



Flex-GTR: Proposal for ACL/PCL injury threshold

**11th Meeting of the GRSP Flex PLI Technical Evaluation Group
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(Federal Highway Research Institute)

Content



Background information

Correlation: EEVC WG 17 PLI SD & FlexPLI ACL/PCL

Correlation: MCL & ACL/PCL

Correlation: FlexPLI SD & ACL EL

Proposal

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ACL/PCL background information

- For cruciate ligament injuries, so far no injury risk curve has been developed.
- 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

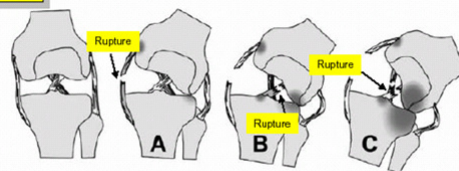


Fig. 8. Stages of the left knee injury (frontal view) in the mechanism of valgus flexion. (A) Avulsion of the medial collateral ligament; (B) avulsion of the anterior cruciate ligament. (C) avulsion of the posterior cruciate ligament. A → C increasing compression of the lateral tibial and femoral condyles.

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

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April 21st, 2010

Slide No. 5

Correlation: EEVC WG 17 PLI and FlexPLI

- As no risk curve for cruciate ligament injuries is available, 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) [see TEG-078].
- This dataset has been amended by inverse AI honeycomb tests (inverse certification) so that it now consists of:
 - Two impact locations on 1Box front
 - Two impact locations on Sedan #1 front (assessed with both EEVC WG 17 PLI and FlexPLI, whereas the FlexPLI values have been calculated from the average of four tests)
 - Three impact locations on Sedan #2 front
 - Two impact locations on SUV front
 - Three inverse tests at +10 / 0 / -10 mm impact height
- All impact locations have been tested with both legform impactors.
- In total, 12 tests with the EEVC WG 17 PLI and 18 tests with the FlexPLI were taken into account.

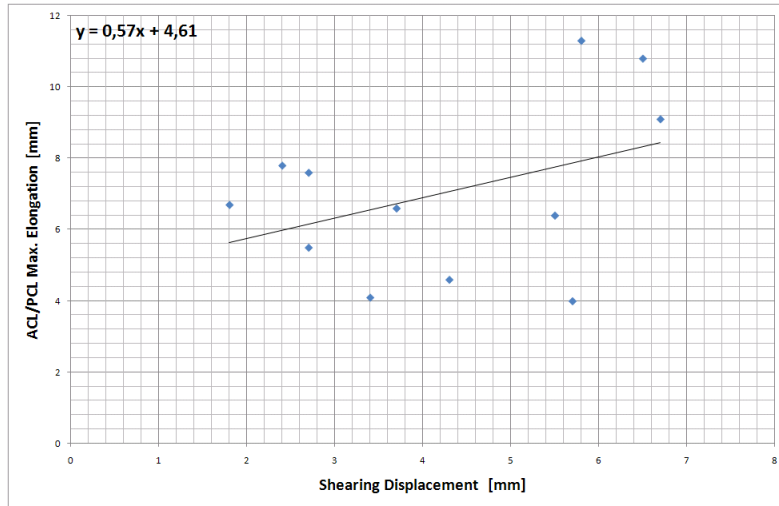
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Slide No. 6

Correlation: EEVC WG 17 PLI and FlexPLI  

1)SD versus ACL/PCL Maxima:



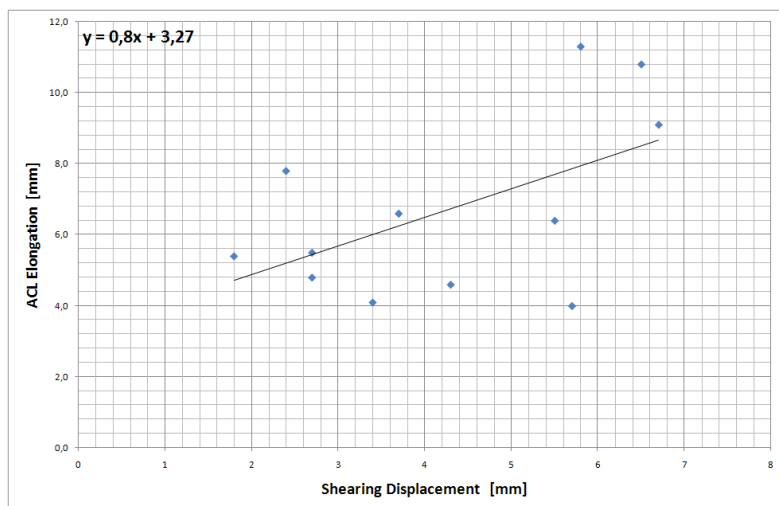
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Slide No. 7

Correlation: EEVC WG 17 PLI and FlexPLI  

2)SD versus ACL:

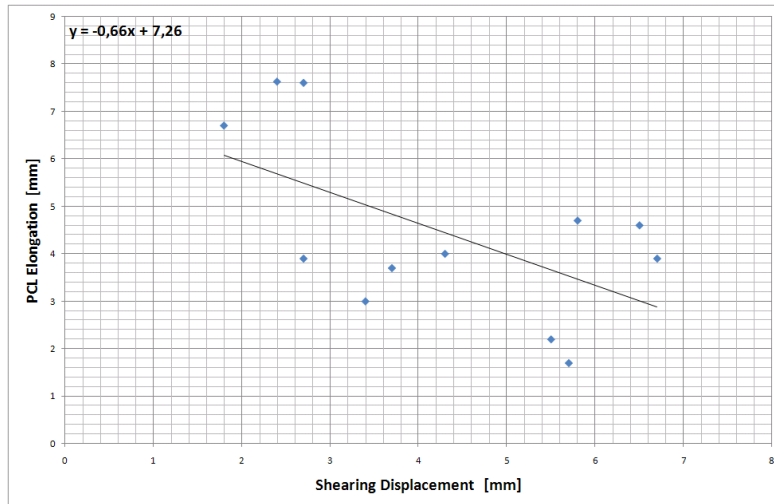


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Slide No. 8

3)SD versus PCL:



- The developed linear regression does not show a good correlation between the EEVC WG 17 PLI shearing displacement and the FlexPLI ACL/PCL elongation.
- The best correlation can be found between SD and ACL (which is the ligament being subjected to tension due to application of shear force):
- According to the transition equation $y = 0,8x + 3,27$ a maximum permitted SD of 6 mm according to the GTR would correspond to 8 mm ACL elongation.

Content



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Proposal

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Slide No. 11

Correlation: MCL and ACL/PCL



- In a second step, a correlation study between FlexPLI MCL and ACL output has been carried out
- The described knee injury mechanism in the defined lateral car-to-pedestrian accidents leads to the assumption that ACL rupture occurs after MCL rupture (but before PCL rupture) (Teresinski et al, 2001)
- The 50% risk of MCL rupture has been determined and agreed by the Flex-TEG at 22 mm elongation
- Dataset for correlation study consists of test results of:
 - Two impact locations on 1Box front
 - Two impact locations on Sedan #1 front
 - Two impact locations on Sedan #2 front
 - Inverse tests
- In total 55 tests with the FlexPLI-GTR were taken into account.

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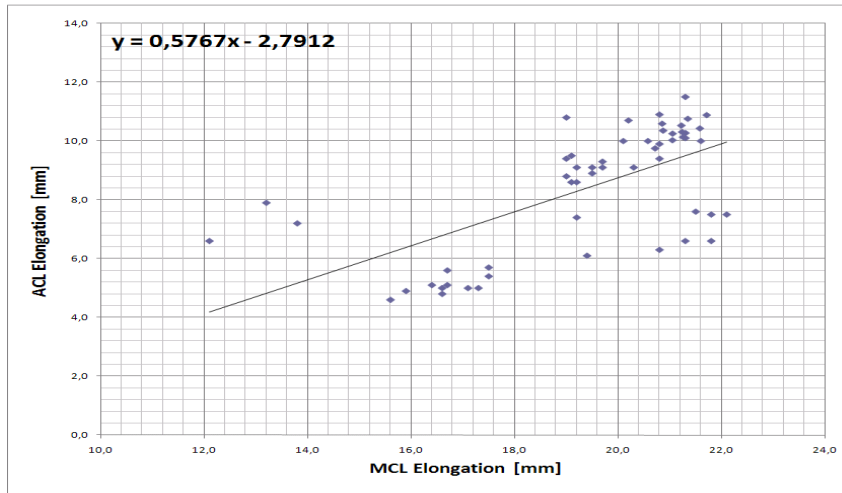
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Slide No. 12

Correlation: MCL and ACL/PCL



Test results:



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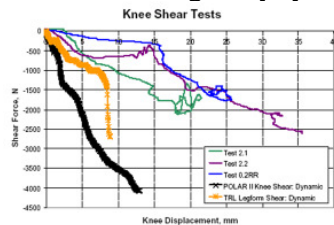
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Slide No. 13

Correlation: MCL and ACL/PCL



- According to the developed transition equation $y = 0,5767x - 2,7912$ a 22 mm Flex-GTR MCL elongation corresponds to 9,9 mm ACL elongation
- Therefore, if the previously made assumptions are correct, it can be assumed that ACL rupture occurs beyond 10 mm elongation output of the Flex-GTR
- On the other hand, Bhalla et al (2003) stated a tolerance of at least 12,7 mm for human knee shear displacement of the 50th male, even if 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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Slide No. 14

Background information

Correlation: EEVC WG 17 PLI SD & FlexPLI ACL/PCL

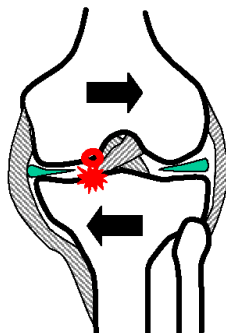
Correlation: MCL & ACL/PCL

Correlation: FlexPLI SD & ACL EL

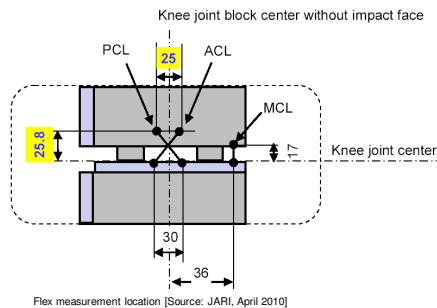
Proposal

Correlation: FlexPLI SD and ACL EL

- **Bhalla et al (2003) found tolerance of 12,7 mm and 17,8 mm for human knee shear displacement of the 50th male**
- **The knee shear displacement can be transformed to FlexPLI ACL /PCL elongation, taking into account the knee measurement locations**

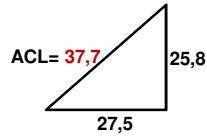
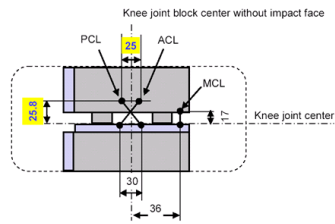


Damage mechanism in knee shear loading
[Source: Bhalla et al, 2003]



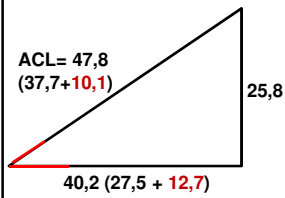
Flex measurement location [Source: JARI, April 2010]

Correlation: FlexPLI SD and ACL EL

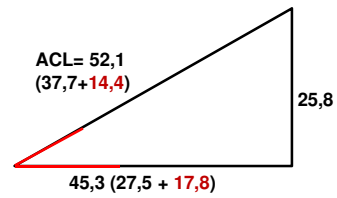


ACL length in unloaded condition @ approx. **37,7 mm**

Shearing of **12,7 mm** causes
ACL elongation of approx. **10,1 mm**



Shearing of **17,8 mm** causes
ACL elongation of approx. **14,4 mm**



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Slide No. 17

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April 21st, 2010

Slide No. 18

Proposal for ACL/PCL injury thresholds

Conclusions / Proposal:

- Under the previously made observations, the following, first estimation was made:
 Flex-GTR ACL elongation performance limit: 8 mm (SD transition)
 Flex-GTR ACL elongation performance limit: 10 mm (MCL transition)
- In absence of injury risk functions for the cruciate ligaments and lacking information on transition between human and Flex-GTR ACL/PCL elongation a threshold value of **13 mm ACL/PCL elongation** is proposed as performance limit.
- German In-depth accident data gives evidence of clearly defined cruciate ligament ruptures.
- ACL was proved to be the more critical because under the defined impact conditions less protected ligament. Therefore, the threshold value regarding PCL may be set as monitoring.
- Anyway, as the FlexPLI should provide at least the same level of protection when being compared to the EEVC WG 17 PLI, the ACL limit should be set mandatorily.

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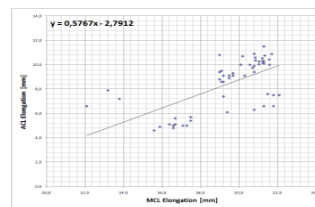
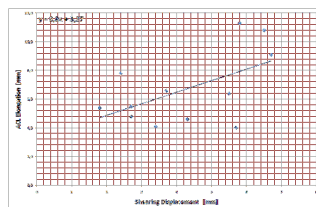
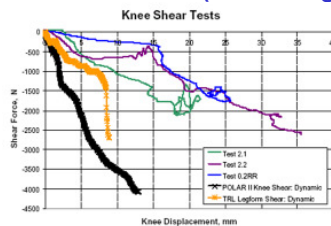
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Slide No. 19

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BASt-Proposal for Flex-GTR:

- ACL EL: 13 mm (mandatory)
- PCL EL: 13 mm (monitoring)



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April 21st, 2010

Slide No. 20

Thank you!

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April 21st, 2010

Slide No. 21