TEG-095

Investigation on Injury Criteria for MCL

The Japan Automobile Manufacturers Association Inc.
Pedestrian Safety WG

Original Proposal (TEG-035)

Flex-GT Tentative Threshold Values

TEG-035

Human value

Body regions		50% Injury risk level of AM50 (tentative)	References
		Human value	
Leg	(Tibia)	BM (312 - 350 Nm)	BM (312 Nm): Kerrigan et al., 2004 BM (350 Nm): INF GR/PS/82
Knee	(MCL)	BA (18 - 20 deg)	BA (18 deg).: Ivarsson et al., 2004 BA (20 deg).: INF GR/PS/82

AM50: 50 percentile of american male

BM: Bending moment, BA: Bending angle, EL: Elongation, SD: Shearing displacement.

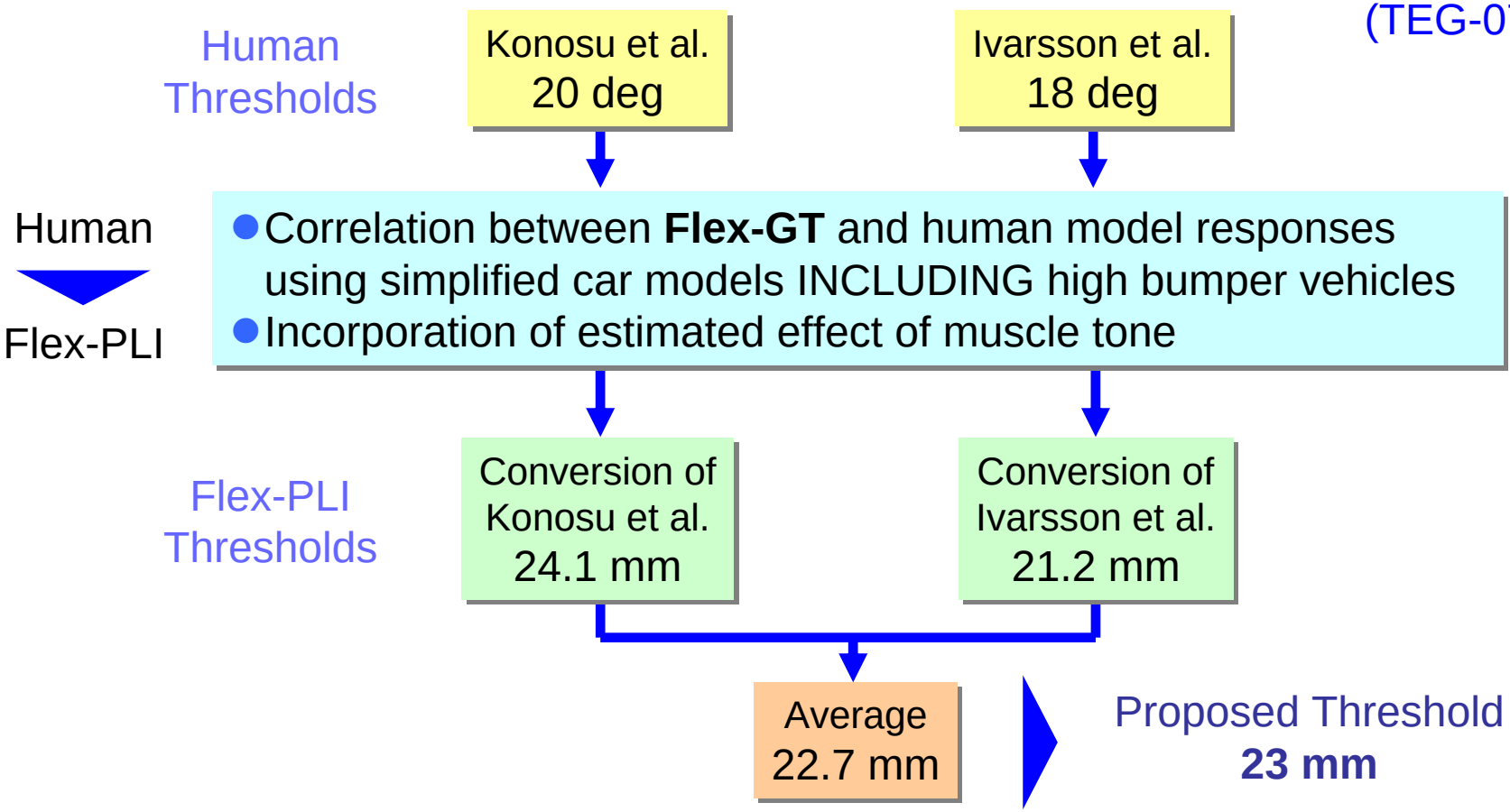
Based on Konosu et al. (2001)

Originally proposed threshold for human MCL (TEG-035)

- 18 deg based on Ivarsson et al. (2004)
- 20 deg based on Konosu et al. (2001)
- No single value proposal

JAMA Proposal at 7th Flex-TEG

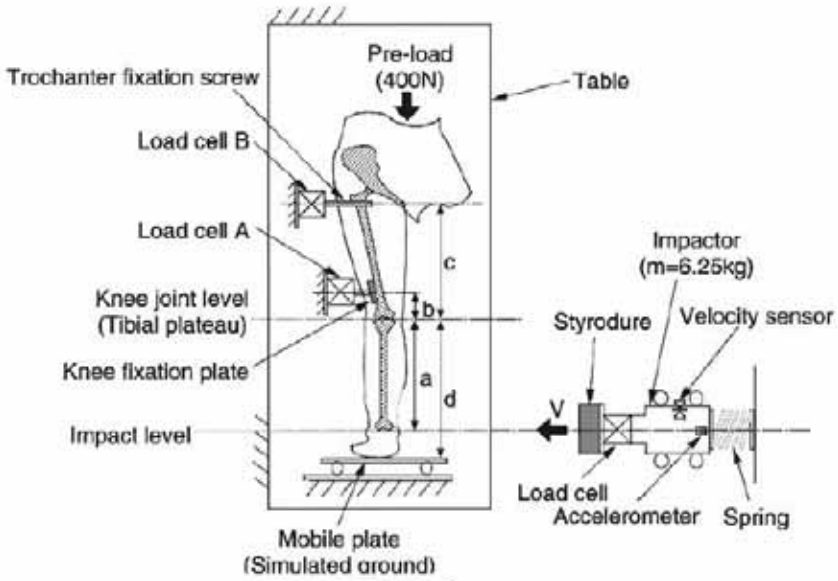
(TEG-076)



Proposed threshold for Flex-PLI was based on simple average of originally proposed two human thresholds

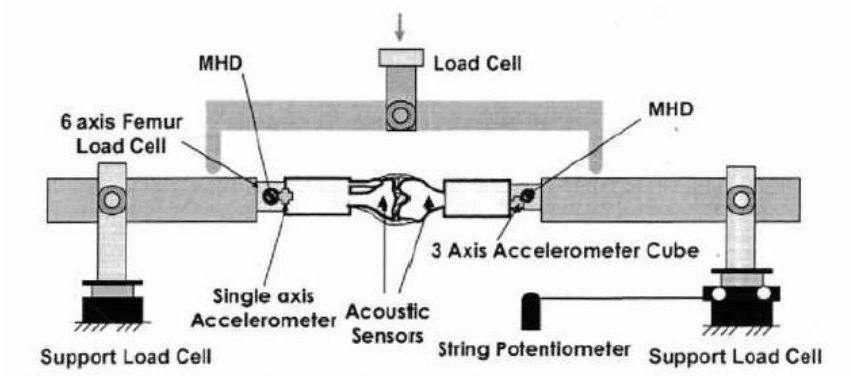
Source Data

Konosu et al. (2001)



- Source data from Kajzer et al. (1997)
- Lateral impact to ankle with femur constraints

Ivarsson et al. (2004)



- Source data from Bose et al. (2004)
- 4-point bending of isolated knee joints

- Different data sources with different test configurations
- No data duplication involved

Injury Risk Function from Konosu et al.

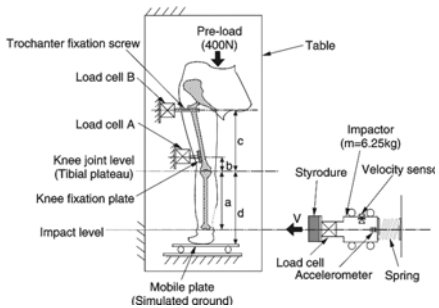
INF GR/PS/82

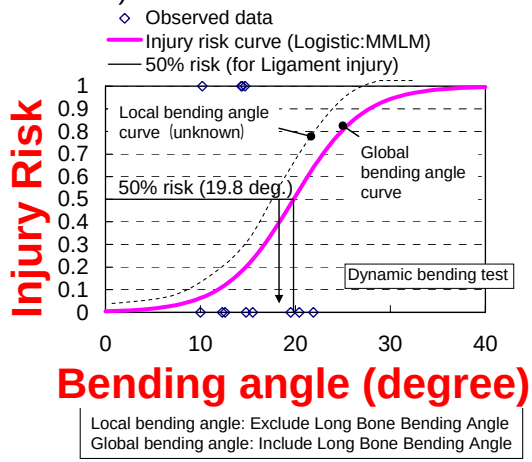
RECONSIDERATION OF INJURY CRITERIA FOR PEDESTRIAN SUBSYSTEM LEGFORM TEST

INF GR / PS / 82

Page 1

- PROBLEMS OF RIGID LEGFORM IMPACTOR -
Konosu A. et al, 2001 (ESV, Paper No. 263)





Proposed injury threshold for Knee bending: 20 deg.

6th Meeting INF GR / PS Japan Paris, France, 24 - 26 Feb. 2004

- Knee bending angle threshold determined directly from the injury risk function for knee bending angle
- Knee bending angle does not scale : No scaling issues involved

Injury Risk Function from Ivarsson et al.

Data Scaling Procedure

SCALING OF THE KNEE BENDING DATA: The inertially compensated moment-deflection responses provided by Bose et al. (2004) needed to be scaled to the size of a 50th percentile male knee prior to being used for corridor development. Rooney et al. (2003) collected anthropometric data for the femur, tibia, and patella from patients undergoing total knee arthroplasty and reported an average medial-lateral width of the proximal tibial epiphysis of 80.7 ± 5.3 mm for the 68 males included in the study. Upon assumption that this average corresponds to the medial-lateral width of the proximal tibial epiphysis in a 50th percentile male, each of the moment-angle curves provided by Bose and co-workers were scaled to the size of a 50th percentile male using length scale factors determined as the specimen medial-lateral width of the proximal tibial epiphysis divided by 80.7 mm (Fig. 6).

Ivarsson et al. scaled moment-angle curves provided by Bose et al. to 50th %ile male using width of proximal tibial epiphysis

Injury Risk Function from Ivarsson et al.

Injury Risk Functions

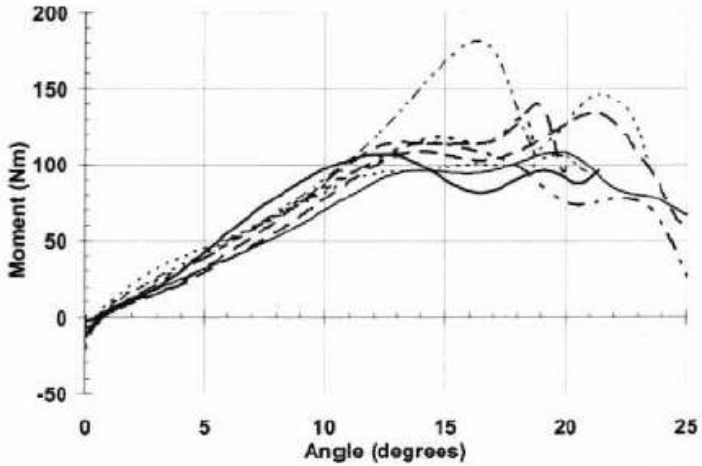


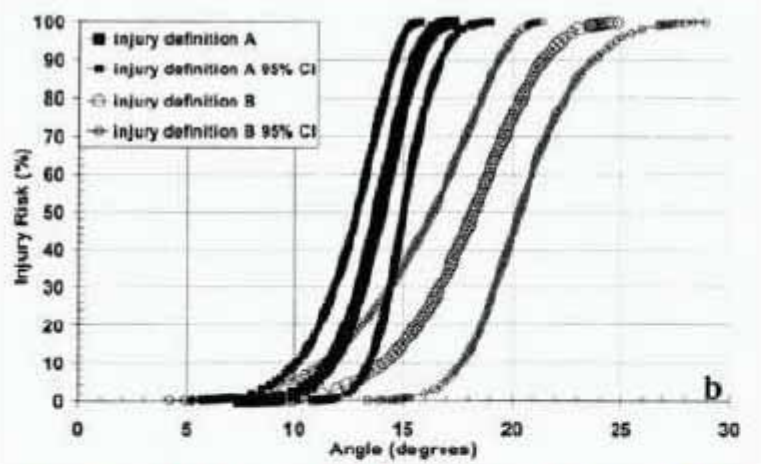
Fig. 6. The moment-angle responses from the eight knee bending tests conducted by Bose et al. (2004) geometrically scaled to the size of the 50th percentile male knee.

DETERMINING OF RISK FUNCTIONS FOR KNEE INJURY: The moment-angle responses from the knee bending tests shown in Fig. 6 do not demonstrate distinctive points corresponding to injury. We therefore adopted two different definitions for when knee injury occurred; at the time of the first local moment peak that occurred within 1-2 ms of significant acoustic emission burst (injury definition A) and at the time of maximum moment (injury definition B). The scaled bending moments and associated bending angles obtained according to these two injury definitions were used to develop four univariate Weibull survival models (Minitab, Minitab Inc., PA, USA) predicting the risk of knee injury in dynamic valgus bending as function of knee moment and knee bending angle.

- Ivarsson et al. identified failure points using two different definitions and then developed injury risk functions for knee moment and knee bending angle
- Knee bending angle does not scale : No scaling issues involved with knee bending angle

Questions Raised at 7th Flex-TEG

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?**

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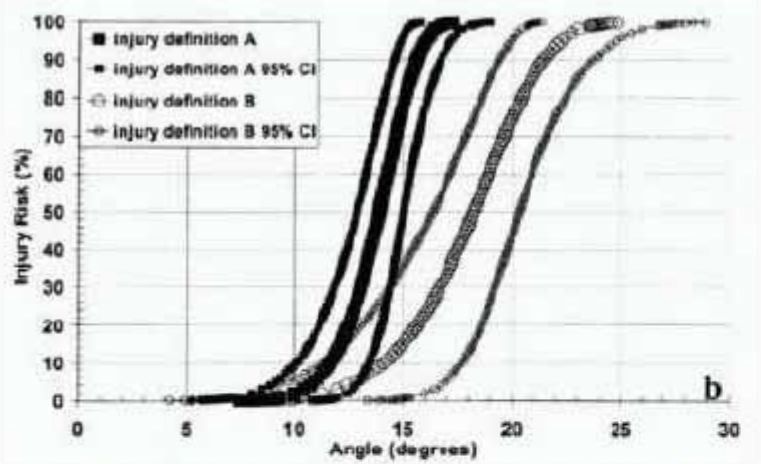

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Questions Raised at 7th Flex-TEG

Ivarsson et al.

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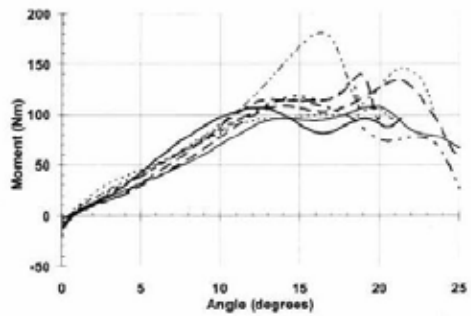
- Definition A : Time of the first local moment peak that occurred within 1-2 ms of significant acoustic emission burst
- Definition B : Time of maximum moment

Questions Raised at 7th Flex-TEG

Scaled moment-angle curves in Ivarsson et al.



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Injuries sustained by each specimen in Bose et al.

Table 3: Injuries observed in each tested specimen

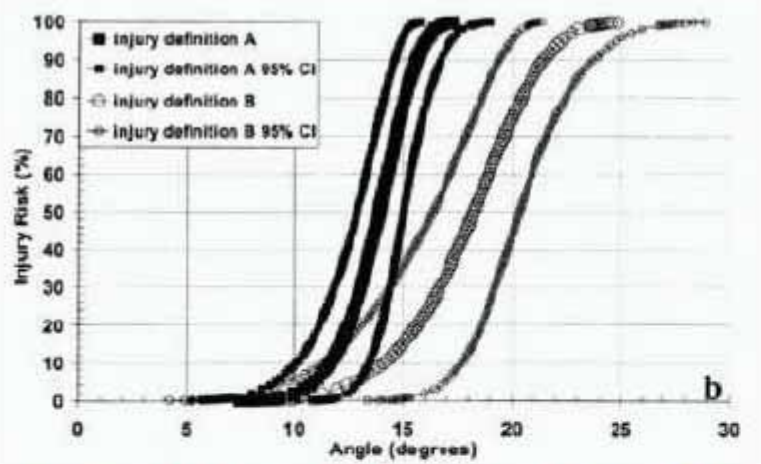
Test #	Specimen #	Aspect	Test	ACL	PCL	MCL	LCL
Bend 1	51000944-004	Right	4 pt	v	v	P	v
Bend 2	2002-FRM-159	Right	4 pt	v	v	P	v
Bend 3	2001-FRM-141	Left	4 pt	v	v	P	v
Bend 4	2002-FRM-179	Right	4 pt	v	v	P	v
Bend 5	2002-FRM-179	Left	4 pt	v	v	C	v
Bend 6	2001-FRM-141	Right	4 pt	v	v	P	v
Bend 7	2003-FRM-187	Left	4 pt	v	v	v	v
Bend 8	2001-FRM-152	Left	4 pt	v	v	P	v
Comb 1	2002-FRM-178	Right	3 pt	v	v	v	v
Comb 8	2001-FRM-152	Right	3 pt	v	v	P	v

4 pt: 4 point bending, 3pt: 3 point combined Loading
v : No injury, P: Partial avulsion, C: Complete avulsion
B: Bony Avulsion, L: Slight laxity

- Time of first local moment peak is not always different from time of maximum moment : No consistency
- Acoustic emission burst would work with bone fractures, but not with ligament failure : May have detected vibration from other phenomenon than MCL failure
- Most of the specimens sustained only partial failure of MCL : Use of first peak is likely to introduce minor failure of other knee components
- For above reasons, use of Definition B (Maximum moment) is recommended

Questions Raised at 7th Flex-TEG

MCL injury threshold



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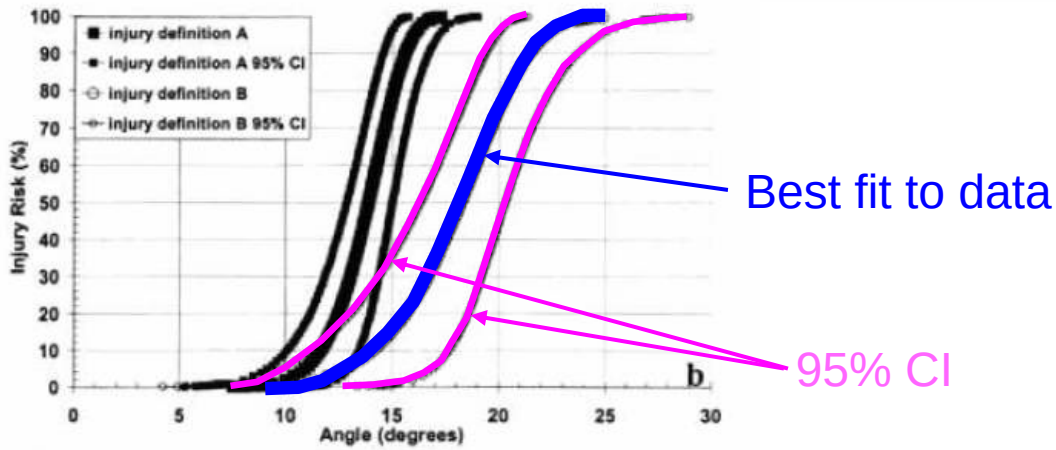
Questions Raised at 7th Flex-TEG

Ivarsson et al.

RESULTS

RISK FUNCTIONS FOR KNEE INJURY: The four univariate Weibull survival models predicting the risk of knee injury (MCL injury) according to injury definition A (injury occurs at the time of the first local moment peak occurring within 1-2 ms of significant acoustic emission burst) and injury definition B (injury occurs at the time of maximum moment) in dynamic valgus bending are shown Table 2. Plots of the moment-based and angle-based models along with associated 95% confidence intervals are shown in Figs. 7a and b, respectively.



- The curves for 95% CI come from statistical parameters related to the degree of data fit, and do not relate to individual variation of human data
- The blue curve in the middle is statistically THE BEST FIT TO DATA : there is no reason not to use this curve considering relatively small number of data available

Proposal for Human MCL Threshold

- No data duplication between Konosu et al. (2001) and Ivarsson et al. (2004) : simple average can be justified to take into account as many data as possible
- Data scaling does not affect injury risk functions for the MCL (bending angle) in both Konosu et al. and Ivarsson et al.
- Use of Injury Definition B in Ivarsson et al. is more appropriate to reasonably represent failure of the MCL
- 95% CI curves in Ivarsson et al. should not be used because the estimated risk function provide the best fit to the data

- Proposed bending angle threshold for human MCL : **19 deg** (virtually the same as previously proposed value)
- Flex-GTR MCL elongation threshold needs to be investigated based on the response correlation between the Flex-GTR and human lower limb