FlexPLI vs. EEVC LFI Correlation

Action List Item 1. j)
Evaluate and decide on performance / injury criteria and threshold values

5th IG GTR9-PH2 Meeting
6-7/December/2012
Japan Automobile Standards Internationalization Center (JASIC)

IWG Questions from NHTSA

GTR9-5-13

GTR9-4-19

Overview of NHTSA Pedestrian Activities

Sept. 17-18, 2012

GTR9-4-19

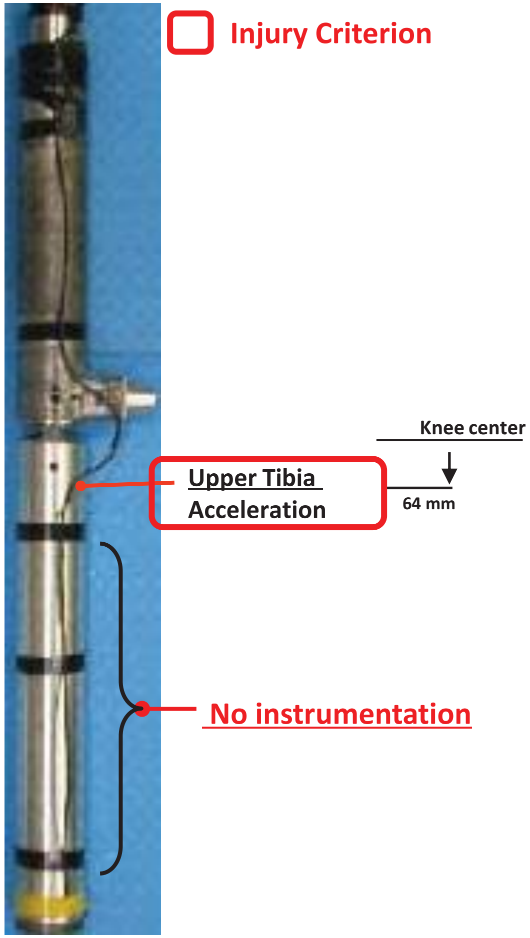
FlexPLI: Injury Criteria

Previous	Current	IWG Question
• Reviewed literature, FlexTEG/IWG Phase 2 studies.	• Testing newer, global vehicles to update baseline fleet performance	• Interested in FlexPLI vs. EEVC LFI correlation results for same vehicles
• While we feel that supporting information is ample, we must first evaluate IC efficacy for NA fleet.	• Part of both round robin and Shape cooperative study	• Concerned about compromise for knee injuries, especially for NA fleet with higher bumpers

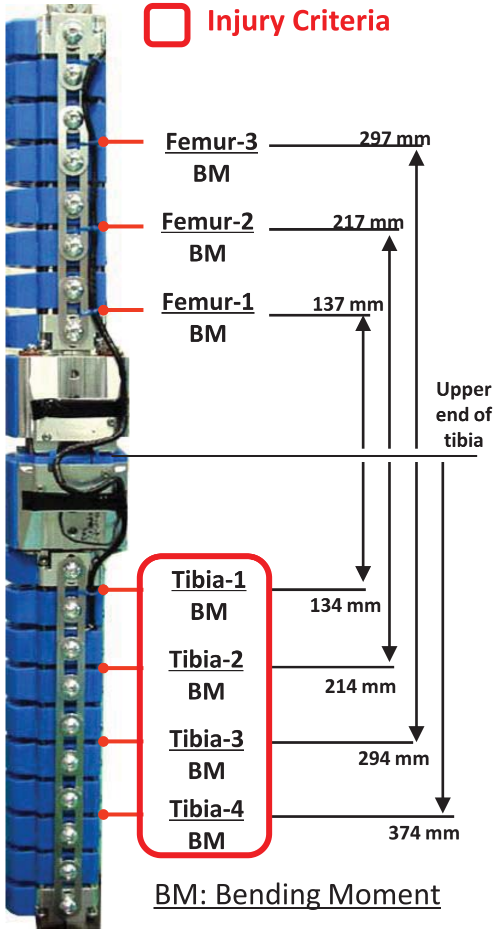
Reference : National Highway Traffic Safety Administration (NHTSA), *Overview of NHTSA Pedestrian Activities*, 4th IG GTR9-PH2 Meeting Document, GTR9-4-19 (2012)

Leg Fracture Evaluation

EEVC LFI



FlexPLI

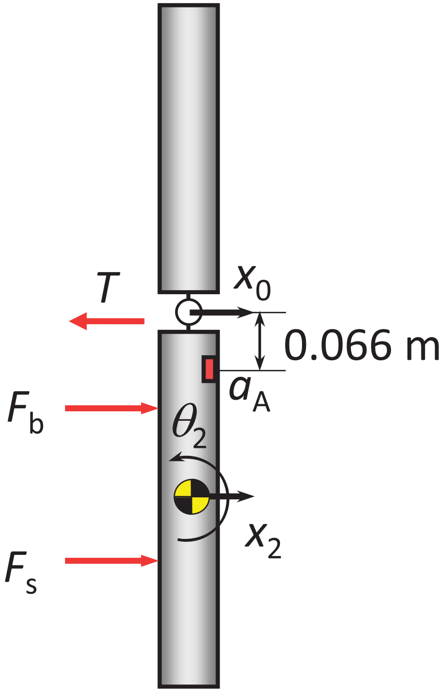


- **EEVC LFI measures upper tibia acceleration at one location**
- **FlexPLI measures tibia bending moment at four locations**

Leg Fracture Evaluation

Mizuno et al. (2012)

EEVC LFI Upper Tibia Acceleration



Equation of Motion of tibia

$$m_2 \ddot{x}_2 = F_b + F_s - T$$

$$a_A = \ddot{x}_0 + 0.066\,\ddot{\theta}_2$$
$$= \ddot{x}_2 - (L_0 - L_2 - 0.066)\,\ddot{\theta}_2$$

$$a_A \approx \ddot{x}_2 \approx \frac{F_b + F_s}{m_2}$$

Tibia acceleration ← **Bumper force** + **Spoiler force**

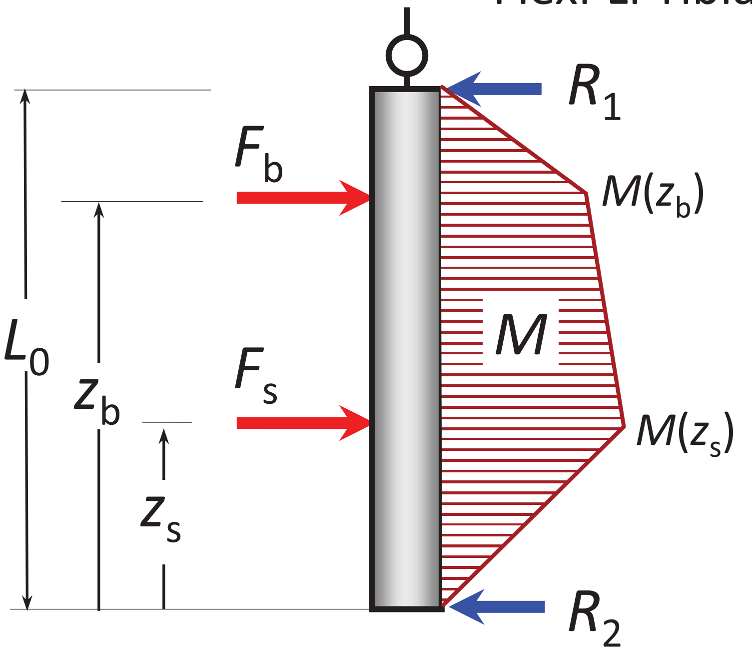
Predominant factor for EEVC LFI upper tibia acceleration → Applied force magnitude

Reference : Mizuno, K. et al., *Comparison of Reponses of the Flex-PLI and TRL Legform Impactors in Pedestrian Tests*, SAE World Congress, SAE Paper #2012-01-0270 (2012)

Leg Fracture Evaluation

Mizuno et al. (2012)

FlexPLI Tibia Bending Moment



Max. tibia bending moment

$$M(z_s) = \frac{F_b(L_0 - z_b) + F_s(L_0 - z_s)}{L_0} z_s$$

$$M(z_b) = \frac{F_b z_b + F_s z_s}{L_0} (L_0 - z_b)$$

$$M_{max} = \max\{ M(z_s), M(z_b) \}$$

Bending moment ← **Bumper and spoiler force** / **Point of force application**

Predominant factor for FlexPLI tibia bending moment
→ Applied force magnitude AND point of force application

Reference : Mizuno, K. et al., *Comparison of Reponses of the Flex-PLI and TRL Legform Impactors in Pedestrian Tests*, SAE World Congress, SAE Paper #2012-01-0270 (2012)

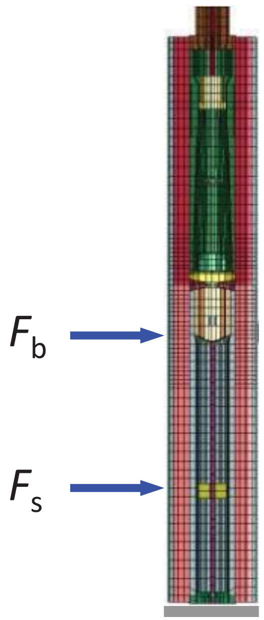
Leg Fracture Evaluation

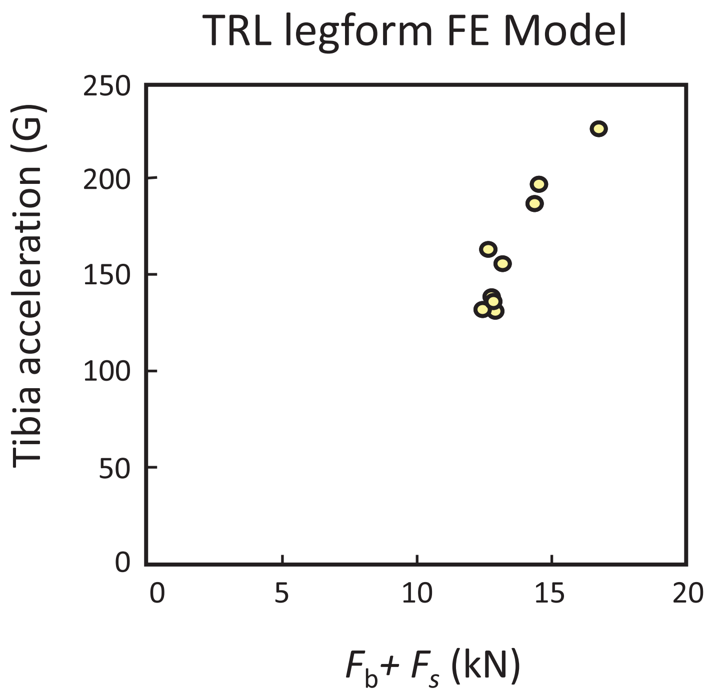
Mizuno et al. (2012)

FE Validation of Predominant Factors for EEVC LFI Upper Tibia Acceleration

Presumed from Rigid body model

Tibia acc. ← **Bumper force** + **Spoiler force**



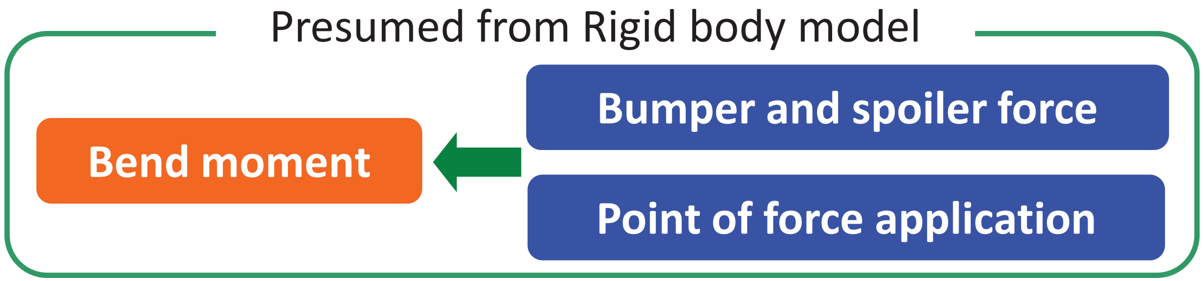


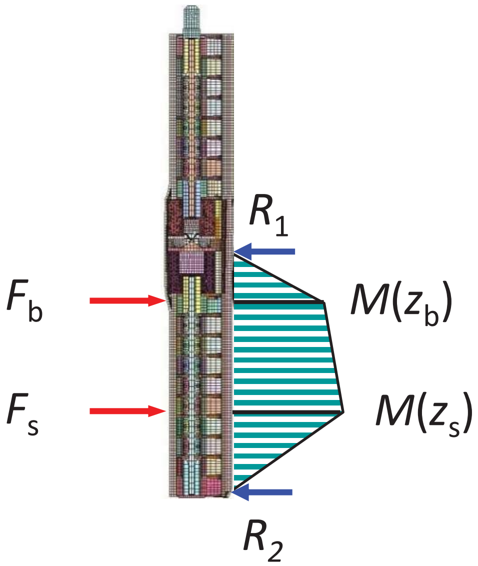
Reference : Mizuno, K. et al., *Comparison of Reponses of the Flex-PLI and TRL Legform Impactors in Pedestrian Tests*, SAE World Congress, SAE Paper #2012-01-0270 (2012)

Leg Fracture Evaluation

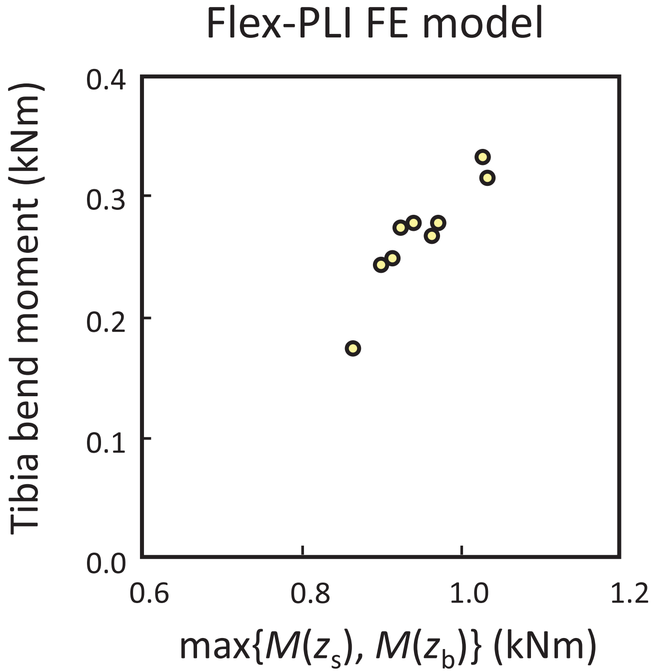
Mizuno et al. (2012)

FE Validation of Predominant Factors for FlexPLI Tibia Bending Moment





Bending moment diagram

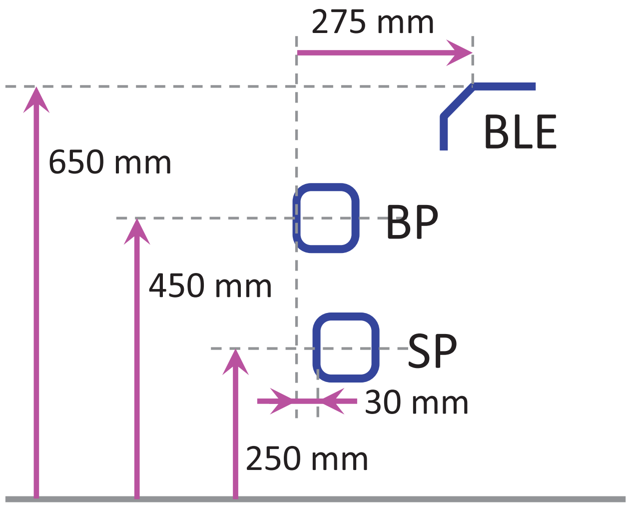


Reference : Mizuno, K. et al., *Comparison of Reponses of the Flex-PLI and TRL Legform Impactors in Pedestrian Tests*, SAE World Congress, SAE Paper #2012-01-0270 (2012)

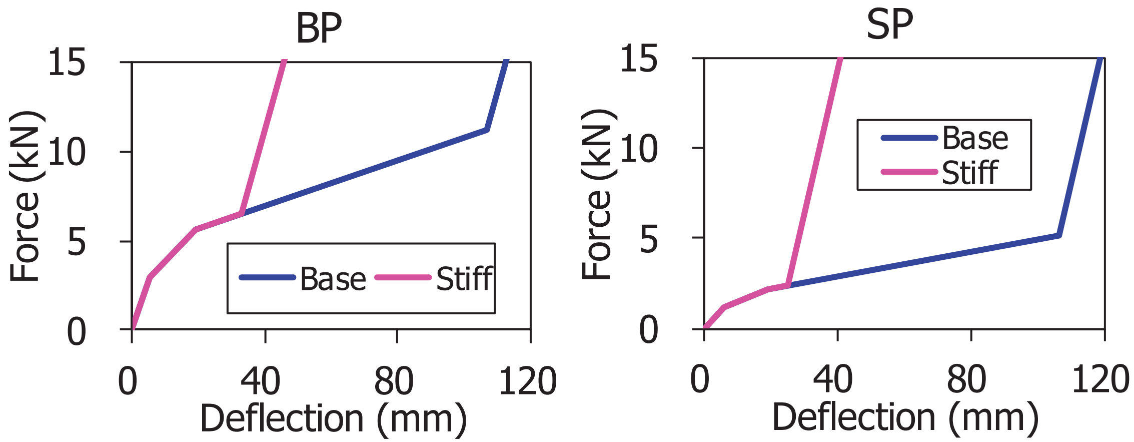
Leg Fracture Evaluation

Takahashi et al. (2012)

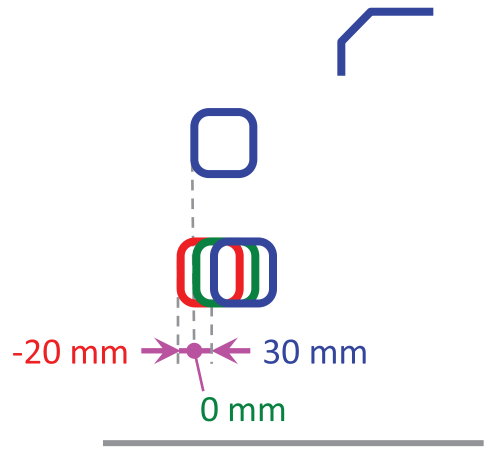
Baseline Model



BP/SP Stiffness



SP Location

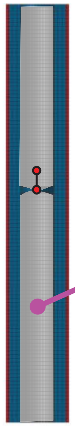


Reference : Takahashi, Y. et al., *Validation of Pedestrian Lower Limb Injury Assessment using Subsystem Impactors*, IRCOBI Conference (2012)

Leg Fracture Evaluation

Takahashi et al. (2012)

EEVC Legform Model



Stiffness of Tibia

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

Simulation Matrix

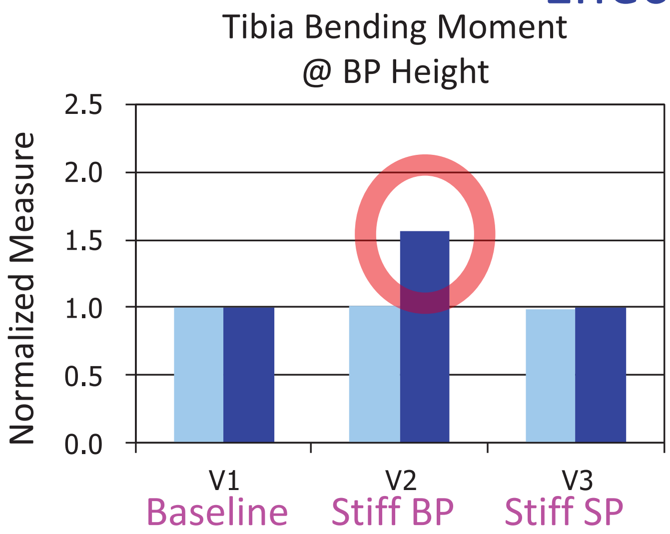
Case	Stiffness			SP Location (L2 in mm)	Case	Stiffness			SP Location (L2 in mm)
	BP	SP	Tibia			BP	SP	Tibia	
^	Base	Base	Bone	30	V1-S	Base	Base	Steel	30
V2-B	Stiff	Base	Bone	30	V2-S	Stiff	Base	Steel	30
V3-B	Base	Stiff	Bone	30	V3-S	Base	Stiff	Steel	30
V4-B	Base	Stiff	Bone	0	V4-S	Base	Stiff	Steel	0
V5-B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

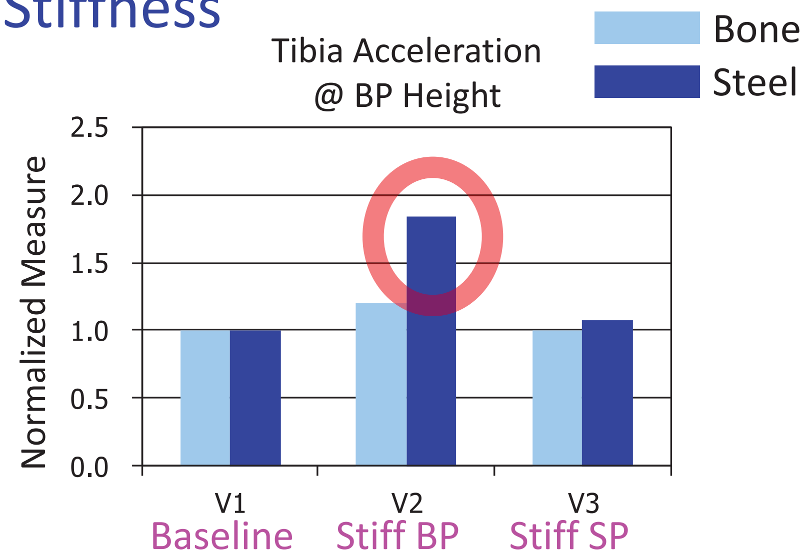
Reference : Takahashi, Y. et al., *Validation of Pedestrian Lower Limb Injury Assessment using Subsystem Impactors*, IRCOBI Conference (2012)

Leg Fracture Evaluation

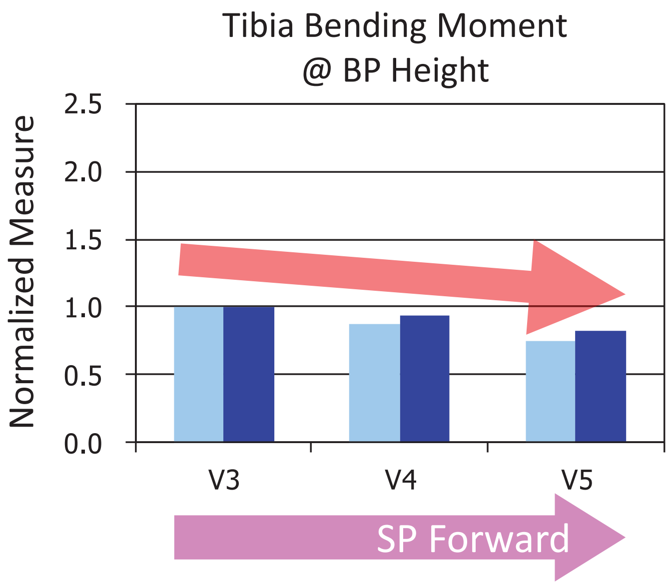
Takahashi et al. (2012)

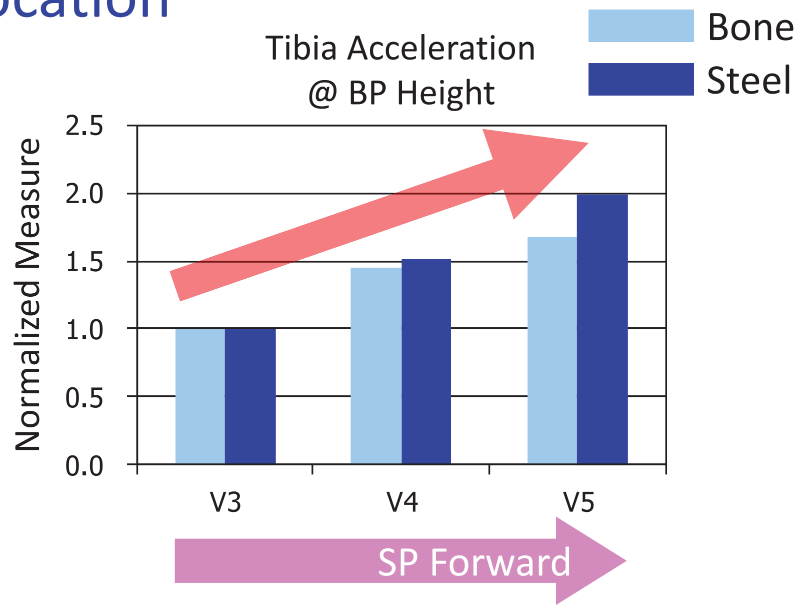
Effect of BP/SP Stiffness





Effect of SP Location





Leg Fracture Evaluation

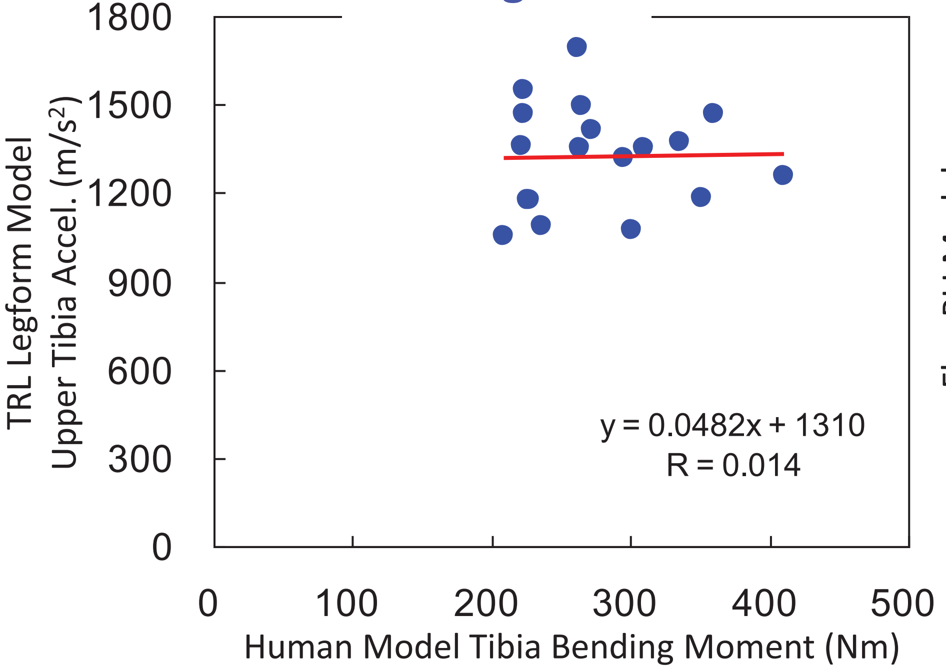
CAE Correlation Study

TEG-096

(Flex-PLI)

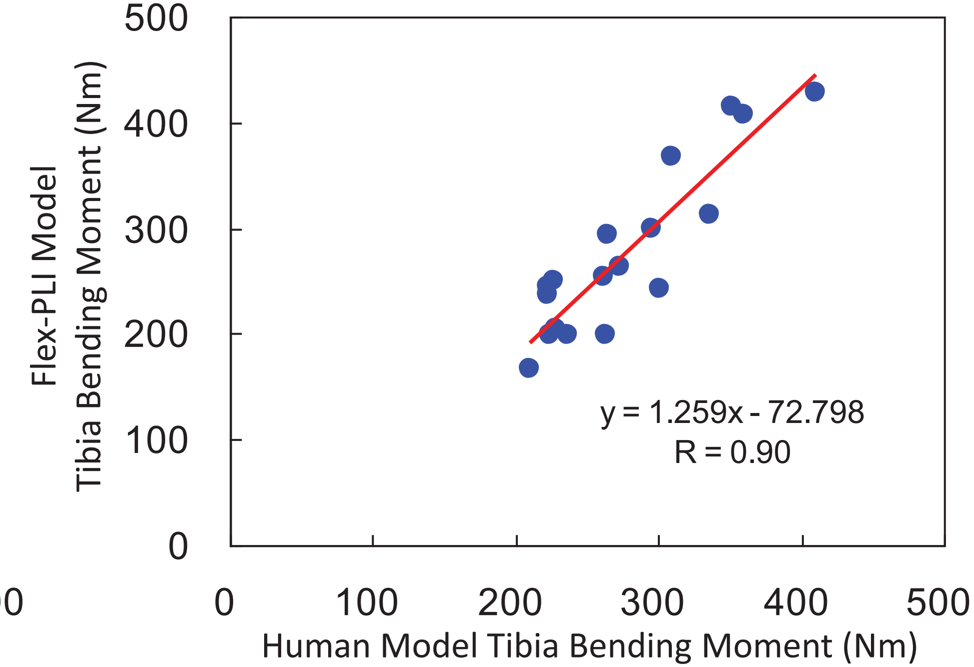
Correlation of Tibia Injury Measures

TRL Legform



Konosu et al. (2009)

Flex-PLI



- **No correlation between TRL legform upper tibia acceleration and human tibia bending moment**
- **Good correlation between Flex-PLI and human tibia bending moment**

Reference : Japan Automobile Standards Internationalization Center (JASIC), *Technical Discussion - Biofidelity*, 1st IG GTR9-PH2 Meeting Document, GTR9-1-05r1 (2011)

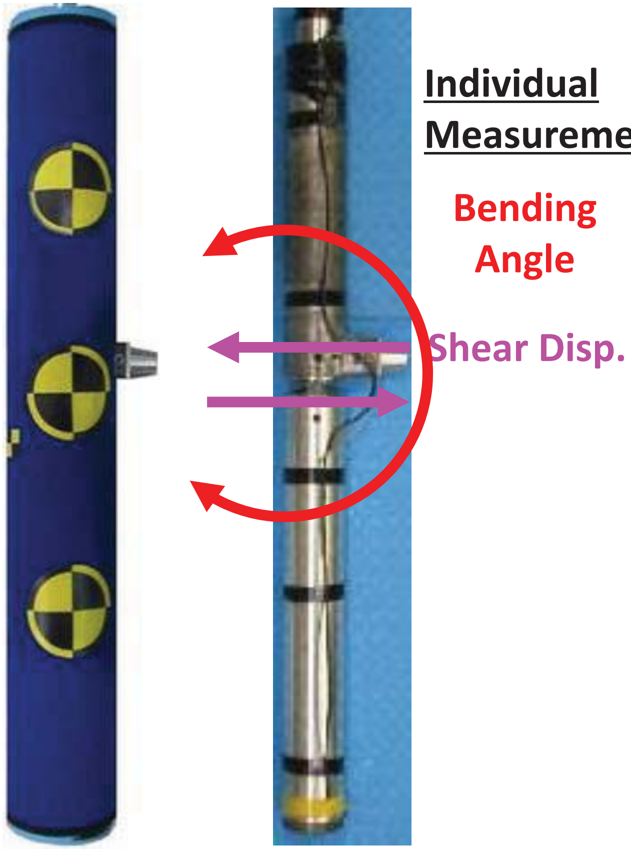
Leg Fracture Evaluation

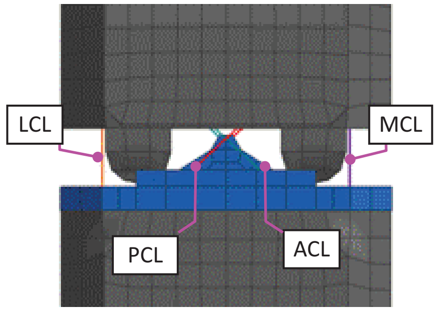
- EEVC LFI upper tibia acceleration is solely determined by the magnitude of applied forces
- FlexPLI tibia bending moment depends on both the magnitude of applied forces and loading locations
- Excessive stiffness of the tibia of EEVC LFI results in much higher sensitivity to the change in the applied force magnitude compared to human bone stiffness
- EEVC LFI upper tibia acceleration shows no correlation with human tibia bending moment due to the use of acceleration as a measure and an excessive stiffness of the tibia
- Direct correlation of EEVC LFI upper tibia acceleration and FlexPLI tibia bending moment makes no sense

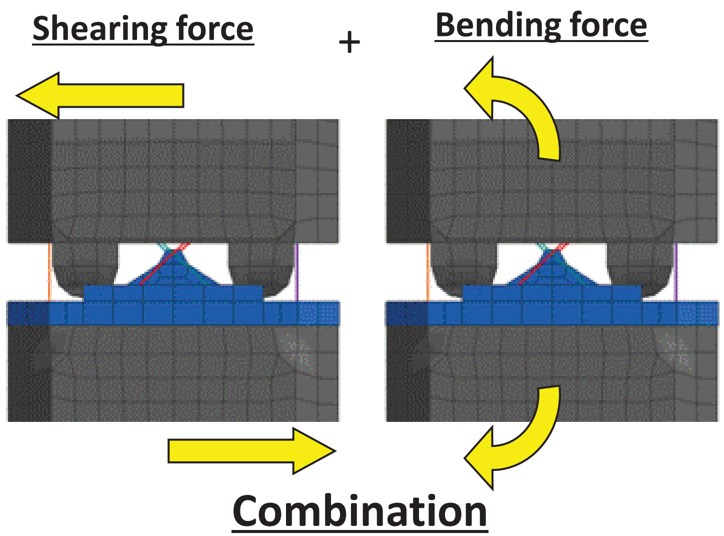
Knee Injury Evaluation

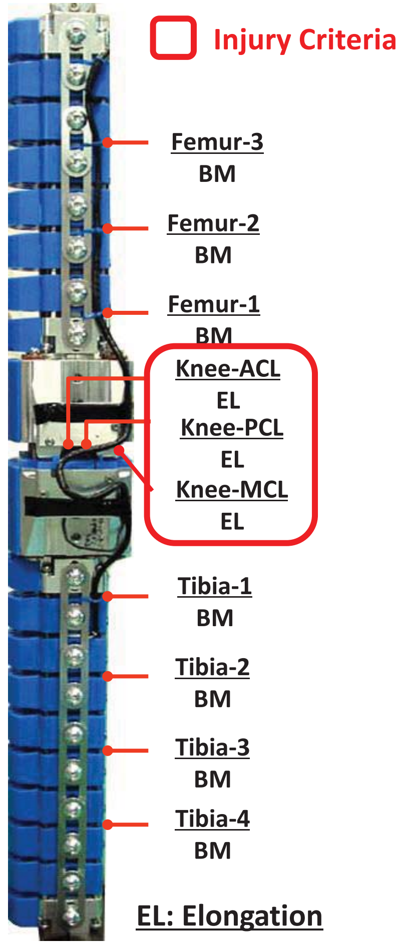
EEVC LFI

FlexPLI







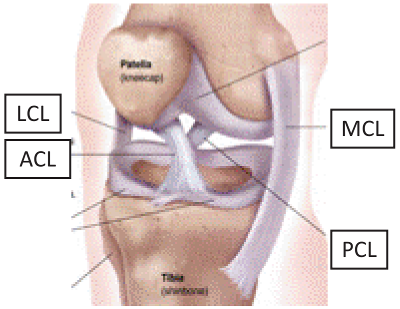


- **EEVC LFI individually evaluates bending and shear**
- **FlexPLI measures elongation of ligaments sensitive to both bending and shear**

Knee Injury Evaluation

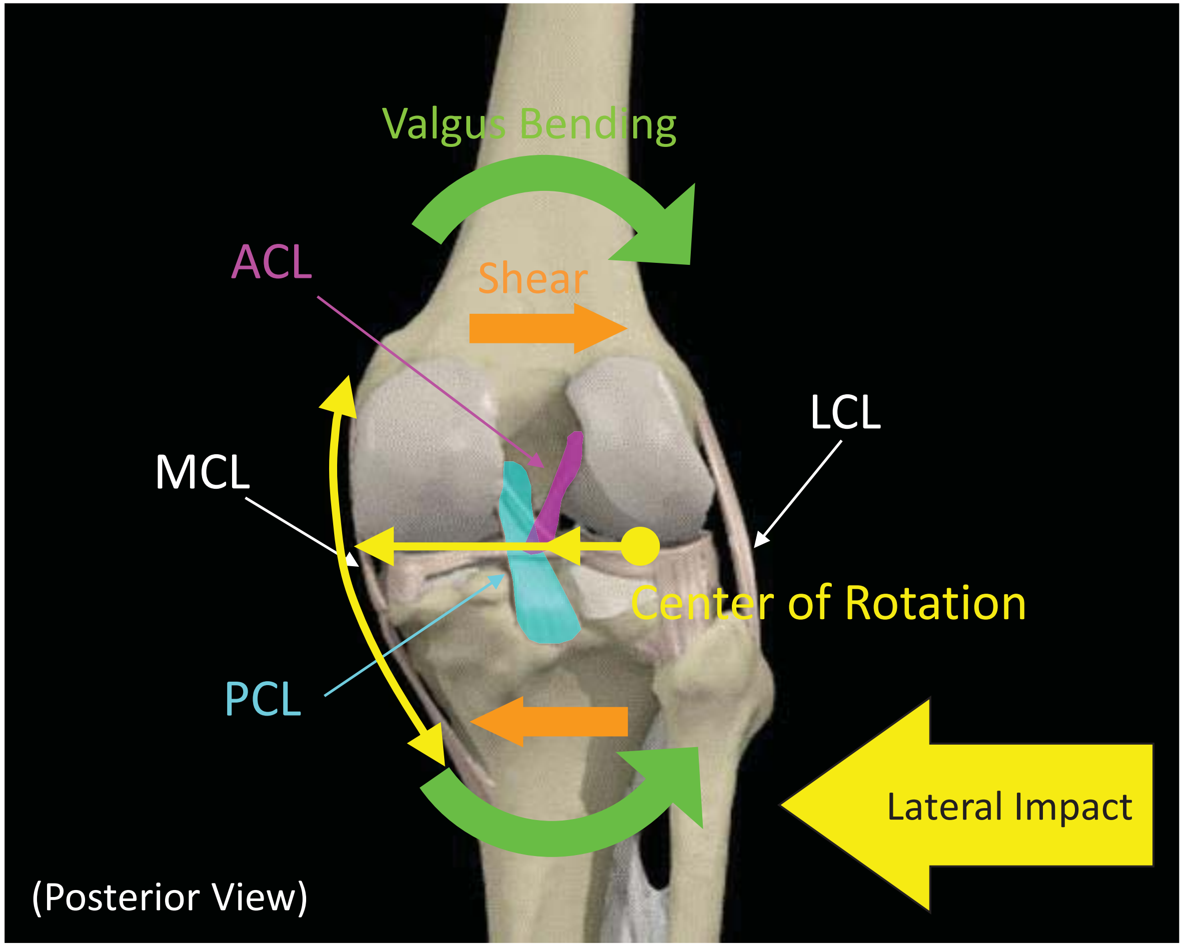
Knee Anatomy

(Anterior-oblique view)



Otte et al. (2005)

MCL: Medial Collateral Ligament
ACL: Anterior Cruciate Ligament
PCL: Posterior Cruciate Ligament
LCL: Lateral Collateral Ligament



- **ACL/PCL elongations are sensitive to both bending and shear**
- **MCL elongation is not sensitive to shear due to its length and distance from center of knee rotation in valgus bending**

GTR9-1-05r1

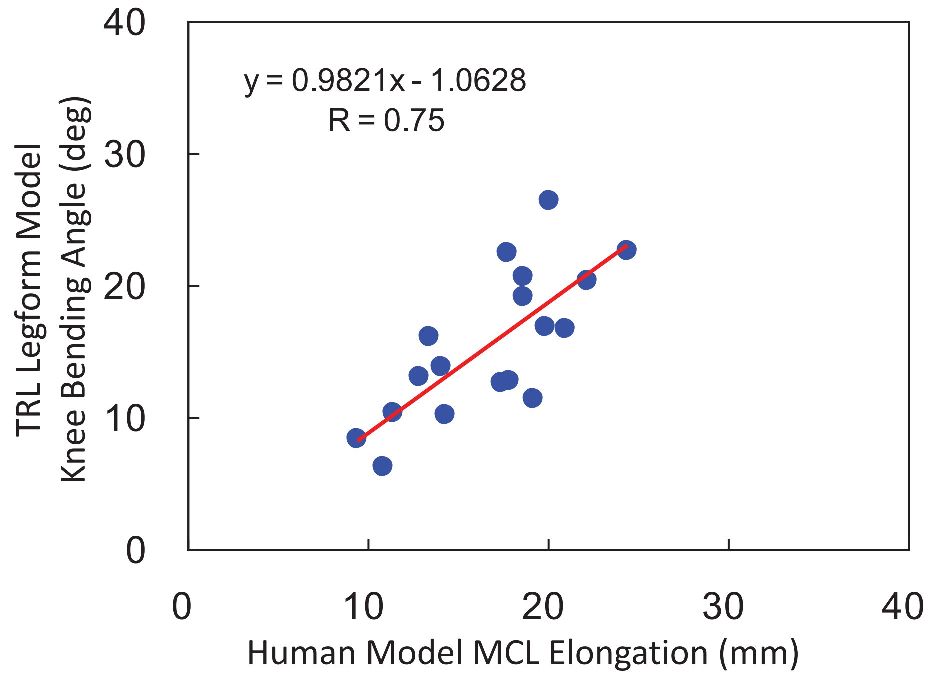
Knee Injury Evaluation

Correlation of MCL Injury Measures

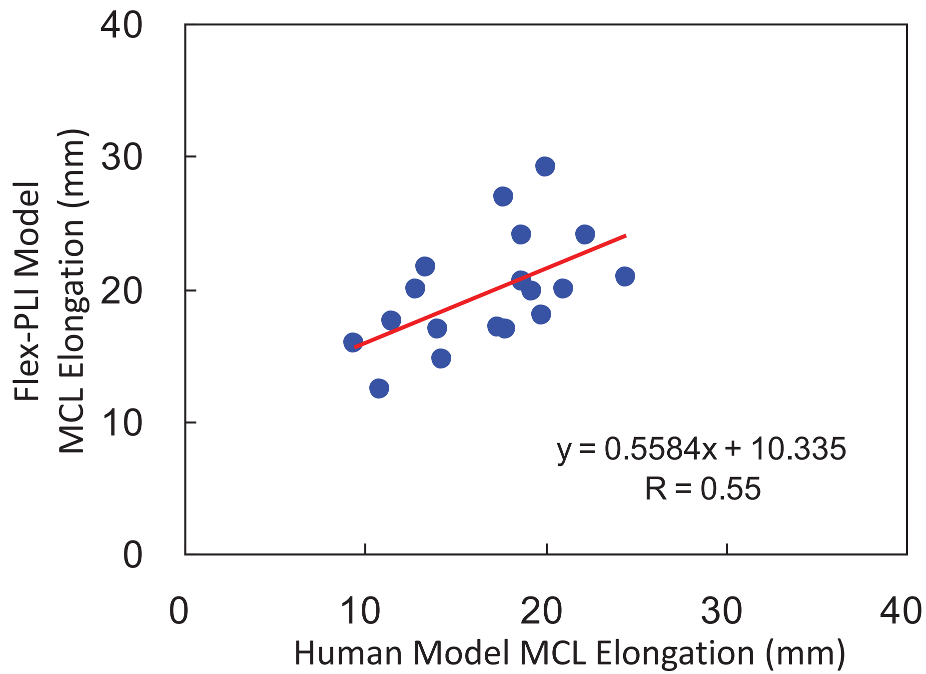
TEG-096

(Flex-PLI)

TRL Legform



Flex-PLI



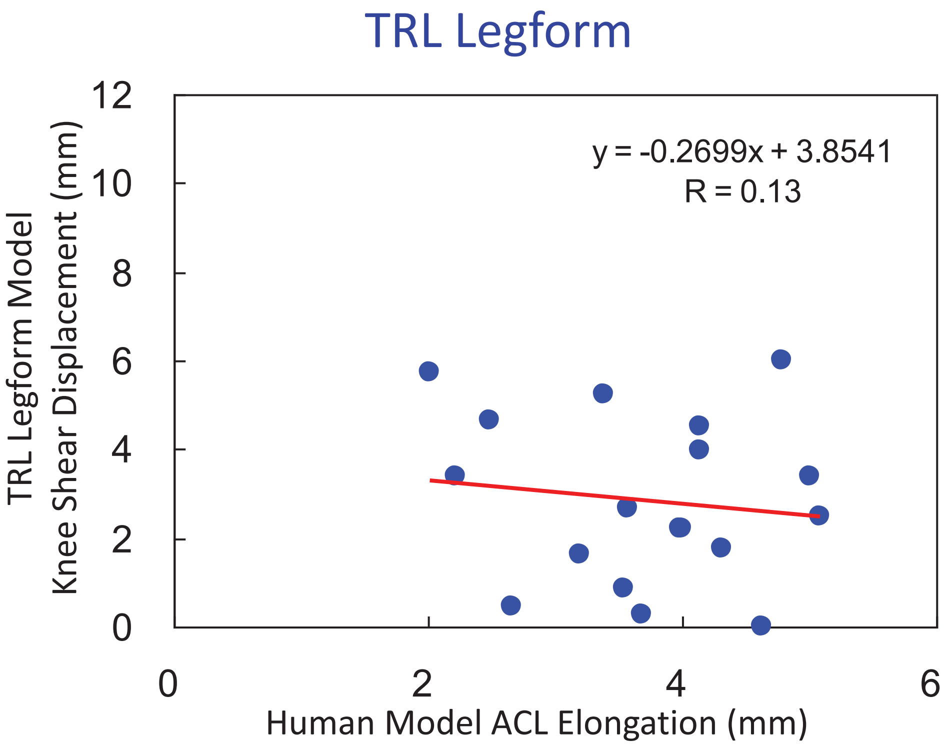
Both TRL legform knee bending angle and Flex-PLI MCL elongation show good correlation with human MCL elongation

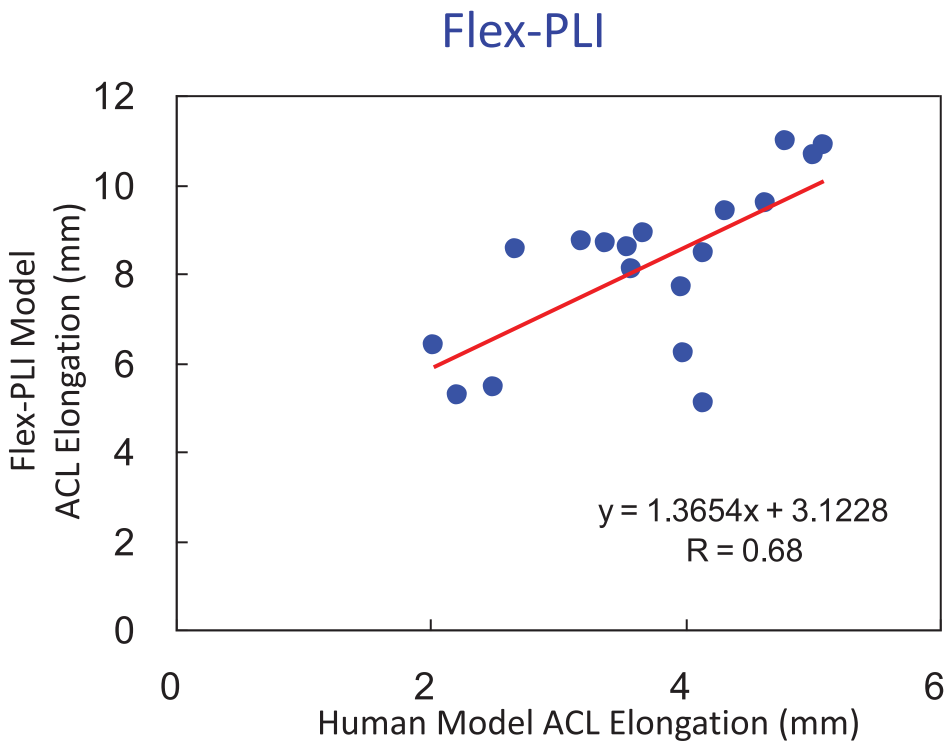
Reference : Japan Automobile Standards Internationalization Center (JASIC), *Technical Discussion - Biofidelity*, 1st IG GTR9-PH2 Meeting Document, GTR9-1-05r1 (2011)

GTR9-1-05r1

Knee Injury Evaluation

Correlation of ACL Injury Measures





- **No correlation between TRL legform knee shear displacement and human ACL elongation**
- **Good correlation between Flex-PLI and human ACL elongation**

Reference : Japan Automobile Standards Internationalization Center (JASIC), *Technical Discussion - Biofidelity*, 1st IG GTR9-PH2 Meeting Document, GTR9-1-05r1 (2011)

Knee Injury Evaluation

- EEVC LFI individually evaluates knee bending and shear
- FlexPLI directly evaluates elongations of knee ligaments
- Human MCL elongation is insensitive to knee shear due to its length and the distance from the center of knee rotation
- Both EEVC LFI and FlexPLI correlate with human MCL elongation
- EEVC LFI knee shear does not correlate with human ACL elongation due to sensitivity of human ACL elongation to knee bending angle
- Correlation analysis between EEVC LFI knee shear displacement and FlexPLI ACL elongation does not make sense, while correlation analysis between EEVC LFI knee bending angle and FlexPLI MCL elongation is valid

GTR9-4-18

GTR9-5-13

Correlation Study - MCL

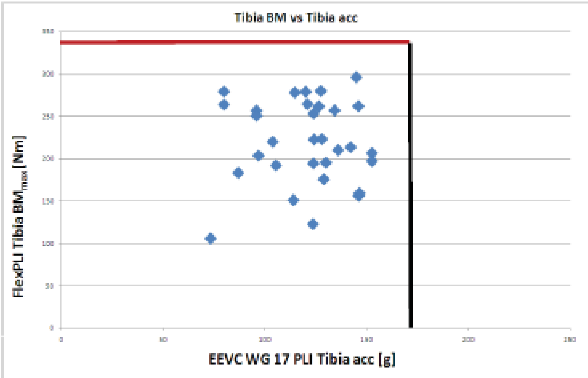
BASt Study

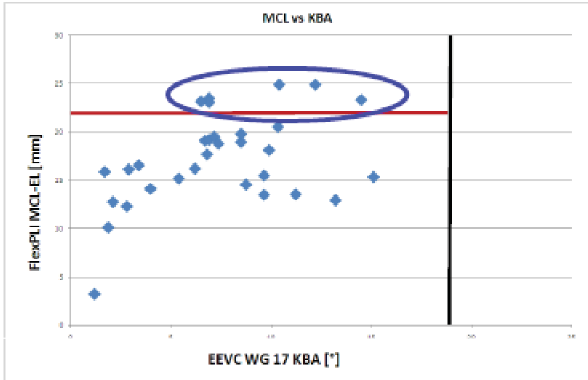
GTR9-4-18

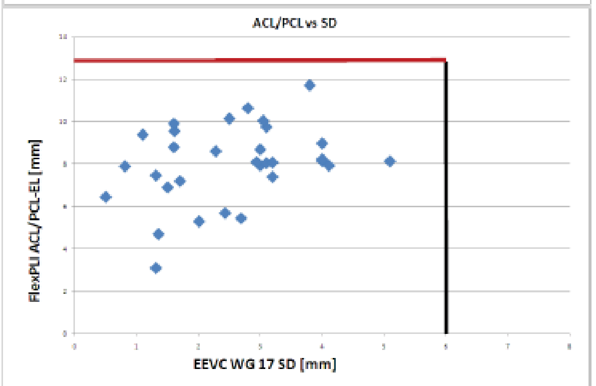
Legform Back2Back Testing

bast

Euro NCAP SG Pedestrian Safety - EEVC WG 17 PLI & FlexPLIBack2back tests:







- **Meeting the proposed FlexPLI draft legal limits leads to still meeting all current (EEVC WG 17 PLI) legal requirements**

BUT:

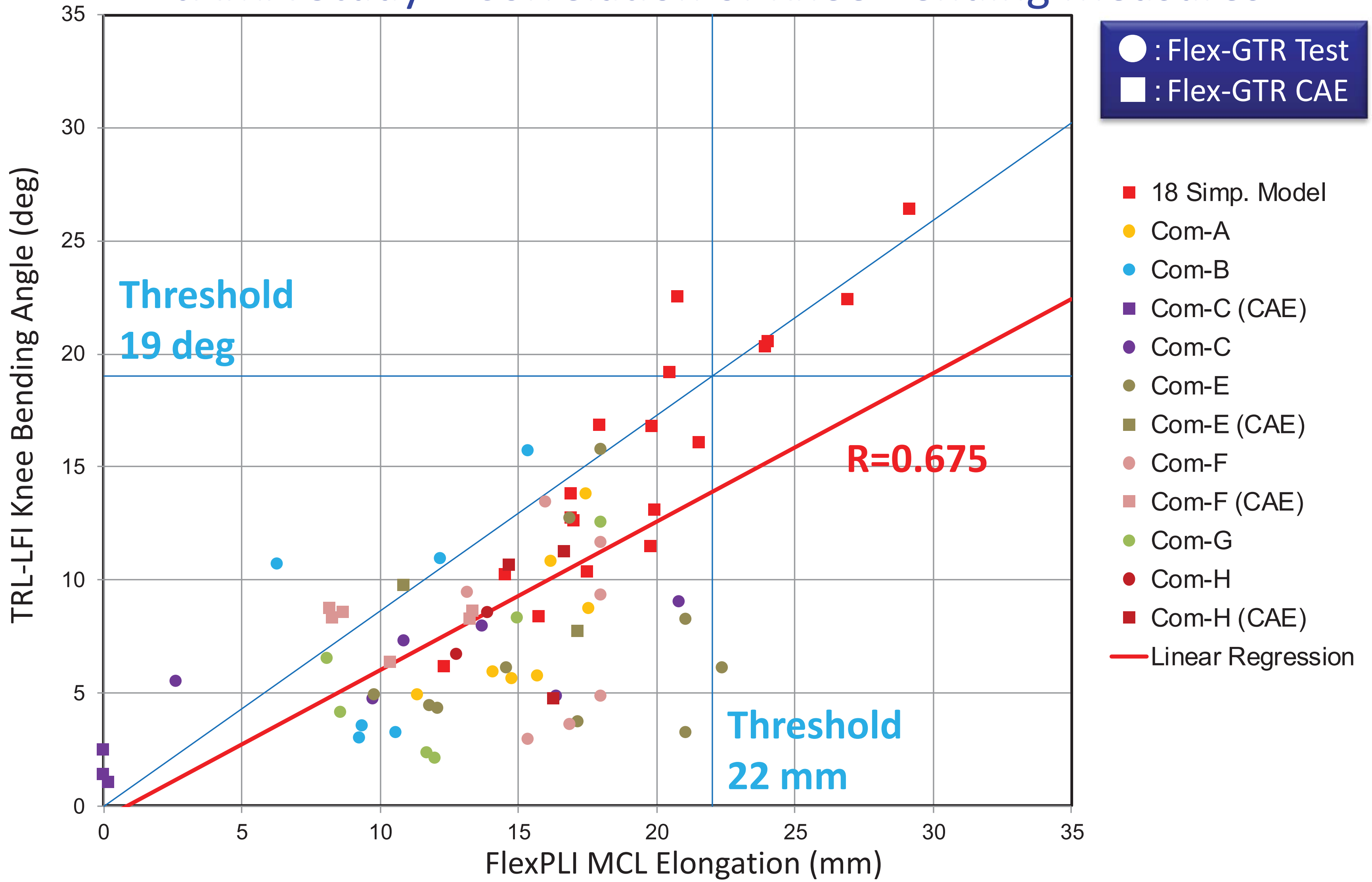
- **Meeting the current (EEVC WG 17 PLI) legal requirements does not always lead to meeting the FlexPLI draft legal limits !!!**

Oliver Zander September 17th-19th, 2012 Slide No. 6

Reference : BASt, *FlexPLI vs. EEVC WG 17 PLI Benefit Estimation*, 4th IG GTR9-PH2 Meeting Document, GTR9-4-18 (2012)

Correlation Study - MCL

JAMA Study – Correlation of Knee Bending Measures



FlexPLI tends to provide more conservative results than EEVC LFI

References

- National Highway Traffic Safety Administration (NHTSA), *Overview of NHTSA Pedestrian Activities*, 4th IG GTR9-PH2 Meeting Document, GTR9-4-19 (2012)
- Mizuno, K. et al., Comparison of Reponses of the Flex-PLI and TRL Legform Impactors in Pedestrian Tests, SAE World Congress, SAE Paper #2012-01-0270 (2012)
- Takahashi, Y. et al., Validation of Pedestrian Lower Limb Injury Assessment using Subsystem Impactors, IRCOBI Conference (2012)
- Japan Automobile Standards Internationalization Center (JASIC), Technical Discussion - Biofidelity, 1st IG GTR9-PH2 Meeting Document, GTR9-1-05r1 (2011)
- BASt, FlexPLI vs. EEVC WG 17 PLI Benefit Estimation, 4th IG GTR9-PH2 Meeting Document, GTR9-4-18 (2012)

Thank you for your attention