Proposal for Procedure to Process FlexPLI Measurements in Rebound Phase

Action List Item 1. f)
Test procedure (rebound phase, best practice, velocity measurement etc.)

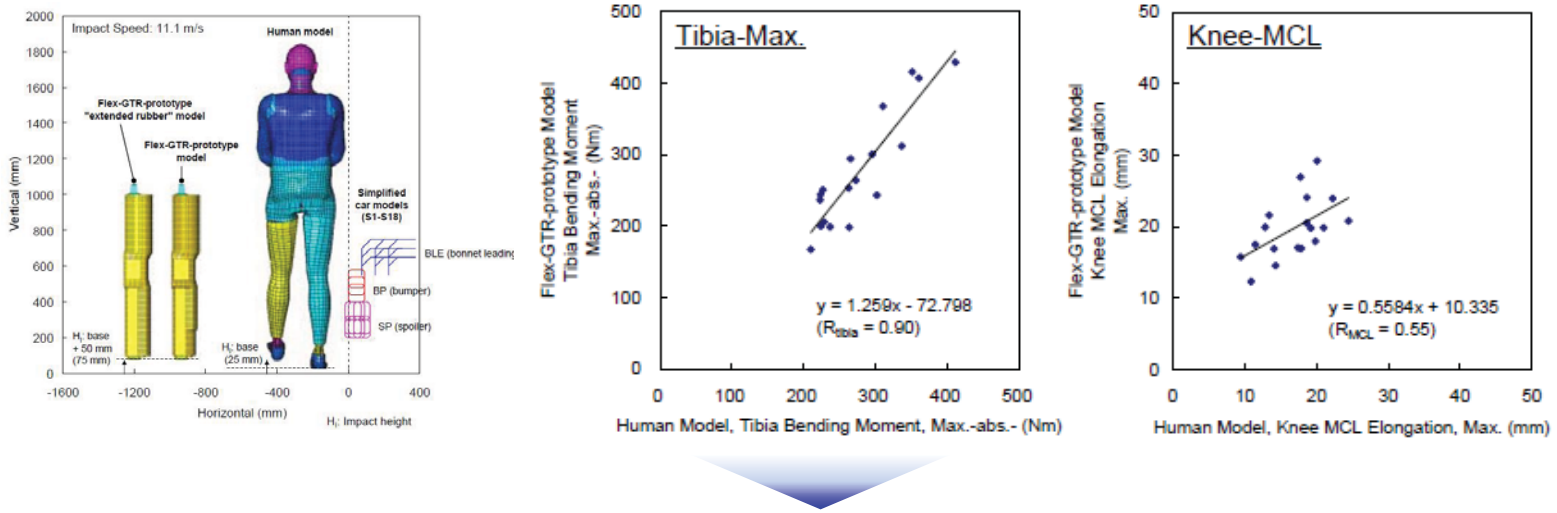
Presented by the pedestrian safety experts of the International Automobile Manufacturers' Organization (OICA)

5th IG GTR9-PH2 Meeting
6-7/December/2012

Background

The biofidelity of the FlexPLI has been validated by comparing its impact responses against simplified vehicle models with those of a human FE model.

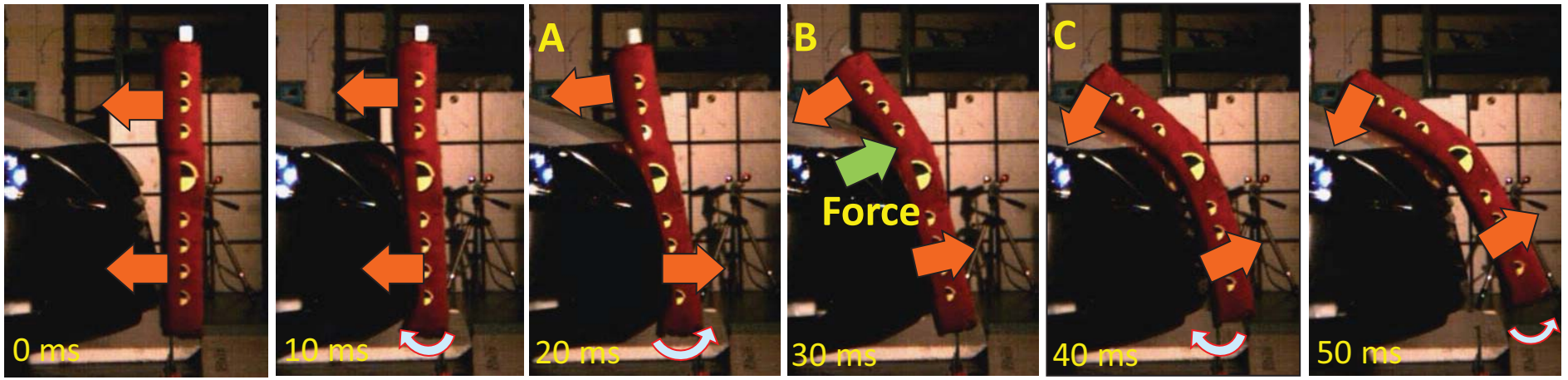
Biofidelity Evaluation using FE Models



Good correlation with the human model for tibia bending moment and MCL elongation

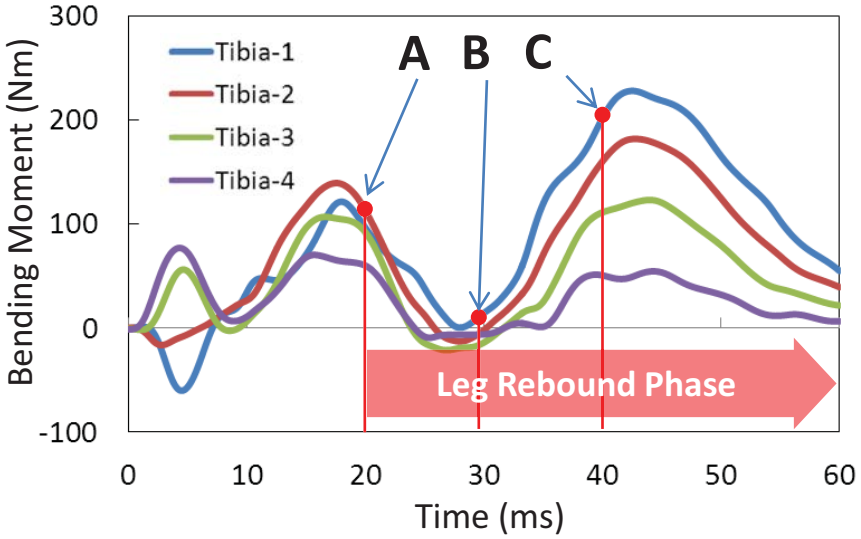
- However, some exceptional cases have been rarely seen that would require special processing of the measurements.
- Since the FlexPLI consists of elastic bone cores and ligament springs, a vibration may occur in the rebound phase of a car test, which could affect peak values of the injury measurements.
- The goal of this proposal is to come up with an appropriate assessment protocol by clarifying the time range where the vibration affects the results.

Example



Kinematics of whole legform
Leg bending direction

Tibia Bending Moment Time History



A Legform starts to rotate due to force from lower part of bumper

B Force is applied from BLE to Femur of rotating legform

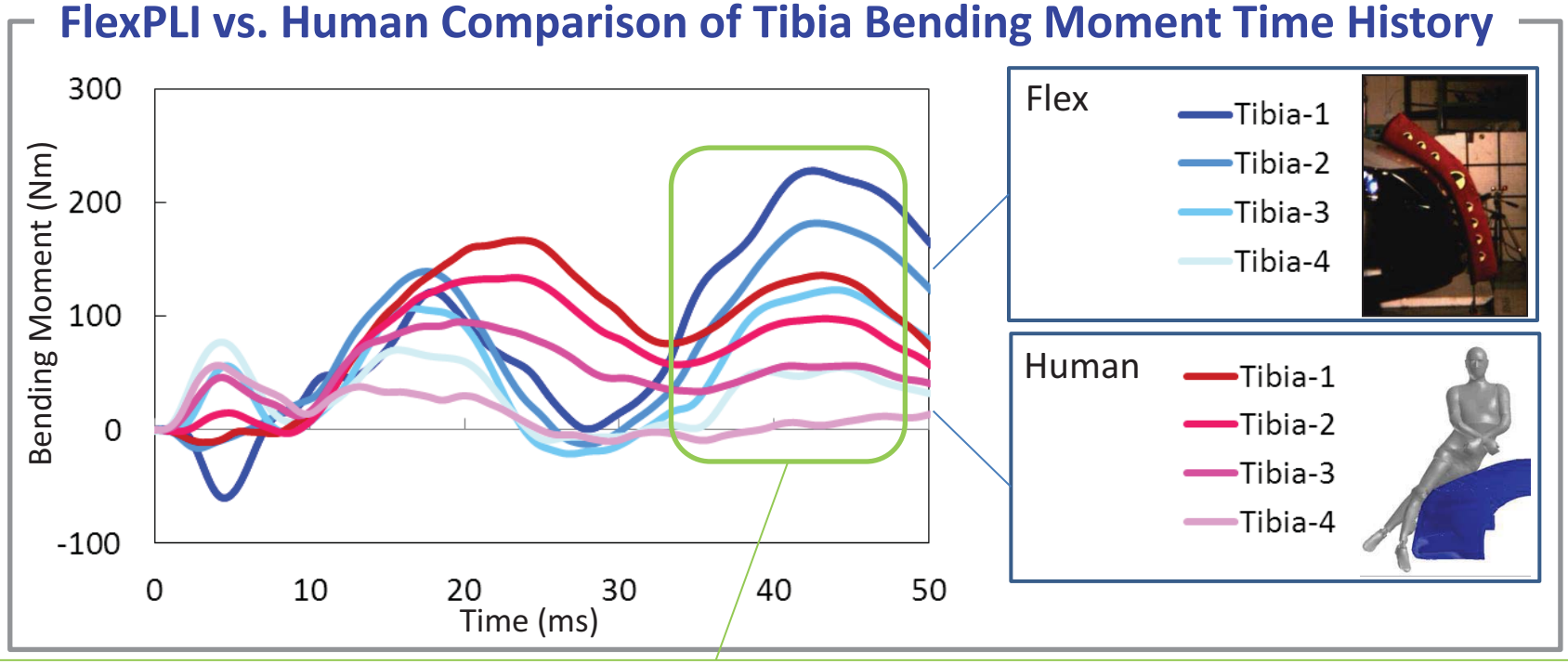
C 'Secondary' peak occurs when force to femur is transmitted to tibia via knee ligaments

Overall peak of the tibia bending moment occurs at the timing when the leg is moving away from the vehicle during the rebound phase

Comparison with Human Response

Tibia bending moment time histories were compared between FlexPLI and human FE models for the same vehicle.

FlexPLI vs. Human Comparison of Tibia Bending Moment Time History



- Human model also exhibits bending moment increase during the rebound phase but overall peak bending moment is determined during vehicle interaction
- FlexPLI overestimates 'Secondary' peak and overall peak is determined in the rebound phase

Although human tibia also shows a 'secondary' peak of the tibia bending moment in the rebound phase, the FlexPLI overestimates it and the overall peak is determined in the rebound phase in some limited cases

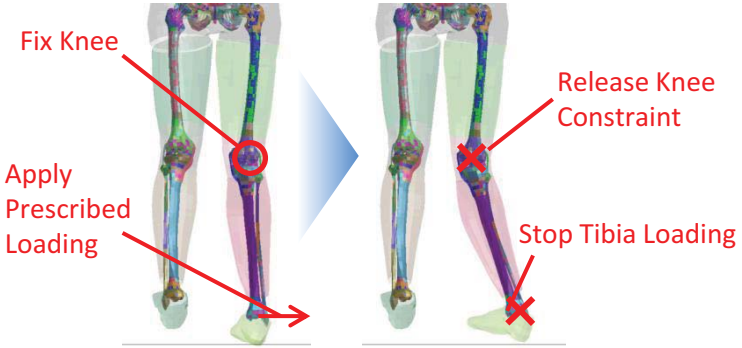
Estimation of Maximum Human Bending Moment in Rebound Phase

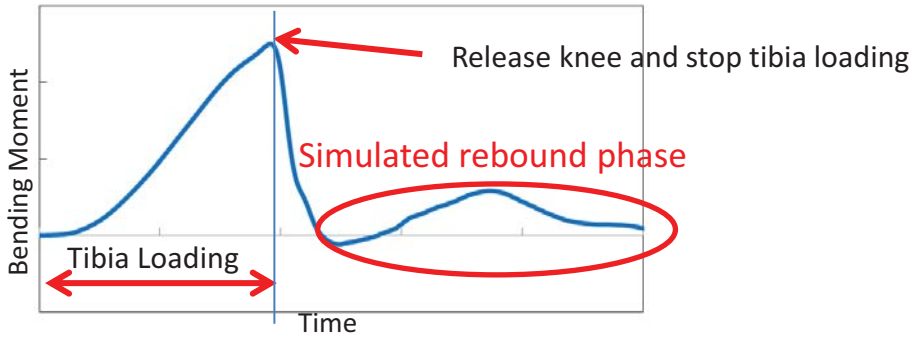
The largest possible tibia bending moment due to femur loading in the rebound phase was examined using a human FE model.

Methodology

1. Prescribed Tibia Loading

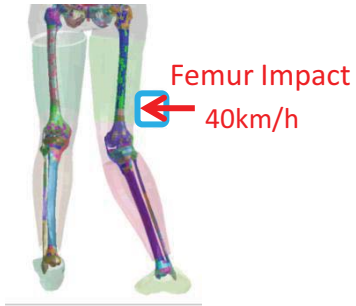
- Prescribed load was applied to the tibia laterally with the knee fixed to represent bumper loading
- Then release the knee and stop tibia loading to represent 'rebound'

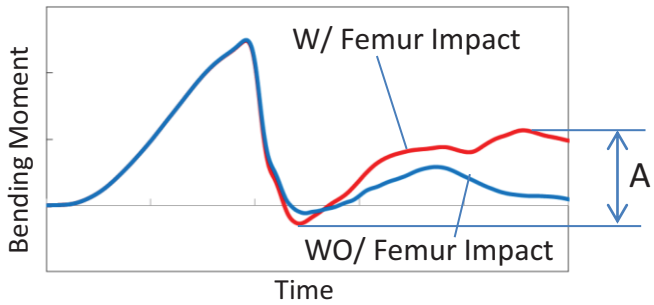




2. Femur Loading

- Femur was loaded from an impactor at 40 km/h in the simulated rebound phase to investigate bending moment increase in this phase (moment difference A in the figure below)
- Peak MCL eningation was limited to 19 mm, which corresponds to 22 mm of proposed FlexPLI limit



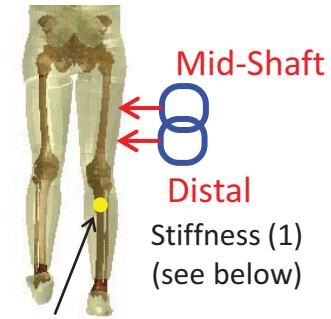


Estimation of Maximum Human Bending Moment in Rebound Phase

Results

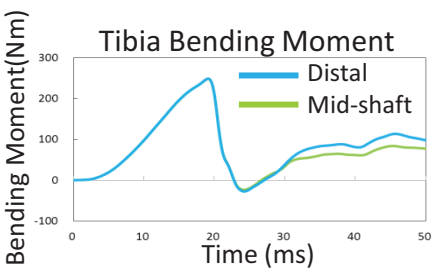
1. Effect of Femur Loading Location

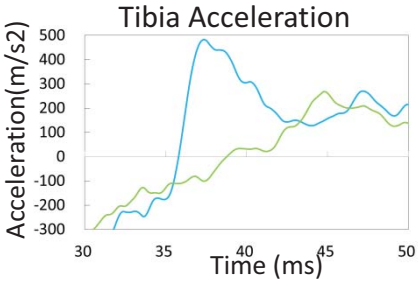
- Compare mid-shaft and distal femur loadings



Results

Location	A (Nm)
Mid-shaft	107
Distal	141

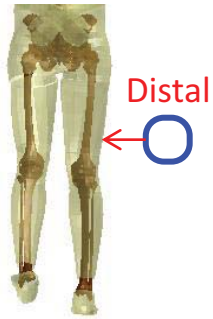




Distal femur loading provided higher secondary peak in the simulated rebound phase

2. Effect of Stiffness of Impactor Simulating BLE

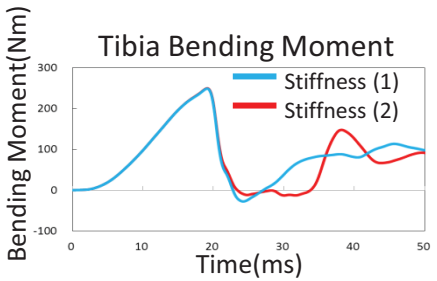
- Vary stiffness of impactor simulating BLE

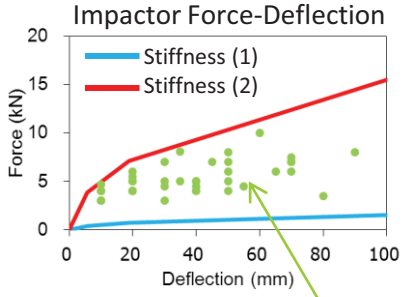


Results

Stiffness	A (Nm)
(1)	141
(2)	160

Stiffness (2) was determined to cover all the maximum force and deflection plots





- Peak force and deflection from BLE tests against passenger cars

Stiffer impactor provided higher secondary peak in the simulated rebound phase

Estimation of Maximum Human Bending Moment in Rebound Phase

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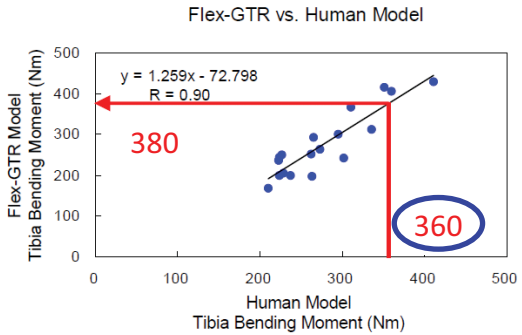
Results

3. Effect of Prescribed Tibia Loading Magnitude

- Prescribed tibia loading increased to 360 Nm, which corresponds to proposed limit for relaxation zone (380 Nm)

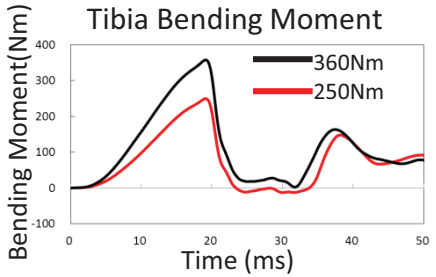
FlexPLI – Human Tibia BM Correlation



Results

Moment	A (Nm)
250 Nm	160
360 Nm	161

Tibia Bending Moment



Insignificant influence of magnitude of prescribed tibia loading simulating vehicle impact

Worst case scenario provided tibia bending moment increase of 161 Nm in the simulated rebound phase

Proposed Protocol

The following protocol is proposed based upon the results of the investigation for the maximum possible bending moment in the rebound phase using a human model.

Proposal

In the cases where all of the following conditions (1) through (3) apply, tibia bending moment time histories shall be used up to the timing of the local minimum value between the maximum before 30 ms and the maximum after 30 ms. The timing shall be determined using the channel providing the maximum value of the four channels after 30 ms.

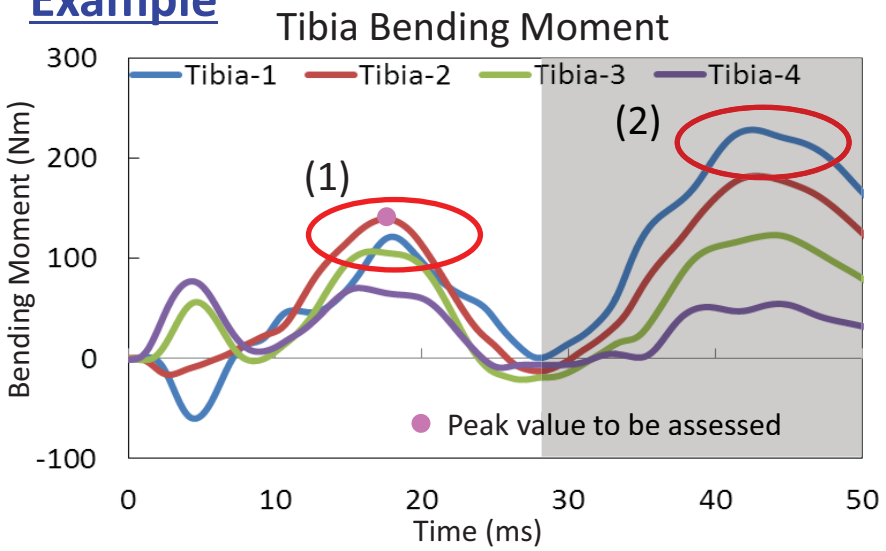
(1) Local peak bending moments are clearly identified before 30 ms[1)]

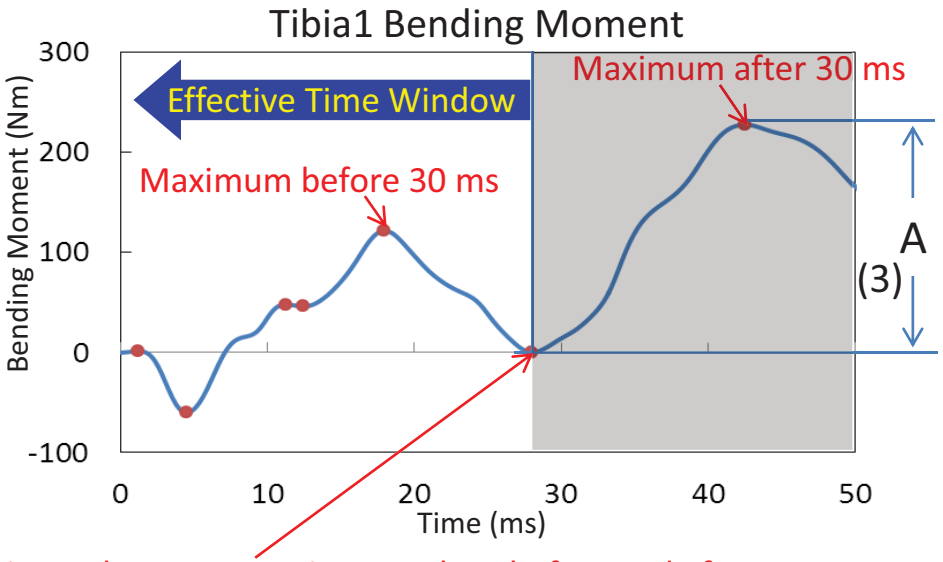
(2) Overall maximum value is determined after 30 ms

(3) Bending moment increase (A) of the channel providing the maximum value of the four channels after 30 ms is greater than 170 Nm

1) Justification provided on the next page

Example





Local minimum between maximum values before and after 30 ms

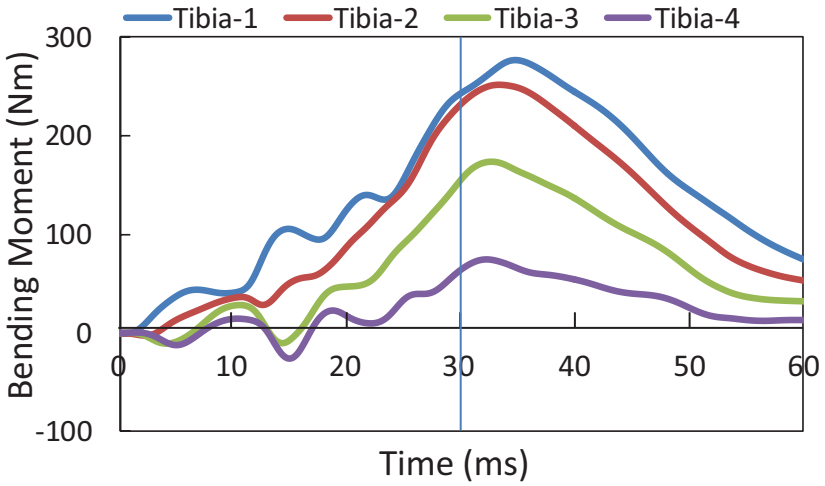
Justification for Note 1)

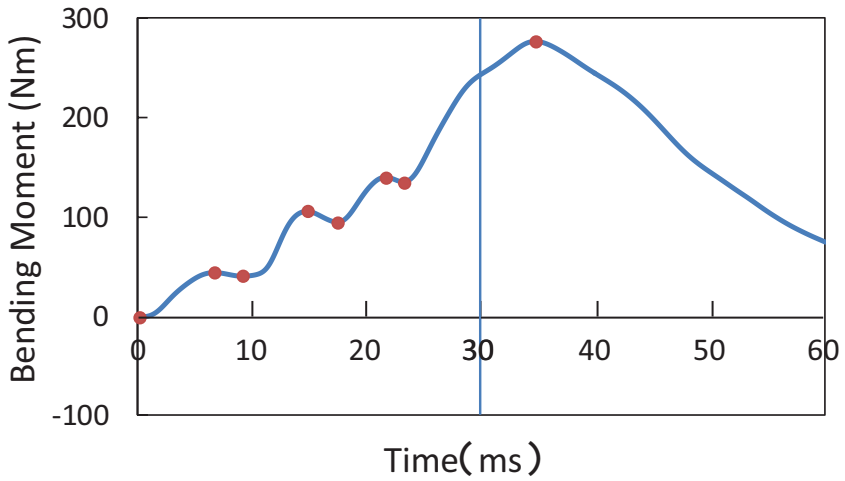
Why is it necessary to require clear identification of peak bending moment before 30 ms ?

- Tibia bending moment increase in the rebound phase is caused by the earlier impact of the legform against the lower part of the bumper and rotation of the femur
- Vehicles with later impact against the lower part of the bumper, such as SUVs, may result in later peak tibia bending moment
- Requirement (1) was included to avoid misinterpretation of the peak bending moment due to vehicle interaction with the tibia bending moment increase in the rebound phase in such cases

Example

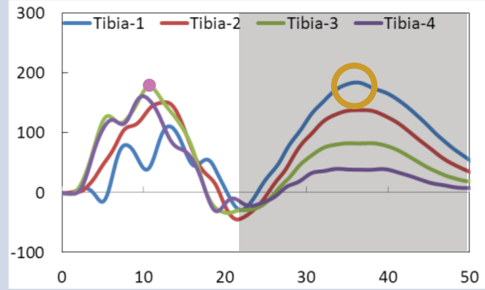
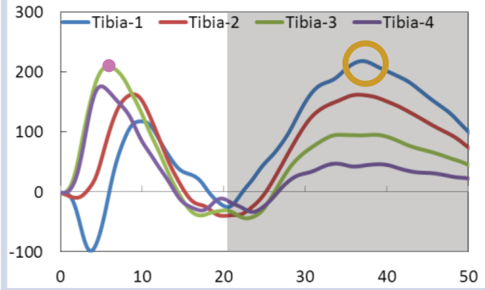
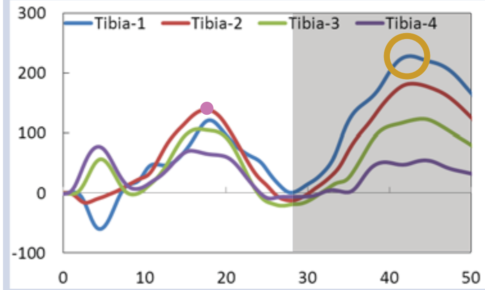
(no clear peak before 30 ms, maximum value after 30 ms)





Case Study (1)

<table>
<tr><th>Vehicle/Location</th><th>Sedan A/CTR</th><th>Sedan A/399 mm</th><th>Small Sport/CTR</th></tr>
<tr><td>Tibia Moment Time History

Vertical: Bending Moment (Nm)
Horizontal: Time (ms)</td><td> 
</td><td> 
</td><td> 
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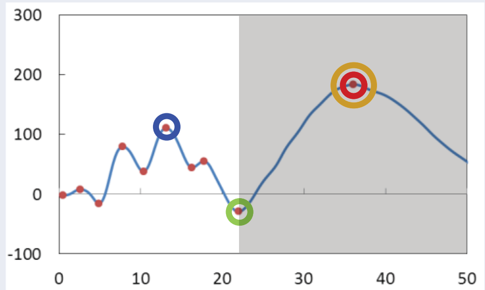
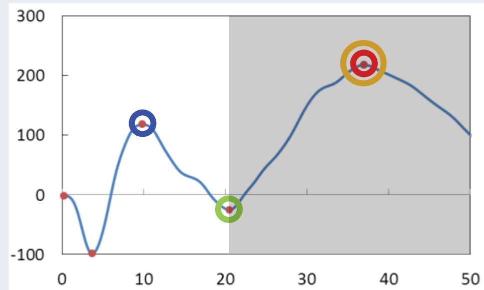
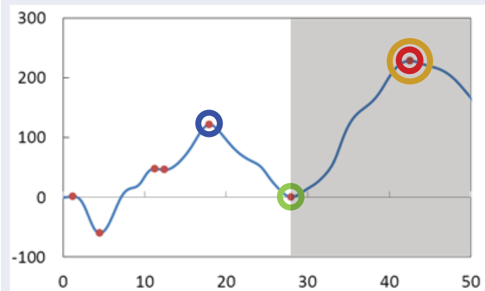
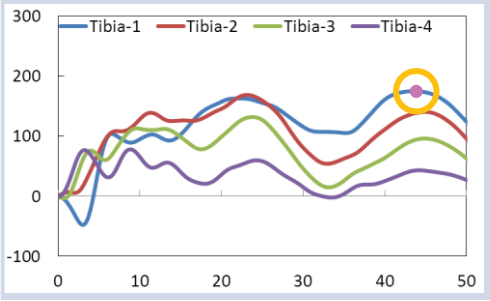
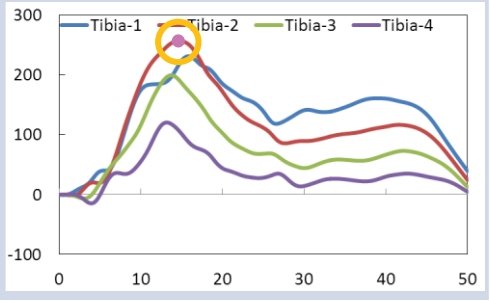
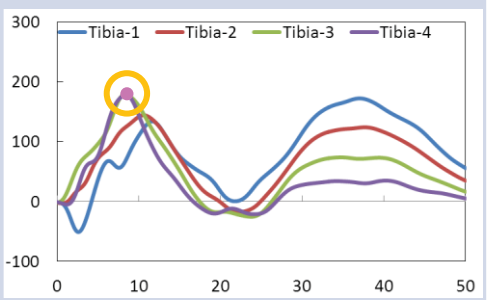
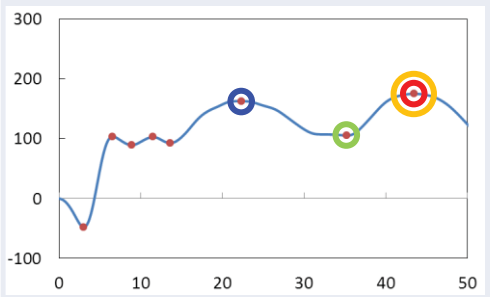
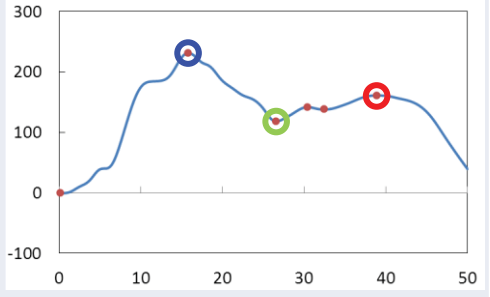
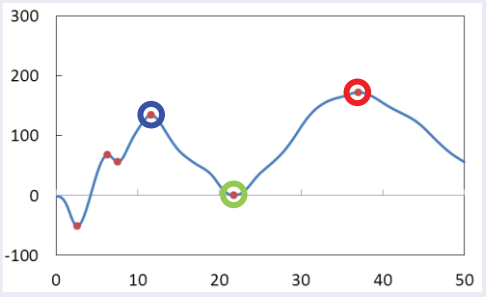
<tr><td>Channel for max after 30 ms

Vertical: Bending Moment (Nm)
Horizontal: Time (ms)</td><td> 
</td><td> 
</td><td> 
</td></tr>
<tr><td>Clear Peak before 30 ms?</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Overall peak after 30ms?</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>BM increase in rebound phase</td><td>214 Nm</td><td>244 Nm</td><td>227 Nm</td></tr>
<tr><td>Apply proposed protocol?</td><td>Yes</td><td>yes</td><td>Yes</td></tr>
</table>

● Peak value to be assessed
O Peak before 30 ms
O Peak after 30 ms
O Local minimum between two peaks
O Overall maximum

Case Study (2)

GTR9-5-08

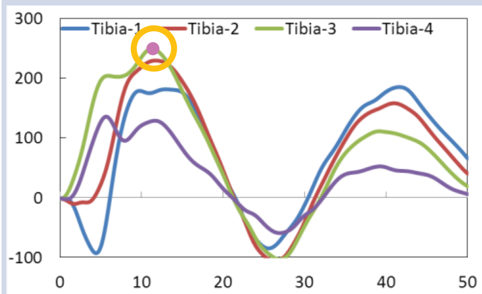
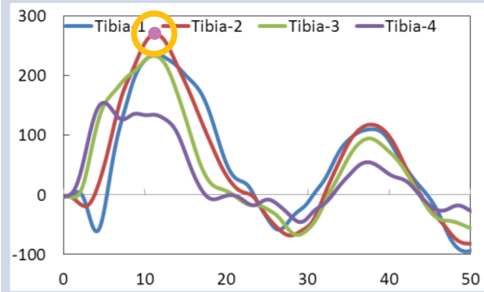
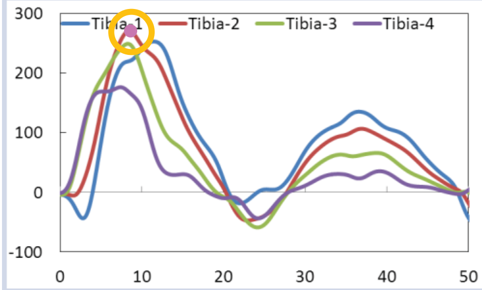
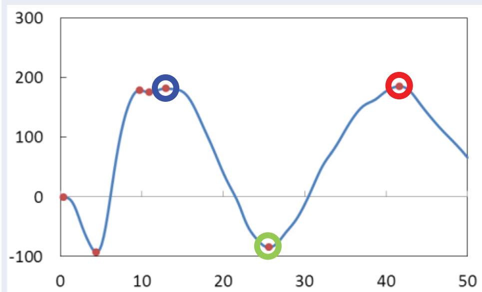
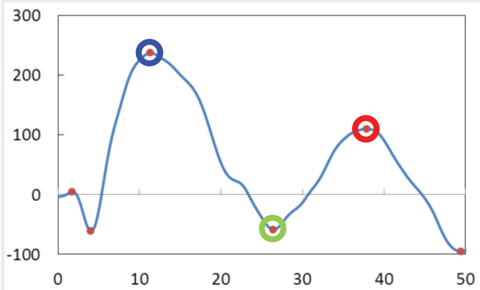
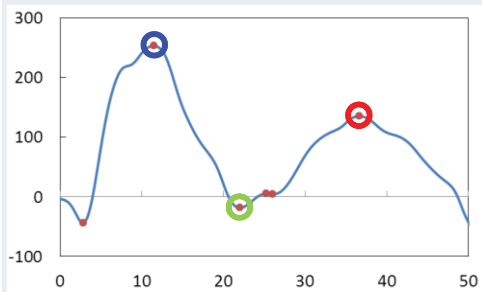
Vehicle/Location	Small Sport/347 mm	Sedan B/CTR	Sedan B/359 mm
Tibia Moment Time History Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Channel for max after 30 ms Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Clear Peak before 30 ms?	Yes	Yes	Yes
Overall peak after 30ms?	Yes	No	No
BM increase in rebound phase	70 Nm	23 Nm	172 Nm
Apply proposed protocol?	No	No	No

Peak value to be assessed

Peak before 30 ms
Peak after 30 ms

Local minimum between two peaks
Overall maximum

Case Study (3)

Vehicle/Location	Sedan C/389 mm	Sedan D/CTR	Sedan D/512 mm
Tibia Moment Time History Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Channel for max after 30 ms Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Clear Peak before 30 ms?	Yes	Yes	Yes
Overall peak after 30ms?	No	No	No
BM increase in rebound phase	270 Nm	169 Nm	131 Nm
Apply proposed protocol?	No	No	No

● Peak value to be assessed

○ Peak before 30 ms

○ Peak after 30 ms

○ Local minimum between two peaks

○ Overall maximum

Case Study (4)

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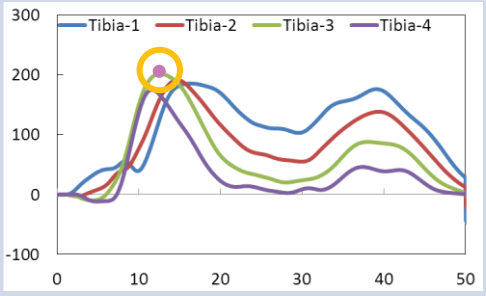
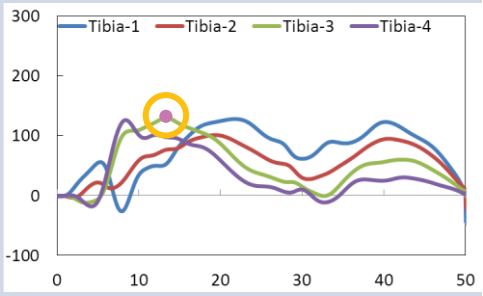
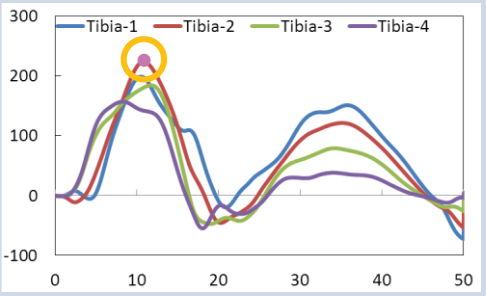
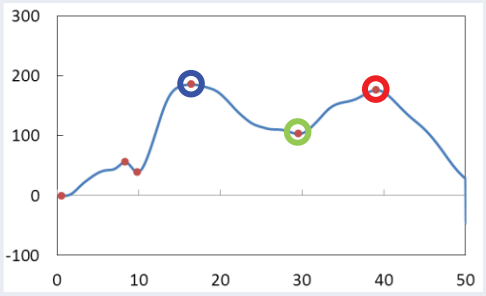
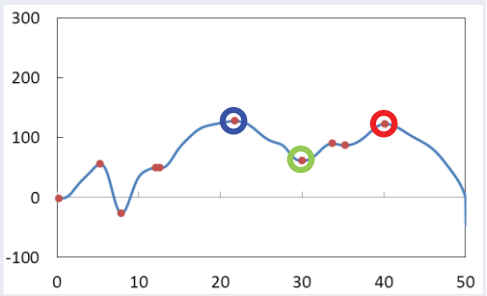
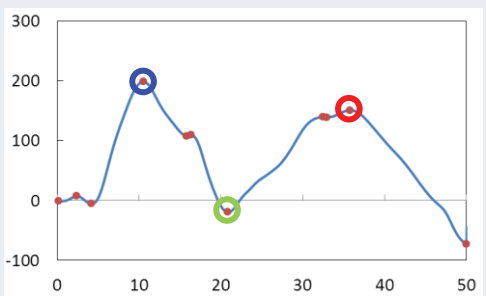
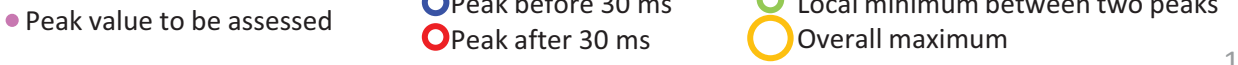
Vehicle/Location	Sedan E/CTR	Sedan E/379 mm	Sedan F/CTR
Tibia Moment Time History Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Channel for max after 30 ms Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Clear Peak before 30 ms?	Yes	Yes	Yes
Overall peak after 30ms?	No	No	No
BM increase in rebound phase	73 Nm	62 Nm	171 Nm
Apply proposed protocol?	No	No	No



Case Study (5)

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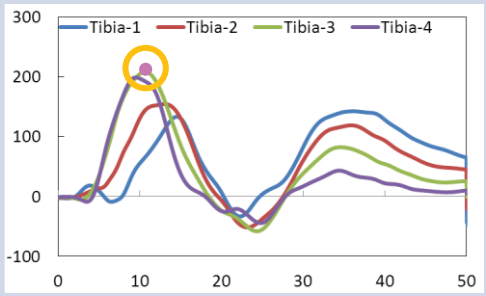
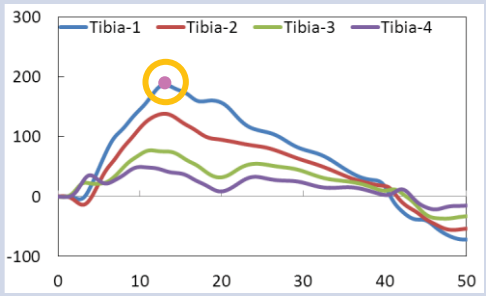
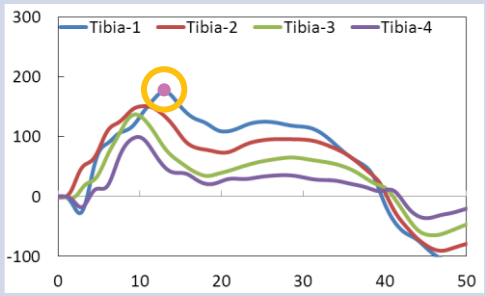
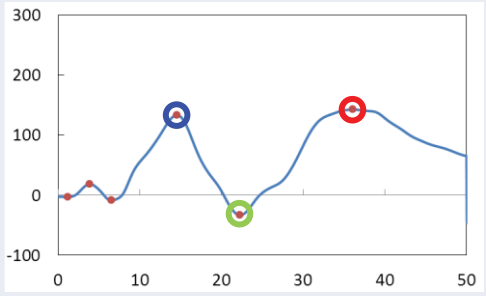
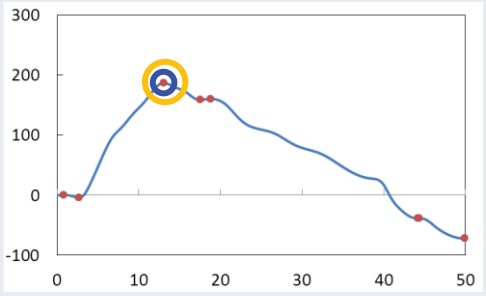
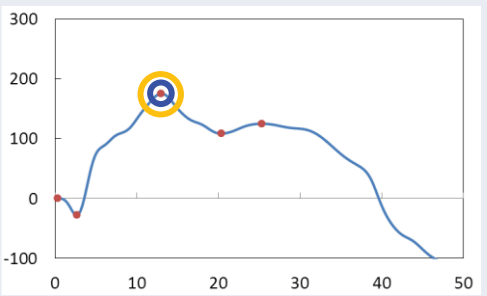
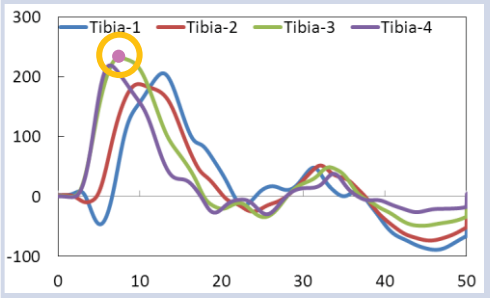
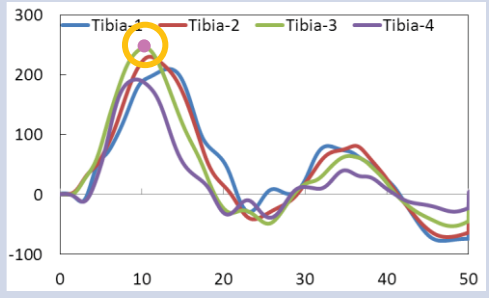
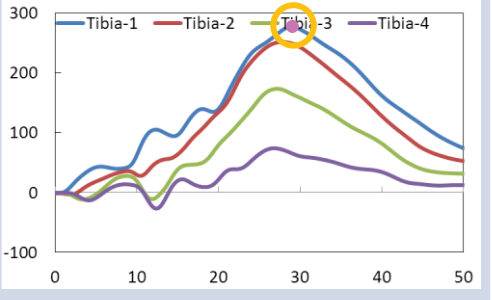
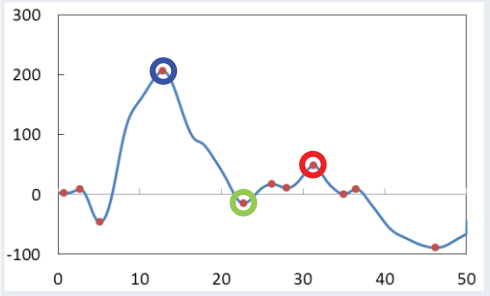
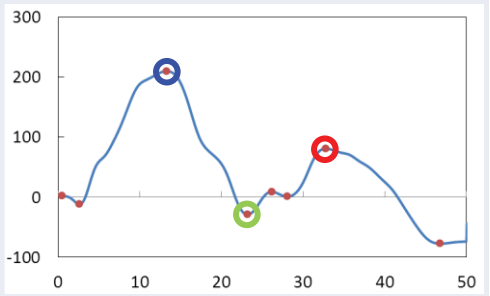
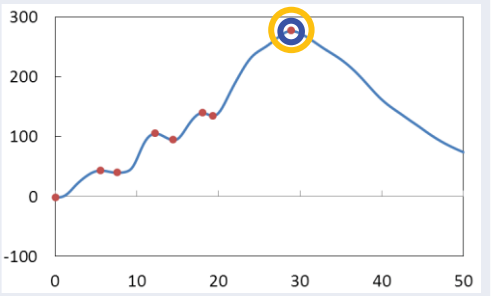
Vehicle/Location	Sedan F/502 mm	MPV/145 mm	MPV/348 mm
Tibia Moment Time History Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Channel for max after 30 ms Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Clear Peak before 30 ms?	Yes	Yes	Yes
Overall peak after 30ms?	No	No	No
BM increase in rebound phase	176 Nm	—	—
Apply proposed protocol?	No	No	No

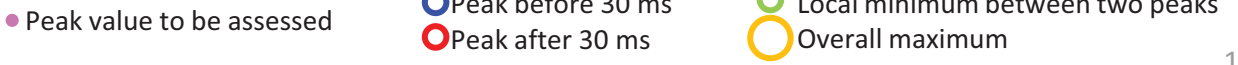
● Peak value to be assessed

Peak before 30 ms
Peak after 30 ms

Local minimum between two peaks
Overall maximum

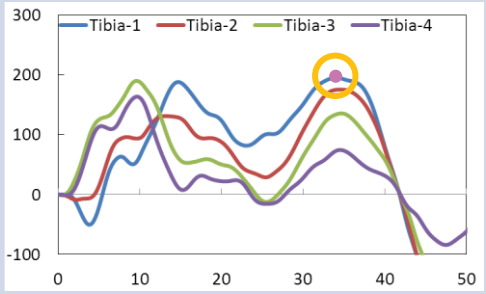
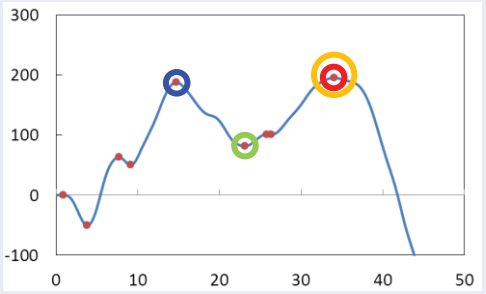
Case Study (6)

Vehicle/Location	Small MPV/85 mm	Small MPV/488 mm	Small SUV/CTR
Tibia Moment Time History Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Channel for max after 30 ms Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Clear Peak before 30 ms?	Yes	Yes	No
Overall peak after 30ms?	No	No	No
BM increase in rebound phase	64 Nm	111 Nm	—
Apply proposed protocol?	No	No	No



Case Study (7)

GTR9-5-08

Vehicle/Location	Simplified Vehicle (S08)		
Tibia Moment Time History Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Channel for max after 30 ms Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Clear Peak before 30 ms?	Yes		
Overall peak after 30ms?	Yes		
BM increase in rebound phase	95 Nm		
Apply proposed protocol?	No		

Peak value to be assessed

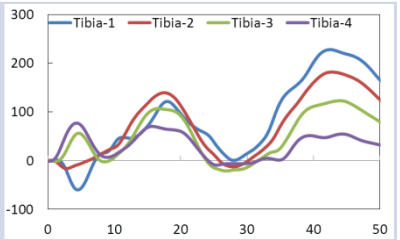
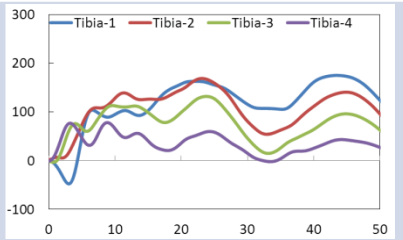
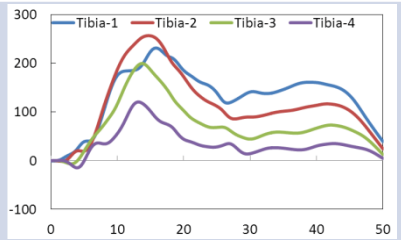
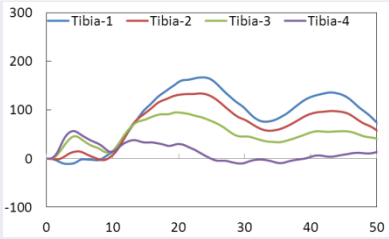
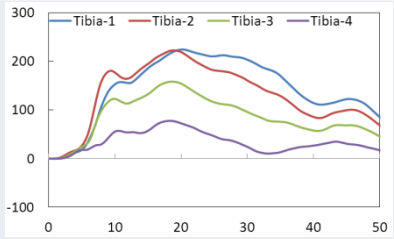
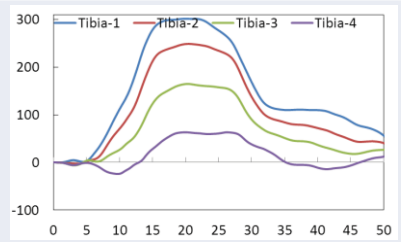
Peak before 30 ms

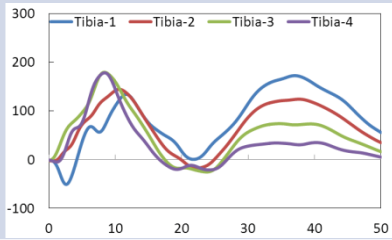
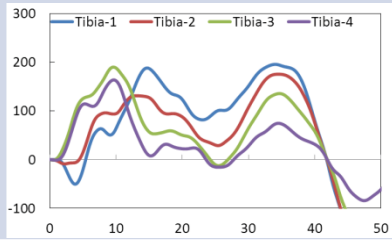
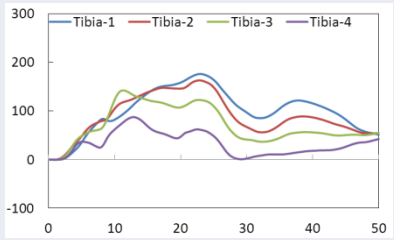
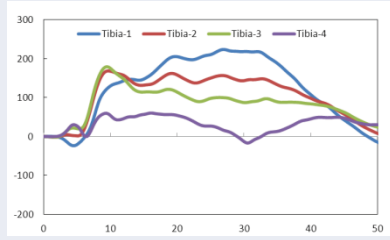
Peak after 30 ms

Local minimum between two peaks

Overall maximum

FlexPLI vs. Human Model Comparison

Vehicle/Location	Small Sport/CTR	Small Sport/347 mm	Sedan B/CTR
Flex Tibia Moment Time History Vertical: Bending Moment (Nm) Horizontal: Time (ms)			
Human Tibia Moment Time History Vertical: Bending Moment (Nm) Horizontal: Time (ms)			

Vehicle/Location	Sedan B/359 mm	Simplified Vehicle (S08)
Flex Tibia Moment Time History Vertical：Bending Moment (Nm) Horizontal：Time (ms)		
Human Tibia Moment Time History Vertical：Bending Moment (Nm) Horizontal：Time (ms)		

FlexPLI tends to provide larger tibia bending moment increase in the rebound phase compared to the human model