Flex-GTR:
Open questions and proposals for ACL, PCL and MCL injury thresholds

7th Meeting of the GRSP Flex PLI Technical Evaluation Group
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ACL/PCL injury thresholds

- **history and tentative threshold values**
- **conclusions and proposal**

MCL injury threshold

- **development and tentative threshold values**
- **conclusions and proposal**

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ACL/PCL injury thresholds

- **For cruciate ligament injuries, so far no injury risk curve has been developed due to the comparatively low priority within real car accidents.**

- **The IHRA/PS just described an example 10 mm from a computer simulation analysis carried out by Dominique Cesari (IHRA, 2004).**

- **The EEVC WG 17 PLI uses the knee shear displacement (relative displacement between tibia and femur at the knee joint level in lateral direction) to evaluate cruciate ligament (ACL, PCL) injuries (EEVC, 2002).**

Injury Mechanism

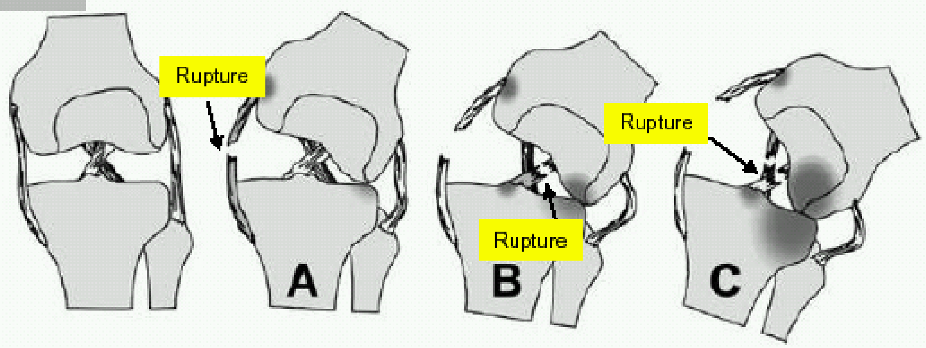


Fig. 8. Stages of the left knee injury (frontal view) in the mechanism of valgus flexion. (A) Avulsion of the medial collateral ligament; (B) avulsion of the anterior cruciate ligament; (C) avulsion of the posterior cruciate ligament. A → C increasing compression of the lateral tibial and femoral condyles.

Knee joint injuries as a reconstructive factors in car-to-pedestrian accidents, Forensic Science International 124 (2001) 74-82
[Source: Teresinski et al, 2001]

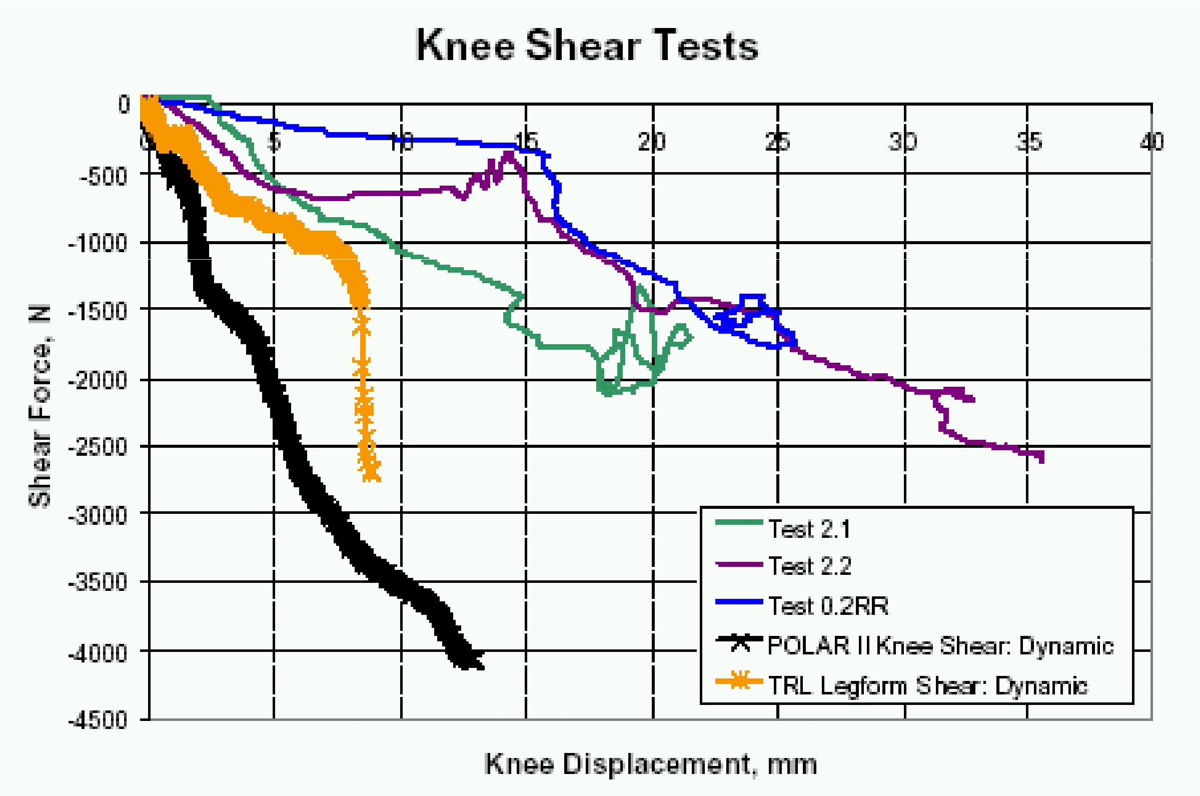
ACL/PCL injury thresholds

- As no injury risk curve is available, for the time being, an injury threshold tried to be derived from impact tests with the Flex-PLI and the EEVC WG 17 PLI on identical impact locations of different vehicles representing a modern vehicle fleet (1box, sedan, SUV)

- According to a developed linear regression, it became obvious that the assessment of cruciate ligament protection provided by vehicle bumpers using the FlexPLI ACL/PCL elongation readings is not comparable to the assessment using the WG 17 PLI shearing displacement results and vice versa

ACL/PCL injury thresholds

- **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]

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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.

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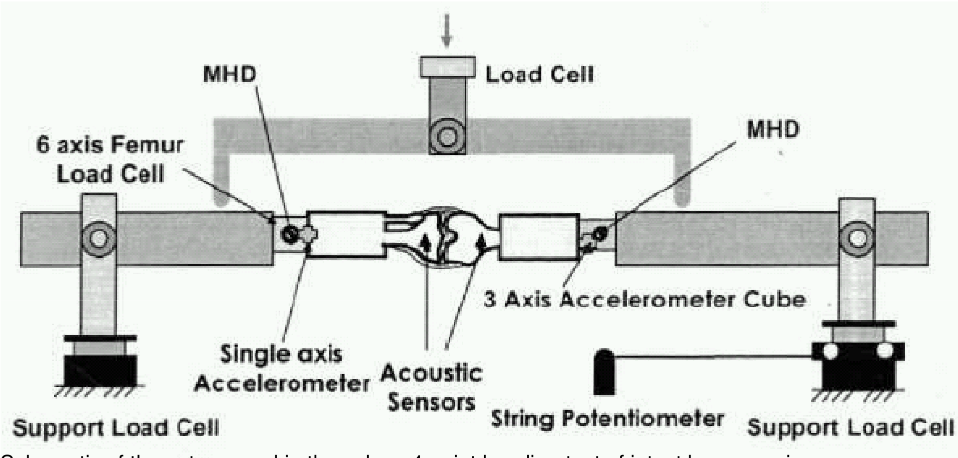
MCL injury threshold

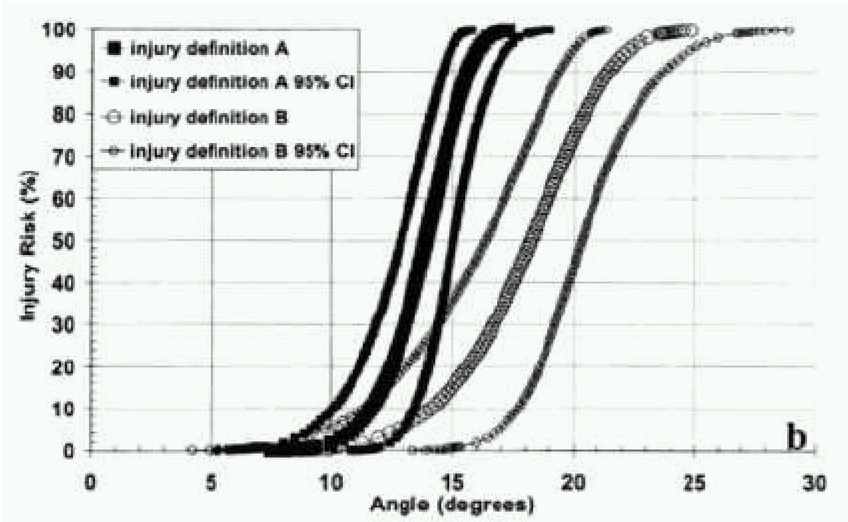
- Currently proposed, tentative MCL injury threshold: 18 – 20 mm elongation
- 18° knee bending angle are based on Ivarsson et al (2004):
- Eight intact knee specimens were subjected to symmetric valgus 4-point bending. The only major load bearing structure injured was the MCL.



Schematic of the set-up used in the valgus 4-point bending test of intact knee specimens
[Source: Ivarsson et al, 2004]

- Moment-deflection responses were scaled down to 50th male
- Two definitions for knee injury occurence:
  a) time of first local moment peak and b) time of maximum moment
- Development of Weibull survival models predicting the risk of knee injury
- Development of dynamic response corridors around the characteristic average responses using standard deviation calculations

MCL injury threshold



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?**

MCL injury threshold

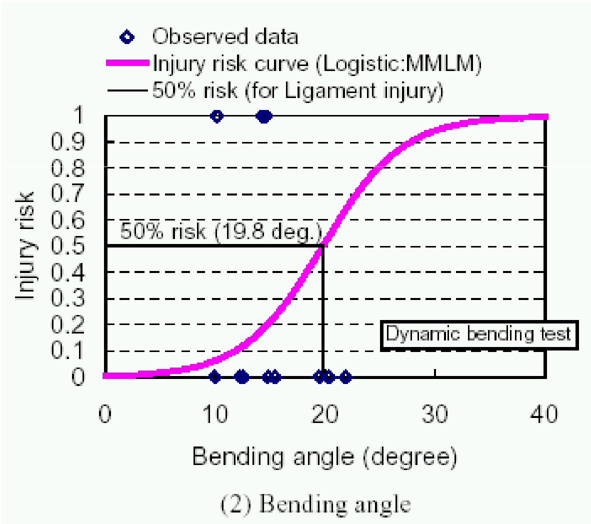
- 20° knee bending angle are based on Konosu et al (2001):
- Several dynamic PMHS tests from Kajzer et al (1997, 1999) were taken to obtain the human knee characteristics versus bending mode.
- A logistic analysis method from Nakahira et al (2000) was applied to the test results and an injury risk curve against the bending angle was obtained.
- From this risk curve, the bending angle at 50% injury risk is 19,8°

Dynamic bending test

Test No.	Bending angle: Ligament: No injury	Bending angle: Ligament: Injury
2B	19.5	
3B		14.4
6B		14.7
7B	21.9	
10B	15.5	
11B	14.8	
14B	10.0	
15B	12.6	
18B	20.4	
22B	12.3	
27B		10.2
30B		14.3

unit (deg.)

PMHS test results (dynamic impact test)
[Source: Kajzer et al, 1997]



Injury risk curve against bending angle
[Source: Konosu et al, 2001]

Proposal for lower performance limit: 19,8° knee bending angle

MCL injury threshold

- **Transformation of human knee bending angle**

➔ human model knee bending angle
➔ human model knee MCL elongation
➔ Flex-GT model knee MCL elongation
➔ Flex-GT knee MCL elongation

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)

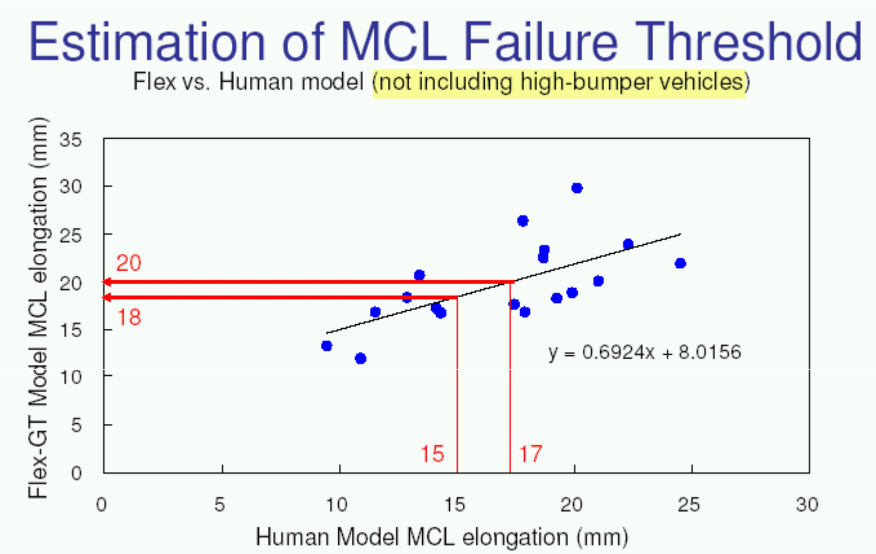
Convert human tolerance values to the Flex-GT ones
(use correlation ratio/formula)

Transformation of human knee bending angle [Source: Konosu 2007]

MCL injury threshold

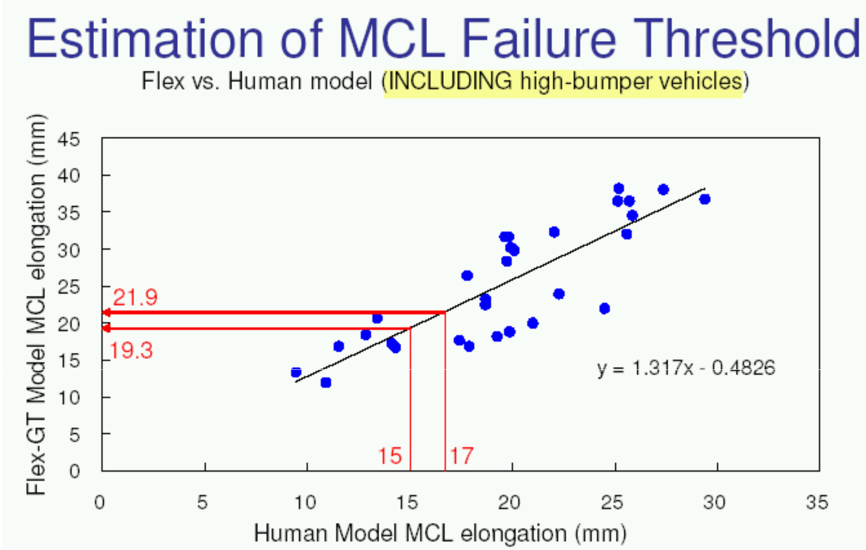
- **Transformation of human model knee MCL elongation**
  ➔ Flex-GT model knee MCL elongation

a) not including high-bumper vehicles:



Deduction of Flex-GT MCL elongation thresholds [Source: Yamaguchi / Takahashi 2008]

b) including high-bumper vehicles:

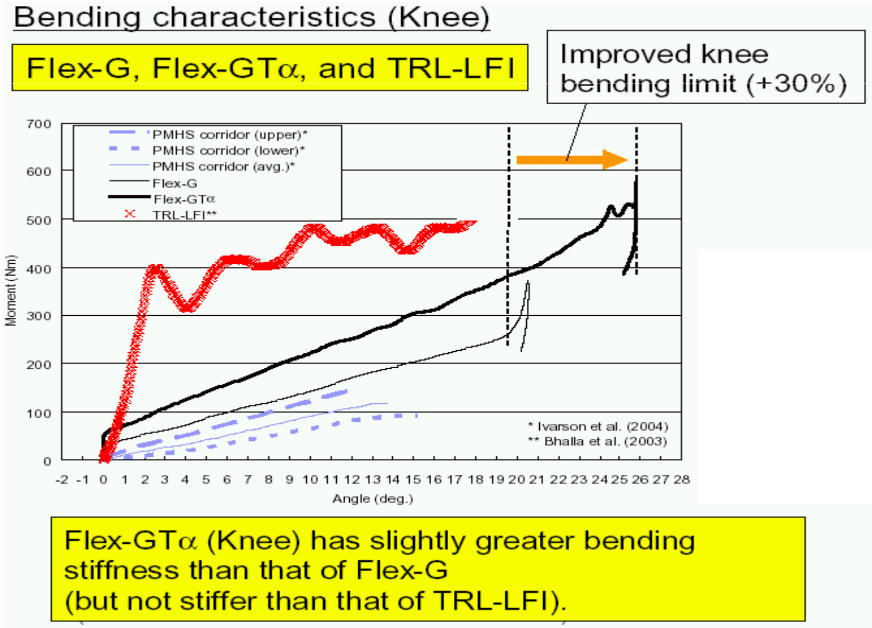


Questions:

- **Number and kind of simplified vehicle models used for transformation of human model results ? How many high-bumper vehicles included afterwards ?**
- **Are simplified car models and car model fleet representative ?**
- **Derivation from which statistics ?**

MCL injury threshold

- **Effect of muscle tone is estimated at 10% in valgus bending**
- **Anyway, a modification of the lower performance limit by 10% would mislead to the assumption of MCL failure / rupture at 23 (instead of 12,5…20) mm knee elongation**
- **The effect of muscle tone therefore should be considered within the knee stiffness**
- **This higher knee stiffness was understood being taken into account already within the development of the Flex-GTα:**



Knee bending characteristics [Source: Konosu 2006]

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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

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References

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Thank you!