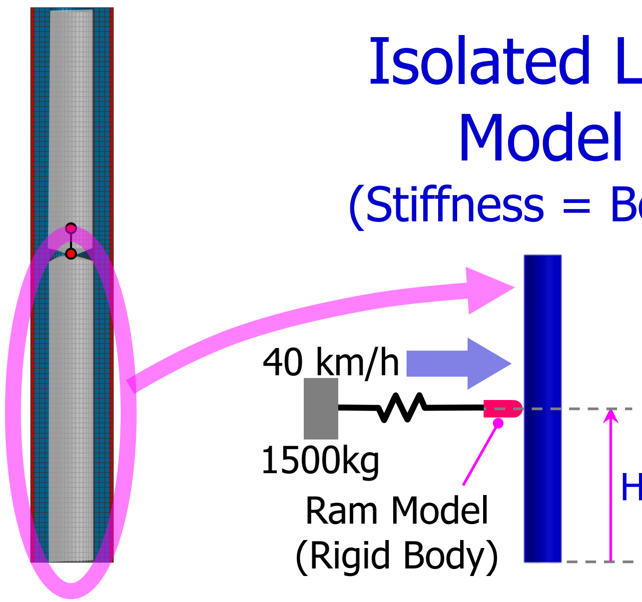




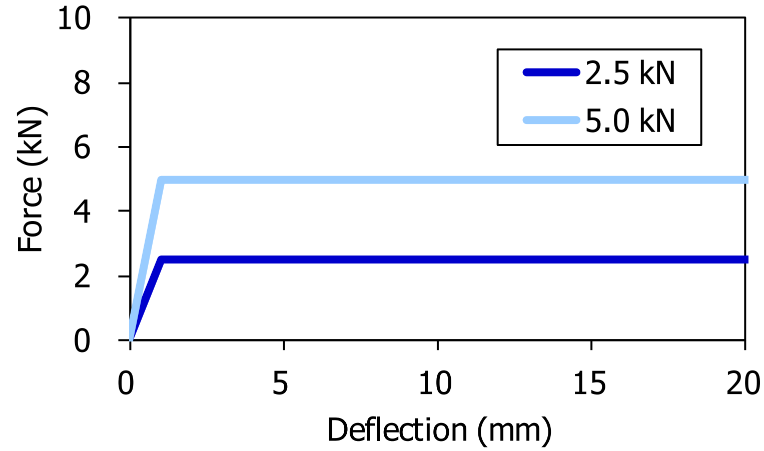
Isolated Leg Impact Simulation

EEVC Legform Model

Isolated Leg Model
(Stiffness = Bone)



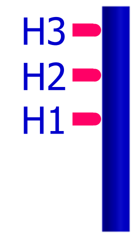
Ram Stiffness Curves

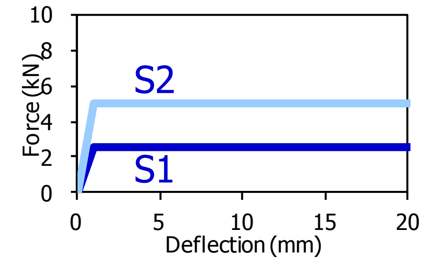


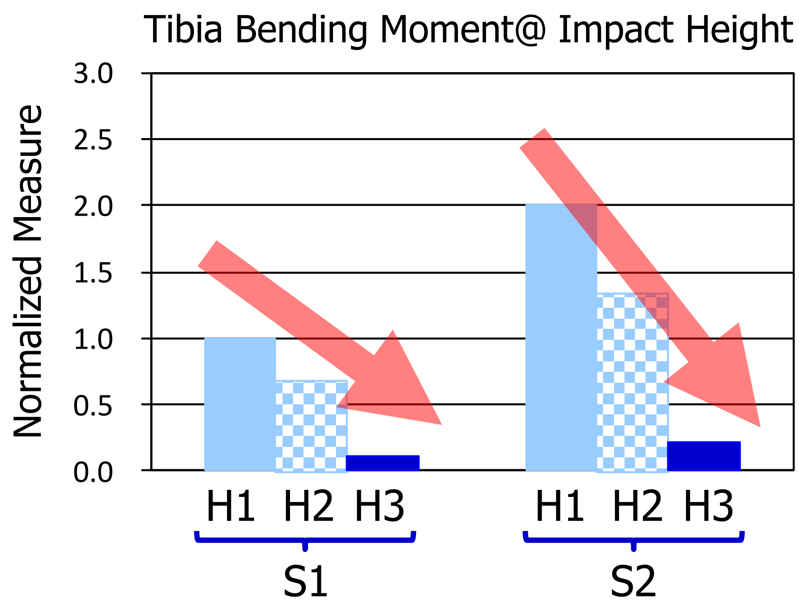
Simulation Matrix

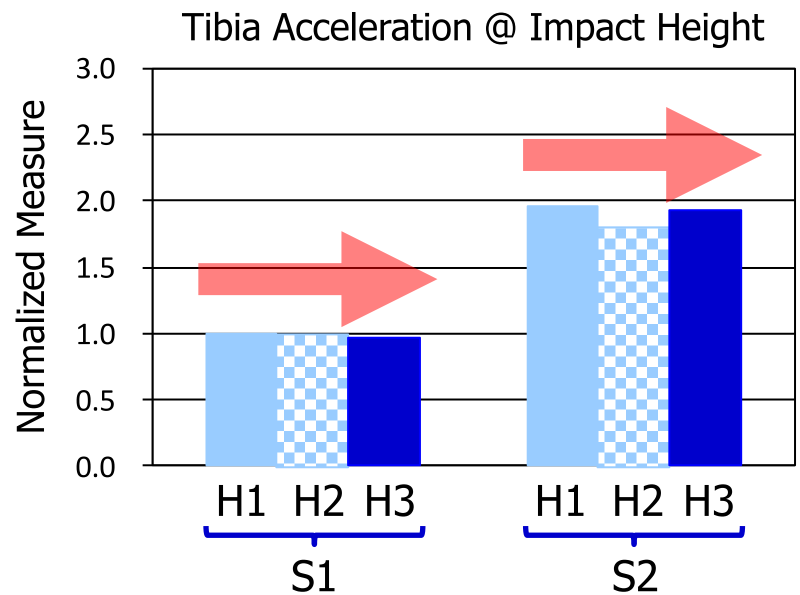
Case	Impact Height (H in mm)	Impactor Stiffness (Force level in kN)	Case	Impact Height (H in mm)	Impactor Stiffness (Force level in kN)
H1-S1	250	2.5	H1-S2	250	5.0
H2-S1	350	2.5	H2-S2	350	5.0
H3-S1	450	2.5	H3-S2	450	5.0

Results









Both bending moment and acceleration are almost two times higher for S2 (5.0 kN) relative to S1 (2.5 kN)

Acceleration does not depend on impact height, while bending moment is highly dependent on impact height

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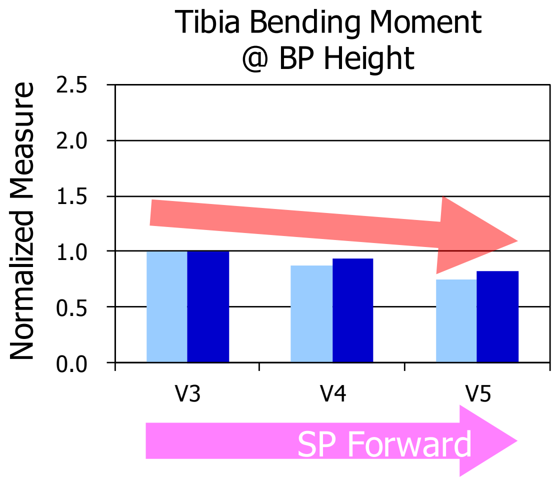
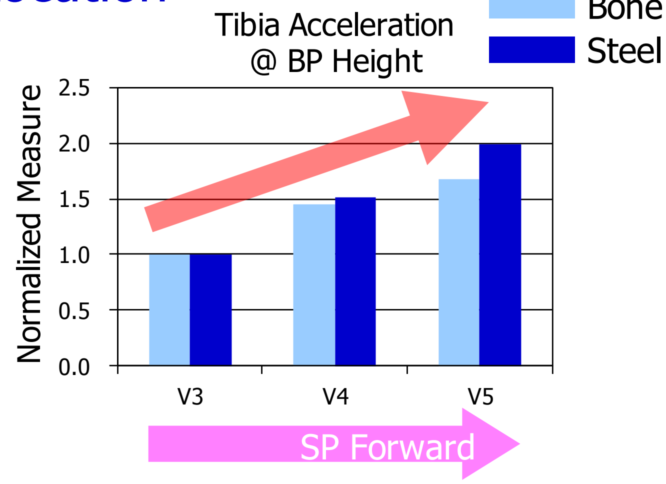
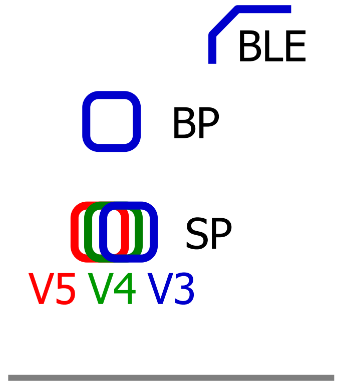
Discussion

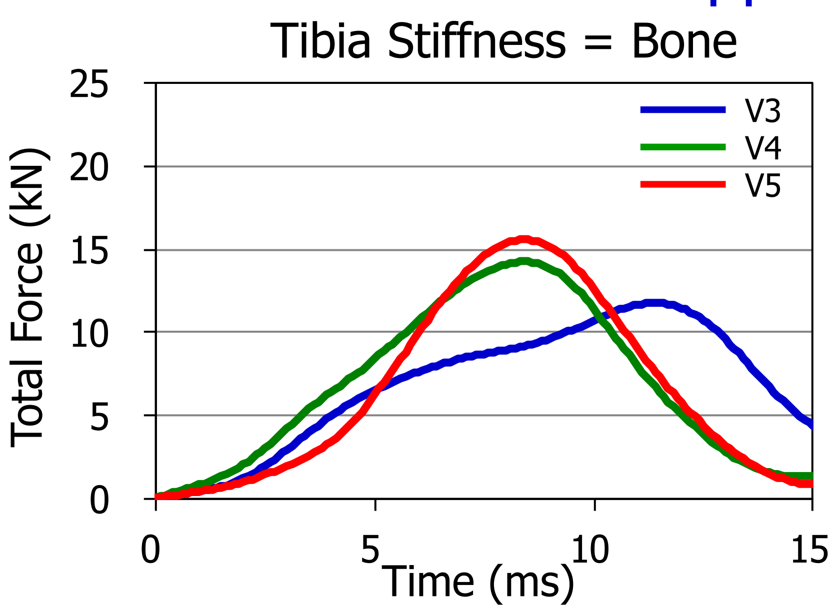
Effect of SP Location

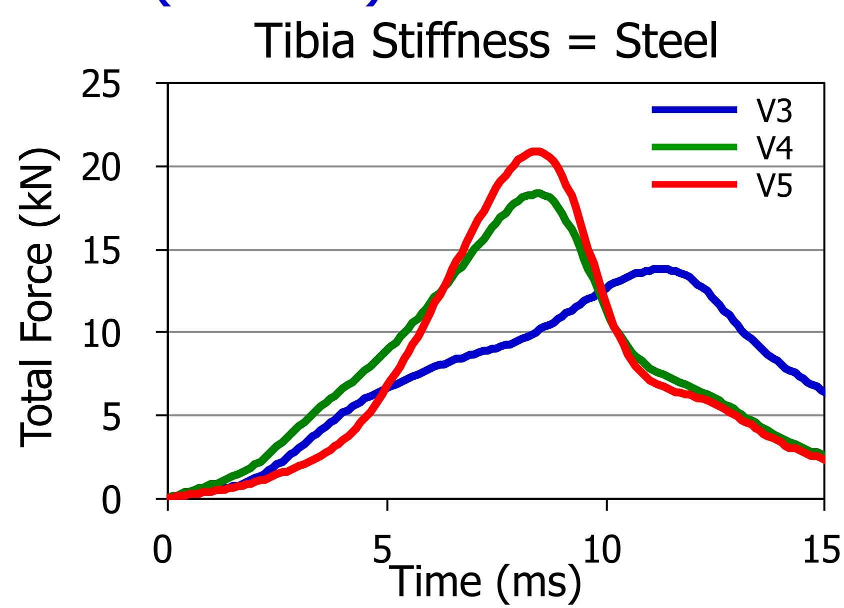




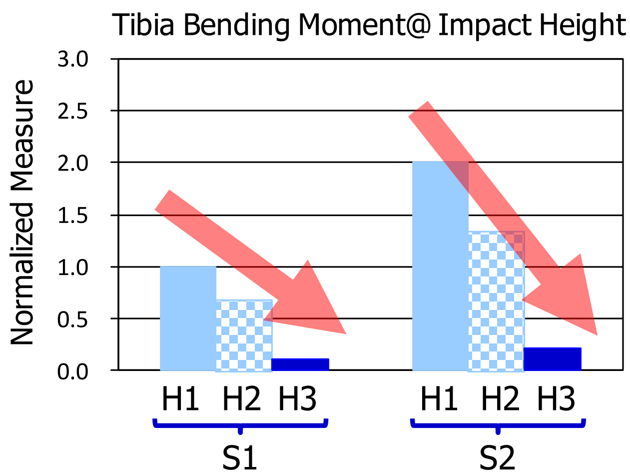


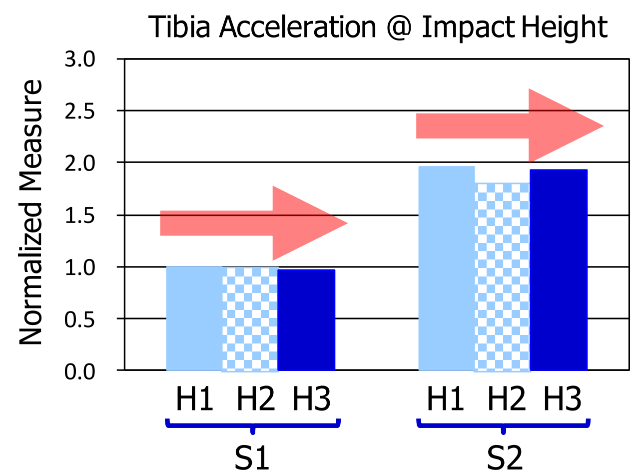
Total Applied Force (BP+SP)





Discussion





Acceleration

Solely determined by applied force magnitude

SP forward → Increased total force → Increased acceleration

Bending Moment

Dependent on both magnitude and location of applied force

SP forward → Increased total force / Lower effective location → Increased moment / Decreased moment

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Conclusions

- Peak tibia bending moment best correlated with peak stress
- Correlation with human injury measures was found to be significantly improved for FlexPLI relative to EEVC legform for tibia fracture and ACL failure measures
- Excessive tibia stiffness resulted in higher sensitivity of tibia fracture measures to vehicle stiffness and geometric characteristics
- Tibia acceleration was found to be solely determined by applied force magnitude, while tibia bending moment depended on both magnitude and location of applied force
- Differences in tibia stiffness and tibia fracture measures resulted in significantly different trend of tibia fracture measures when vehicle geometry was changed

Thank you for your attention

Questions?

HONDA
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