Flex-GTR:
Proposal for Tibia Bending Moment Injury Threshold

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Anthropometric Data

PMHS Data

Injury Risk Curve

Calculation of Maximum Tibia Bending Moment

Annotations

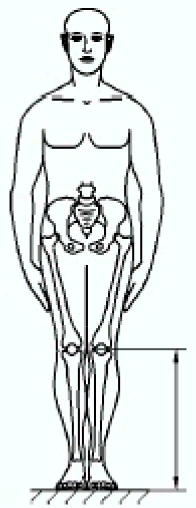
References

Anthropometric Data

- Values for tibial plateau height have been taken from DIN 33402-2
- Vertical distance from base to tibial plateau
- Statistically representative data (1999-2002) obtained from anthropometrical measurements of german inhabitants
- Value for 50th percentile Male aged 18-65 is in line with reference tibial plateau height of Kerrigan et al. (2004) ➔ 460,7 mm
- Within this study, the values for 50th percentile Male aged 41-60 and 61-65 (according to PMHS data used) taken into account

DIN 33402-2:2005-12

Tabelle 8 — Tibialhöhe



Altersgruppen	Tibialhöhe mm					
	Männer			Frauen		
	Perzentil					
Jahre	5	50	95	5	50	95
18–65	**430**	**460**	**480**	**400**	**425**	**450**
18–25	440	465	500	405	430	460
26–40	435	460	485	400	425	450
41–60	425	455	475	395	420	445
61–65	420	450	470	395	420	435

Source: DIN 33402-2 (2005)

PMHS Data

Test	Source	Gender	Age	Stature (cm)	Body Mass (kg)	Impact Speed (m/s)	Loading Direction	Peak BM at Midspan (CFC 60) [Nm]	Peak BM at Midspan M_{Max} [Nm]	Anatomical Measurement (Heel to Tibial Plateau) L [mm]	Standardized tibia height (DIN 33402-2) L_{ref} [mm]	Scaled Fracture Moment M_{scaled} [Nm]
118	Nyquist et. al.	M	54	182	68	3,5	LM*	395	434,5	520	455	291,1
124	Nyquist et. al.	M	64	177	82	4,2	LM*	287	315,7	490	450	244,5
126	Nyquist et. al.	M	58	174	73	4,2	LM*	224	246,4	480	455	209,9
127	Nyquist et. al.	M	56	176	79	3,7	LM*	237	260,7	465	455	244,2
129	Nyquist et. al.	M	57	178	99	3,7	LM*	349	383,9	500	455	289,3
132	Nyquist et. al.	M	57	187	45	3,8	LM*	264	290,4	445	455	310,4

*: Lateral to Medial

Source: Nyquist et al. (1985)

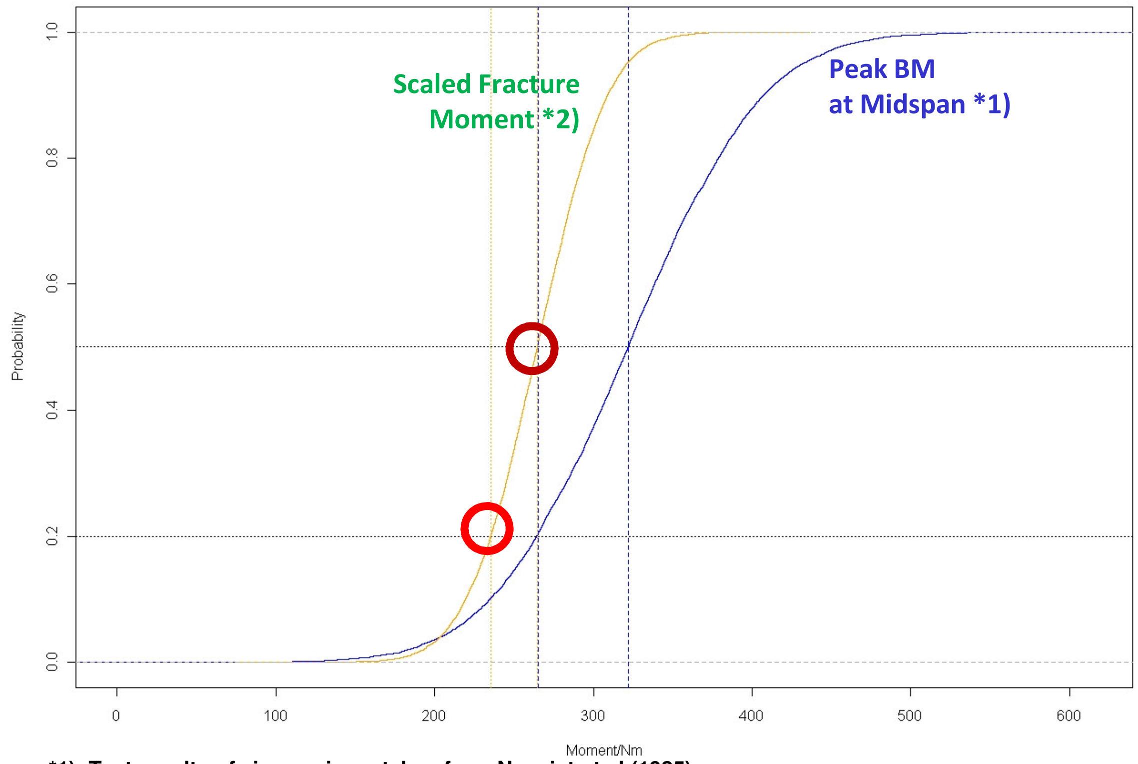
- **Consideration of six male tibia specimen tested by Nyquist et al. (1985) with known heel to tibia plateau heights**
- **Acquisition of Bending Moment to fracture at Midspan**
- **Due to attenuation of peak values by CFC 60 filtering: increase of bending moment values by 10% (➔ M_{max})**
- **Calculation of scaled Fracture Bending Moments according to the formula: $M_{scaled}=[(L_{ref}/L)^3]*M_{max}$**

Injury Risk Curve

Shapiro Wilk Normality Test results in Gaussian distribution of both the Peak BM at Midspan as well as the Scaled Fracture Moment results (P>95%).

Scaled Fracture Moment results take into account the standardized tibia heights of DIN.

Therefore, the injury risk thresholds are to be derived from this risk curve.



*1): Test results of six specimen taken from Nyquist et al (1985)
*2): according to formula $M_{scaled}=[(L_{ref}/L)^3]*M_{max}$ under consideration of DIN standardized tibia heights

Source: Pastor C. (2009)

20% risk of tibia fracture:

$$P_{0,2} = \sum_{1}^{6} M_{Max} / 6 = 235{,}7\,Nm$$

50% risk of tibia fracture:

$$P_{0,5} = \sum_{1}^{6} M_{Scaled} / 6 = 264{,}9\,Nm$$

Calculation of Maximum Tibia BM

Flex-GT Tibia Bending Moment = […] = 0,9977 * Human Tibia Bending Moment – 12,325

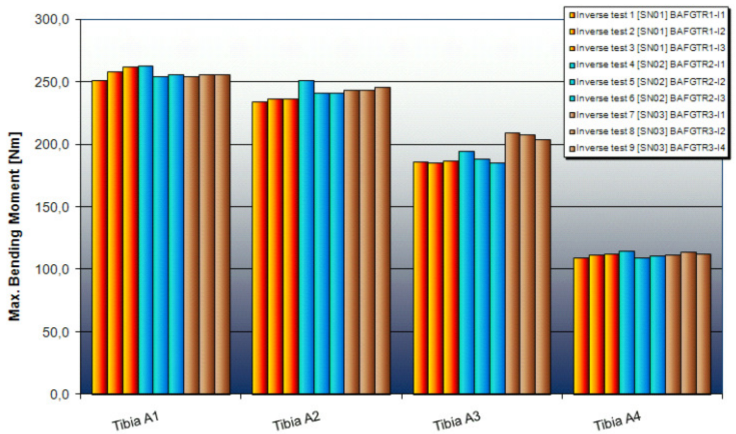
assumption: $H_{TBM} = HM_{TBM}$, $FGT_{MTBM} = FGT_{TBM}$
$FGT_{MTBM} = 0.9977 * HM_{TBM} - 12.325$ (from reguration curve)

Source: TEG-048

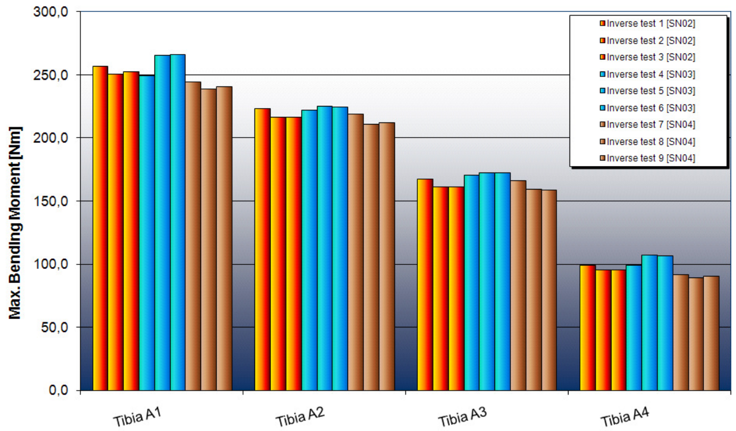
Flex-GT BM_{Tibia} = 0,9977 * 264,9 – 12,325 = 252 Nm

Increase of Flex-GTR BM_{Tibia} values compared to Flex-GT BM_{Tibia} :
A1: +1,83%, A2: +10,18%, A3: +17,04%, A4: +14,58%

➔ **Mean increase of Flex-GTR BM_{Tibia} compared to Flex-GT BM_{Tibia} in idealised tests: 11%**
(Flex-GT and Flex-GTR readings within ACEA/BASt joint projects on Flex-GT/GTR evaluation)



←Flex-GTR
Flex-GT →



Source: TEG-051

Calculation of Maximum Tibia BM

Flex-GTR Tibia Bending Moment =
1,11 * (0,9977 * Human Tibia Bending Moment – 12,325)

Flex-GTR BM_{Tibia} = 1,11 * (0,9977 * 264,9 – 12,325) = 279,7 Nm

Maximum deviation of tibia value from mean value within inverse tests: 7,66 %
(measured at Tibia A3)

Nine inverse tests with Flex-GTR, three with SN01, SN02, SN03 each, at 40 km/h

Test #	**Tibia A1**	**Tibia A2**	**Tibia A3**	**Tibia A4**
Inverse test 1 [SN01]	251,4	234,3	186,2	108,9
Inverse test 2 [SN01]	257,9	236,6	184,9	111,8
Inverse test 3 [SN01]	262,0	236,1	186,8	112,7
Inverse test 4 [SN02]	262,7	251,3	194,9	114,5
Inverse test 5 [SN02]	254,0	241,2	188,4	108,9
Inverse test 6 [SN02]	256,1	240,9	185,1	110,5
Inverse test 7 [SN03]	254,2	243,2	209,0	111,5
Inverse test 8 [SN03]	255,8	243,7	207,9	113,6
Inverse test 9 [SN03]	255,6	245,8	204,0	112,6
MV	256,63	241,46	194,13	111,67
CV	**1,44**	**2,21**	**5,23**	**1,75**
Max	262,70	251,30	209,00	114,50
Min	251,40	234,30	184,90	108,90
max. Dev. from MV [%]	2,36	4,08	**7,66**	2,54

Upper Performance Limit (UPL) = Flex-GTR BM_{Tibia} / 1,0766 = 259,8 Nm
Lower Performance Limit (LPL) = Flex-GTR BM_{Tibia} * 1,0766 = 301,1 Nm

As type approval requires pass-/fail threshold:
Proposed Threshold Value for Flex-GTR Max. Tibia Bending Moment: 302 Nm

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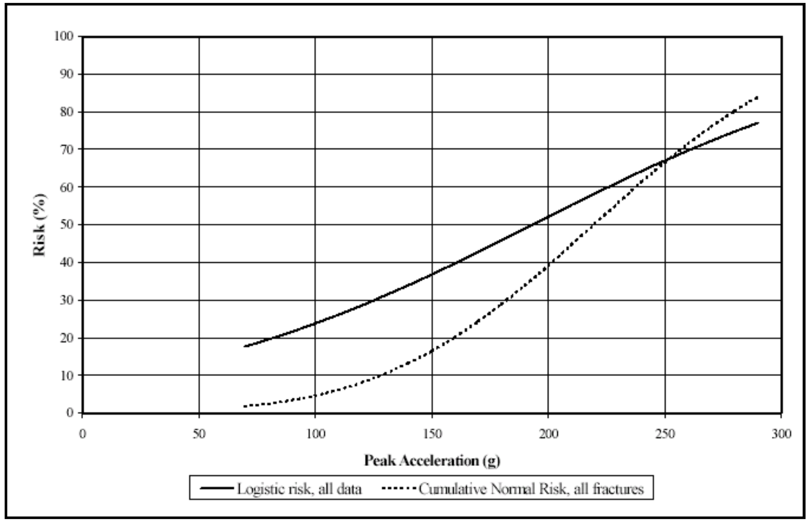
- This study is limited to six cases under consideration of the anthropometric data according to DIN that is in line with Kerrigan et al. (2004).

- The test results of those six cases are found to be Gaussian distributed (not Weibull).

- The study is based on a 50% risk of tibia fracture, but:

- EEVC WG 17 proposed a maximum tibia acceleration of 150 g equal to almost 20% risk for an AIS 2+ lower leg fracture.



Source: EEVC (2002)

References

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Thank you!