Influence Of Test Parameter Variations On The Flex GTR Joint Project of ACEA and BASt

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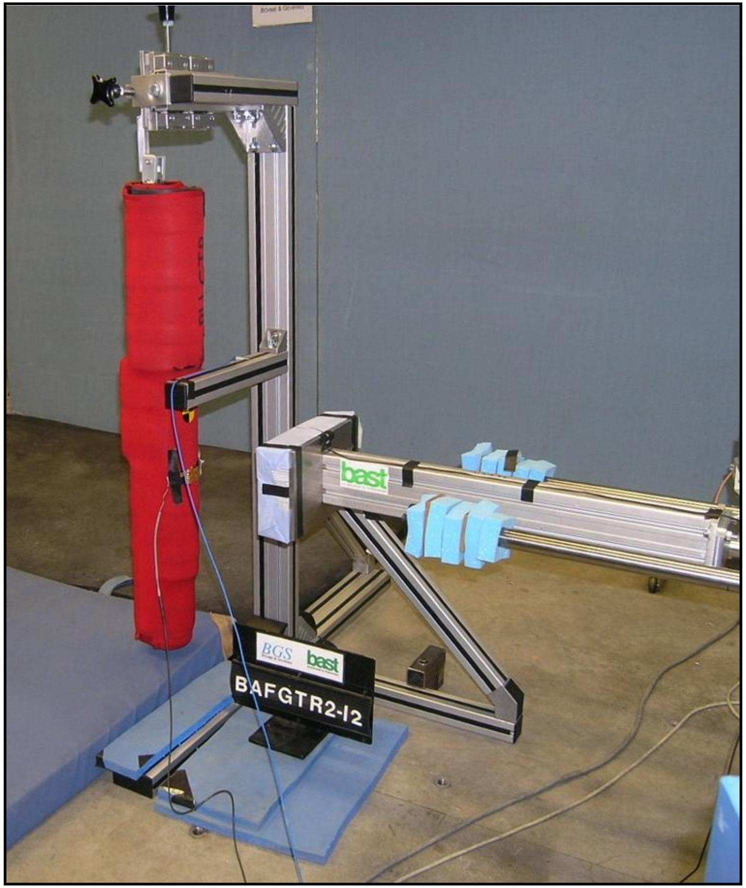
Test Objective

- Determination of the influence of test parameter variations on the sensor outputs of the Flexible Pedestrian Legform Impactor Flex PLI, Version GTR, using the inverse test setup

- The influence of the following test parameters was investigated:
  - Impact angle (Rotation around z-axis)
  - Impact height
  - Impact velocity

Test Programme

Test No.	Parameter
BAFGTR2-I4	**Reference Tests w/o Variation (previous project)**
BAFGTR2-I5	
BAFGTR2-I6	
BAFGTR2IA-10-1	**Z-Rotation -10°**
BAFGTR2IA-10-2	
BAFGTR2IA-10-3	
BAFGTR2IA10-1	**Z-Rotation +10°**
BAFGTR2IA10-2	
BAFGTR2IA10-3	
BAFGTR2IH-10-1	**Impact Height -10mm**
BAFGTR2IH-10-2	
BAFGTR2IH-10-3	
BAFGTR2IH-10-4	
BAFGTR2IH10-1	**Impact Height +10mm**
BAFGTR2IH10-2	
BAFGTR2IH10-3	
BAFGTR2IV-0.5-1	**Impact Velocity -0,5m/s**
BAFGTR2IV-0.5-2	
BAFGTR2IV-0.5-3	
BAFGTR2IV-1.0-1	**Impact Velocity -1,0 m/s**
BAFGTR2IV-1.0-2	
BAFGTR2IV-1.0-3	
BAFGTR2IV-1.0-4	
BAFGTR2IV0.5-1	**Impact Velocity +0,5m/s**
BAFGTR2IV0.5-2	
BAFGTR2IV0.5-3	
BAFGTR2IV1.0-1	**Impact Velocity +1,0m/s**
BAFGTR2IV1.0-2	
BAFGTR2IV1.0-3	



Test Results (1)

Test No.	Velocity [m/s]	Femur A3 [Nm]	Femur A2 [Nm]	Femur A1 [Nm]	Tibia A1 [Nm]	Tibia A2 [Nm]	Tibia A3 [Nm]	Tibia A4 [Nm]	ACL [°]	PCL [°]	MCL [°]	LCL [°]	Accel-eration [g]	Tempe-rature[°]	Parameter
BAFGTR2-I4	10,94	90,2	156,4	201,6	261,8	250,7	193,2	109,5	12,1	5,1	20,9	14,3	245,7	19,7	Reference tests w/o variation
BAFGTR2-I5	10,94	88,4	153	198,1	259,7	244,4	190,4	107,4	11,7	5	20,5	15,1	249,3	19,9	
BAFGTR2-I6	10,96	87,6	151,9	197,8	260,4	245,3	192,1	107,9	11,4	5,2	20,6	15,5	248,8	19,8	
BAFGTR2IA-10-1	11,18	79,5	138,3	189,2	268,3	246,0	190,0	108,0	9,8	5,3	19,9	12,0	249,2	20,5	Z-Rotation -10°
BAFGTR2IA-10-2	11,09	77,4	138,3	182,6	260,4	245,6	188,8	104,6	10,2	4,9	19,2	13,9	230,8	20,5	
BAFGTR2IA-10-3	11,17	78,1	137,8	182,9	264,1	244,7	187,7	106,0	10,1	4,8	19,3	13,4	237,2	20,7	
BAFGTR2IA10-1	11,09	81,1	141,3	189,1	264,6	245,4	186,7	105,2	10,4	5,2	19,9	13,6	239,0	20,6	Z-Rotation +10°
BAFGTR2IA10-2	11,03	81,8	139,8	187,5	261,0	246,4	189,7	105,7	10,8	4,8	19,5	10,1	236,2	20,8	
BAFGTR2IA10-3	11,05	79,5	139,0	187,2	269,7	250,9	192,3	106,4	11,2	4,8	19,4	14,9	242,7	20,9	
BAFGTR2IH-10-1	11,23	77,7	139,4	189,7	263,0	252,3	194,0	104,4	10,8	5,0	20,4	15,5	224,3	20,1	Height -10mm
BAFGTR2IH-10-3	11,12	76,8	137,0	190,6	268,1	253,9	194,1	105,1	9,4	4,9	19,4	13,8	230,6	20,4	
BAFGTR2IH-10-4	11,22	74,1	136,5	184,2	270,1	256,3	194,2	96,1	9,7	5,1	19,5	15,6	227,9	20,5	
BAFGTR2IH10-1	11,22	90,1	153,1	204,0	257,1	235,9	179,4	102,1	11,5	5,1	21,4	13,2	258,0	20,6	Height +10mm
BAFGTR2IH10-2	11,22	92,4	155,8	205,5	253,5	234,3	177,0	99,7	10,4	5,2	21,4	12,7	242,3	20,6	
BAFGTR2IH10-3	11,16	90,1	155,4	204,7	256,6	233,0	177,5	99,9	10,0	5,4	21,1	12,6	247,4	20,3	

Test Results (2)

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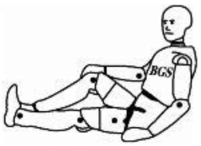
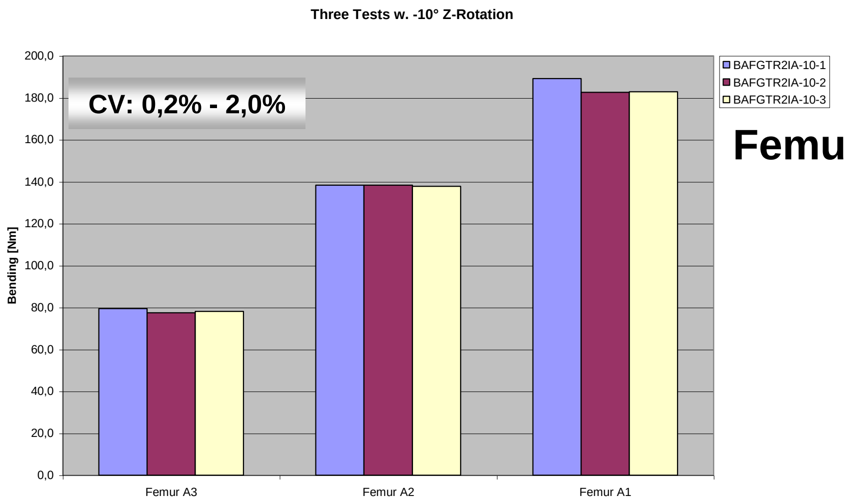
Test No.	Velocity [m/s]	Femur A3 [Nm]	Femur A2 [Nm]	Femur A1 [Nm]	Tibia A1 [Nm]	Tibia A2 [Nm]	Tibia A3 [Nm]	Tibia A4 [Nm]	ACL [°]	PCL [°]	MCL [°]	LCL [°]	Accel-eration [g]	Tempe-rature[°]	Parameter
BAFGTR2IV-1.0-1	10,14	67,5	127,0	169,7	245,2	235,0	179,2	98,7	10,1	4,2	17,7	12,4	228,3	20,4	Velocity -1,0 m/s
BAFGTR2IV-1.0-2	10,11	71,6	130,5	172,6	239,1	229,9	177,4	98,4	9,1	5,0	17,9	13,9	227,8	19,8	
BAFGTR2IV-1.0-3	10,08	78,4	135,6	174,5	236,1	224,3	174,4	98,7	9,3	4,6	18,4	11,5	230,8	20,3	
BAFGTR2IV-1.0-4	10,09	82,0	140,0	180,7	233,9	220,1	171,8	98,3	10,4	4,7	18,9	9,9	232,7	20,8	
BAFGTR2IV-0.5-1	10,71	82,5	144,2	190,9	248,8	236,8	183,0	102,2	10,0	4,8	19,2	11,5	238,7	20,0	Velocity -0,5m/s
BAFGTR2IV-0.5-2	10,70	76,3	138,8	185,3	252,0	237,9	184,4	101,7	10,8	4,8	19,0	11,1	244,9	20,2	
BAFGTR2IV-0.5-3	10,50	74,4	136,7	181,2	249,0	235,6	182,5	101,5	10,5	4,8	19,1	13,2	246,6	20,3	
BAFGTR2IV0.5-1	12,01	80,4	147,9	199,1	283,0	264,0	203,7	115,0	11,1	5,4	21,2	14,3	254,6	20,1	Velocity +0,5m/s
BAFGTR2IV0.5-2	11,97	82,7	150,7	202,6	282,9	257,6	200,0	112,5	10,6	5,7	21,2	13,8	238,8	20,0	
BAFGTR2IV0.5-3	11,89	86,6	154,3	206,1	279,0	262,2	200,0	110,8	11,0	5,4	21,2	14,4	262,9	20,2	
BAFGTR2IV1.0-1	12,10	83,6	148,9	205,9	280,6	257,9	198,3	108,3	11,1	5,6	21,3	15,3	245,6	20,8	Velocity +1,0m/s
BAFGTR2IV1.0-2	12,09	82,9	148,0	203,0	284,4	263,8	202,6	112,7	11,0	5,4	20,8	15,2	260,9	21,1	
BAFGTR2IV1.0-3	12,05	84,0	148,8	202,0	283,7	263,0	201,9	112,5	10,9	5,3	20,6	15,3	258,9	21,0	



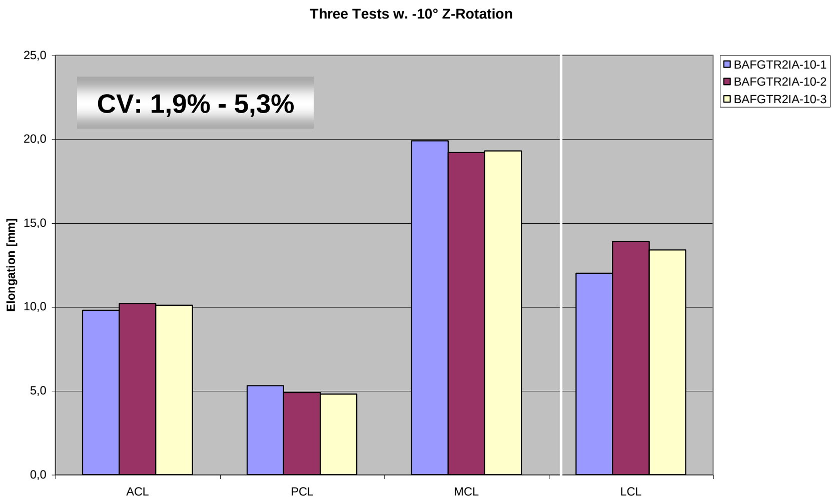
Rotation around Z-axis

- Evaluation Diagrams
  - Results of tests with -10°
  - Results of tests with +10°
  - Comparison of average values
  - Quantification diagrams:
    - Tibia moments vs. rotation variation
    - Knee elongations vs. rotation variation

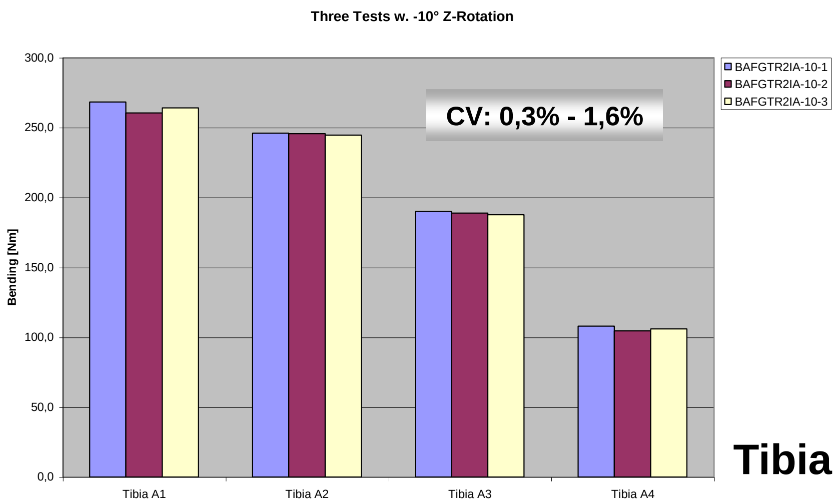
Rotation around z-axis:
Results of three tests with -10°



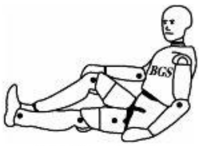
Femur bending moments



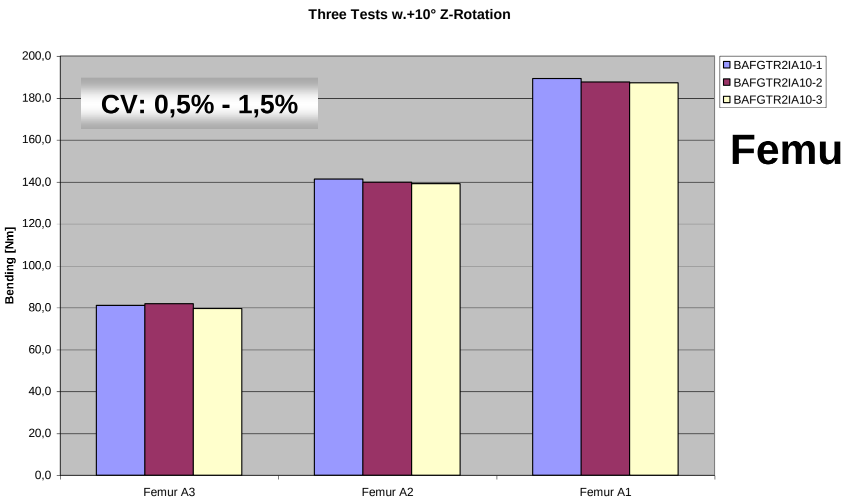
Knee elongations



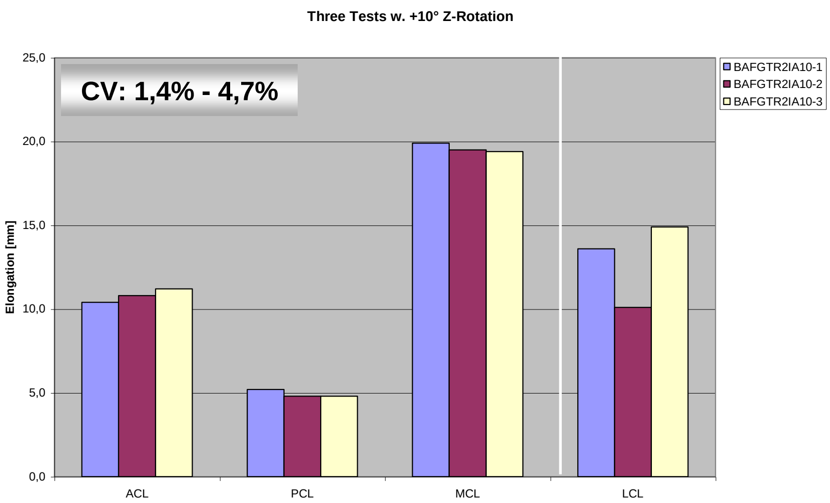
Tibia bending moments



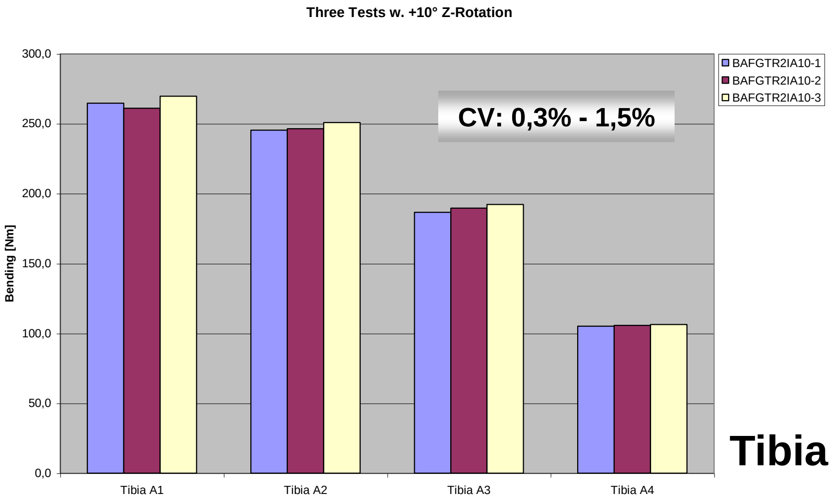
Rotation around z-axis:
Results of three tests with +10°



Femur bending moments

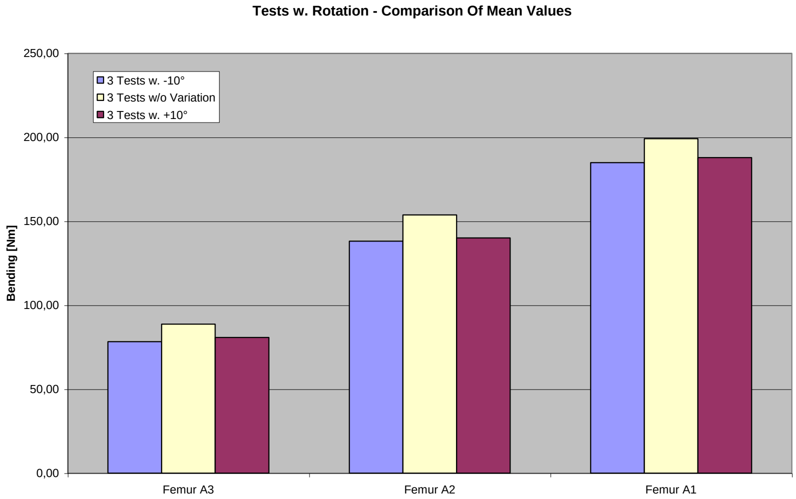


Knee elongations

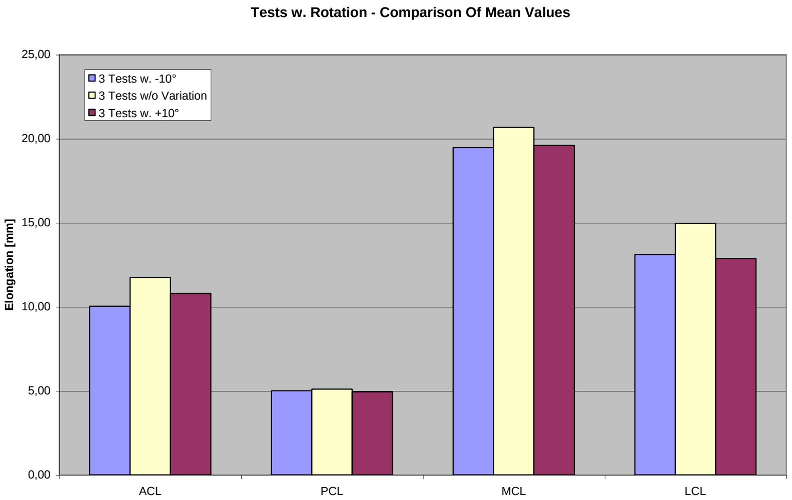


Tibia bending moments

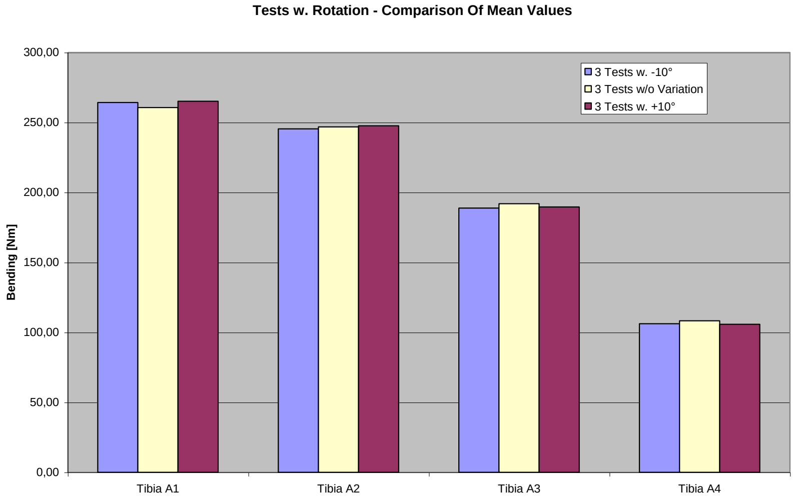
Rotation around z-axis (-10°, 0, +10°): Comparison of average values



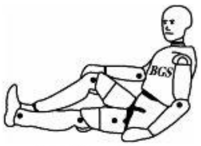
Femur bending moments



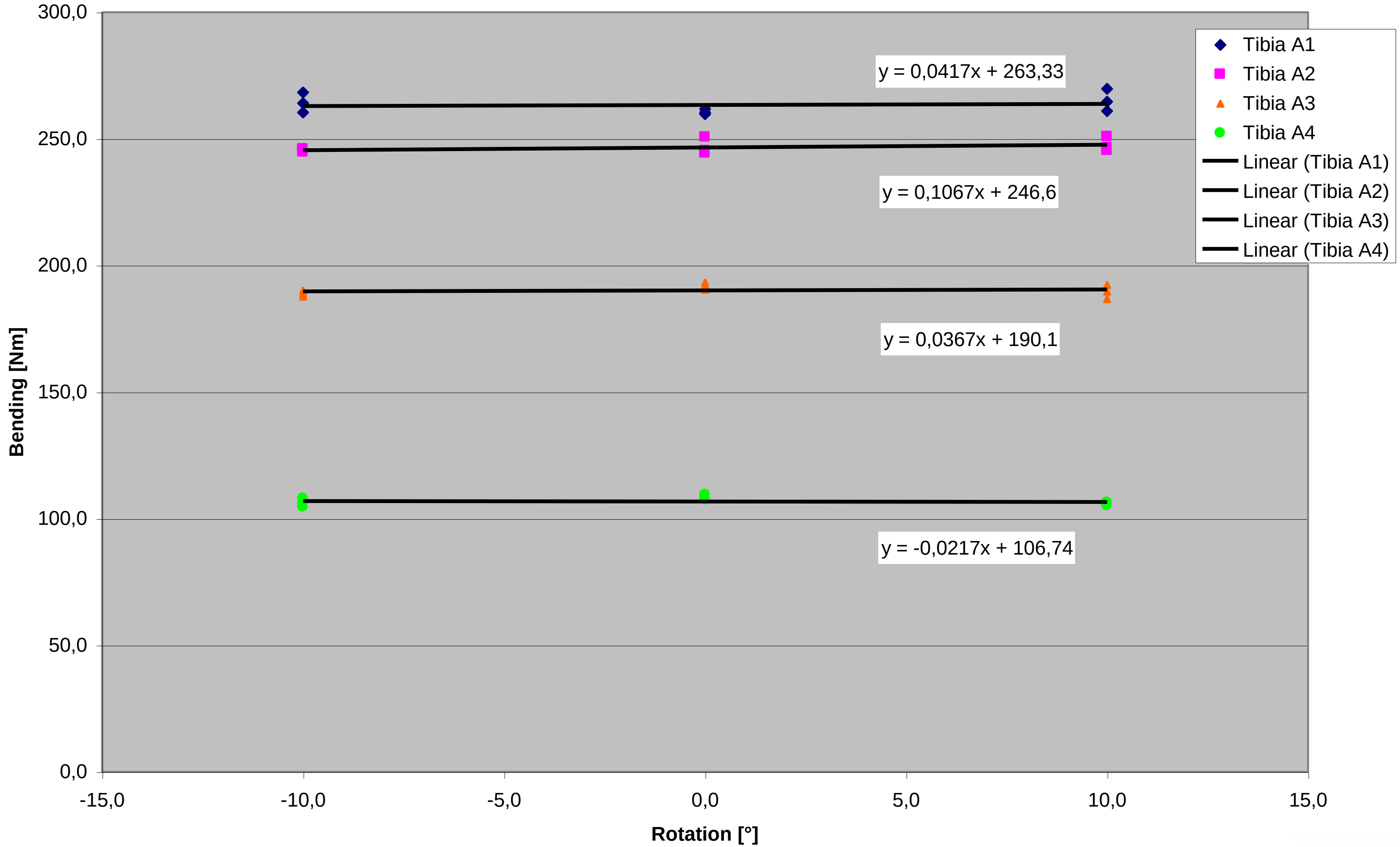
Knee elongations



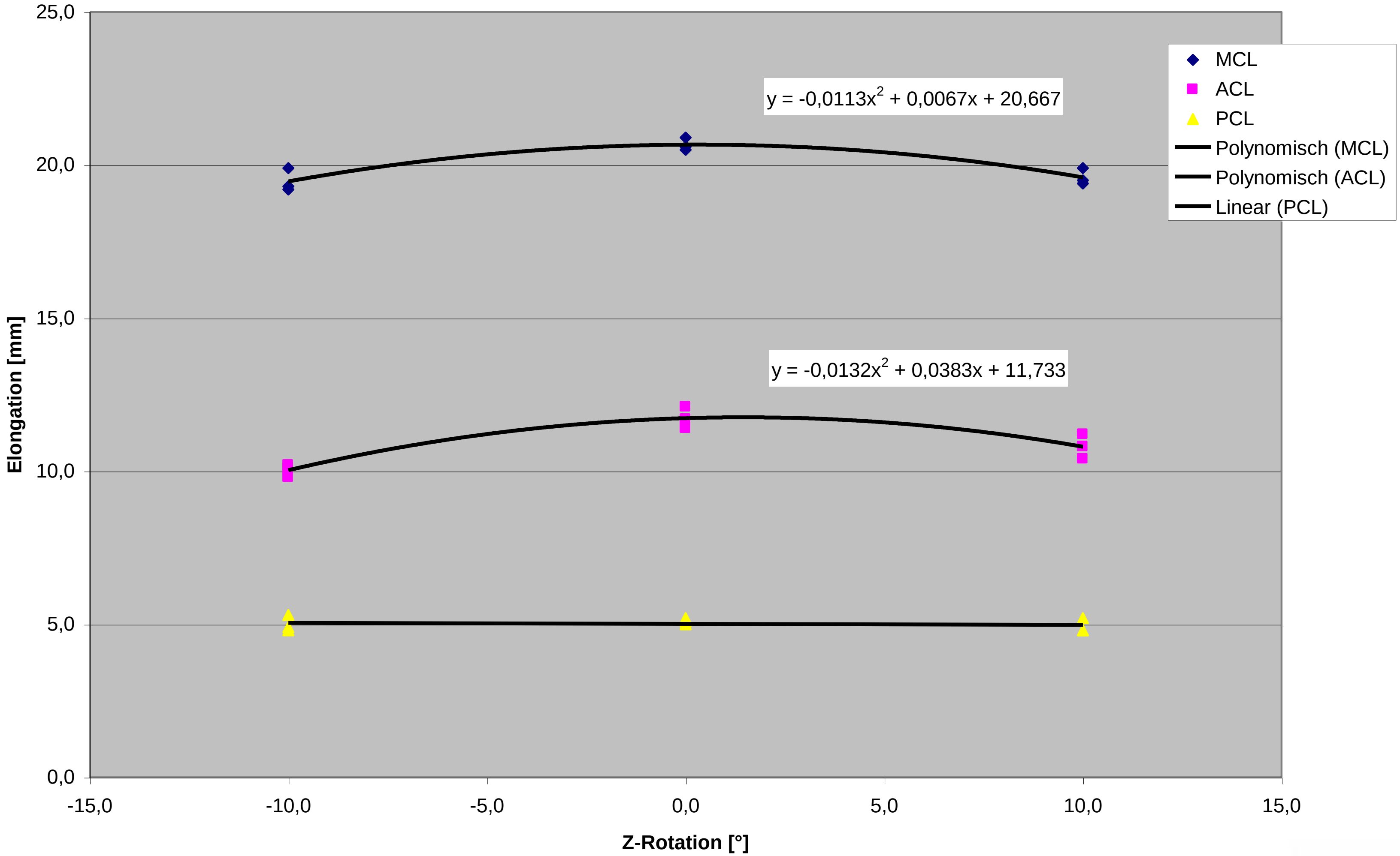
Tibia bending moments



Rotation around z-axis: Tibia Bending Moments



Rotation around z-axis: Knee Elongations

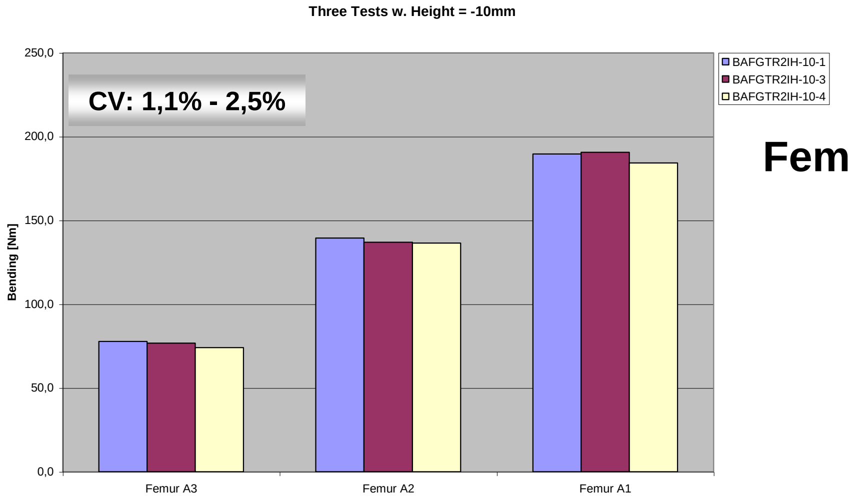


Impact height variation

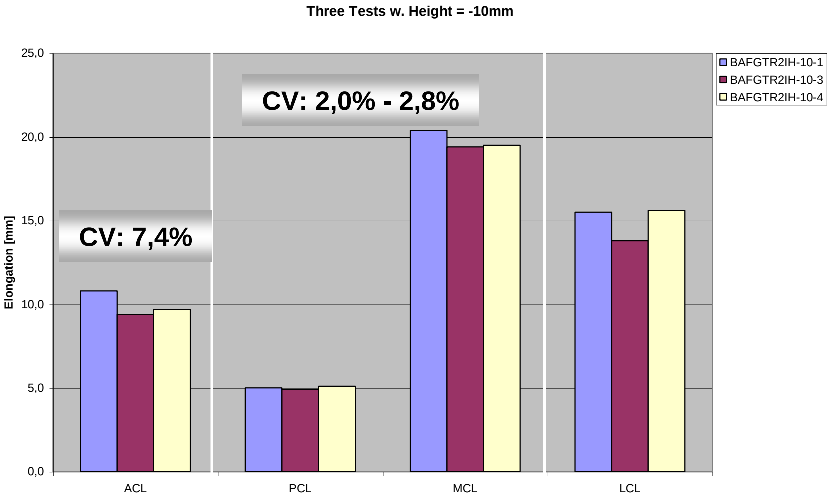
- Evaluation Diagrams
  - Results of tests with -10 mm
  - Results of tests with +10 mm
  - Comparison of average values
  - Quantification diagrams:
    - Tibia moments vs. height variation
    - Femur moments vs. height variation
    - Knee elongations vs. height variation

Impact height variation: Results of three tests with -10mm

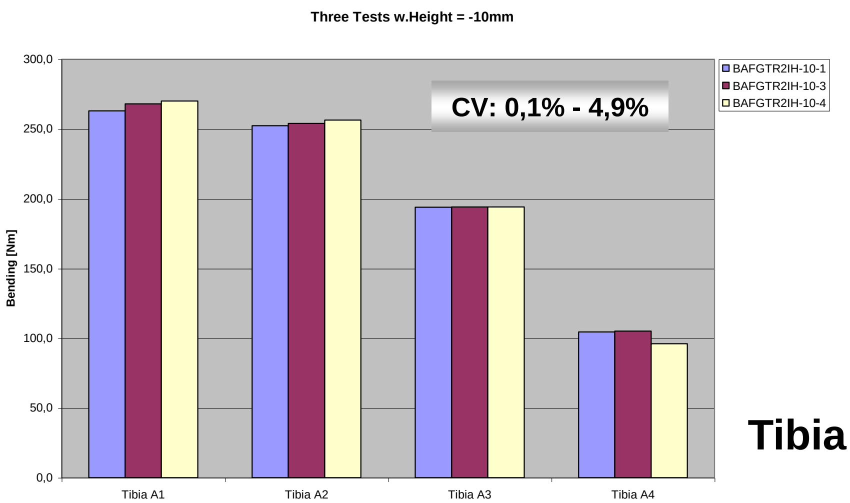
BGS



Femur bending moments

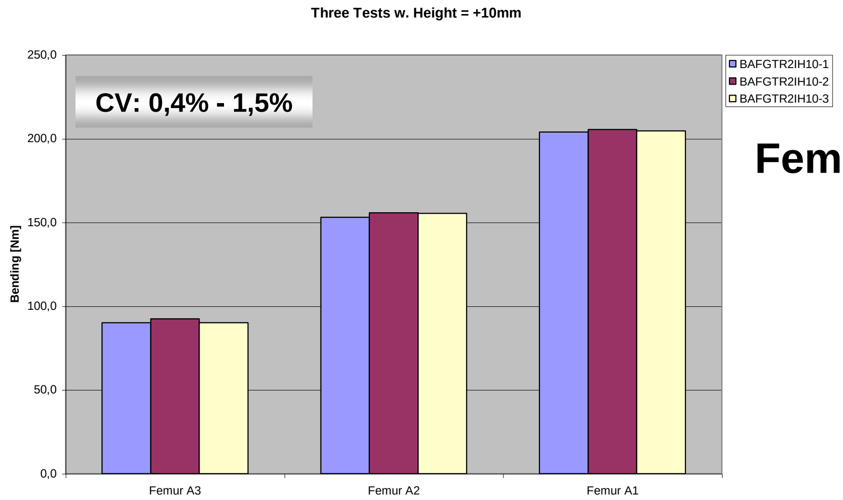


Knee elongations

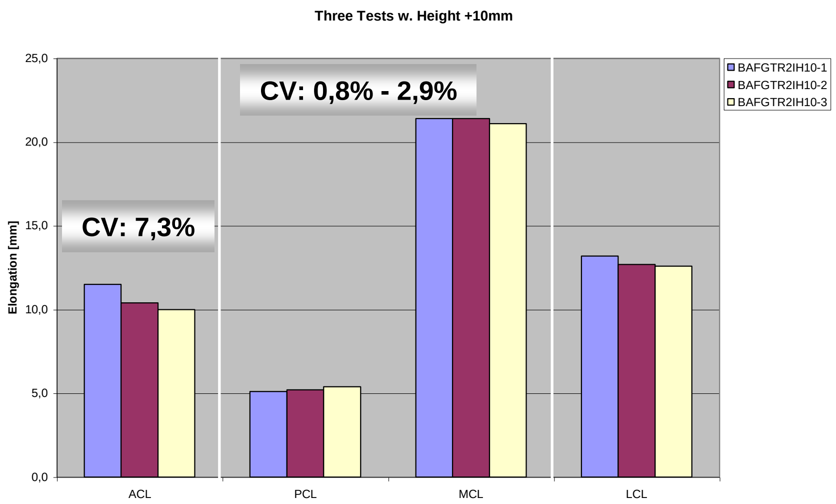


Tibia bending moments

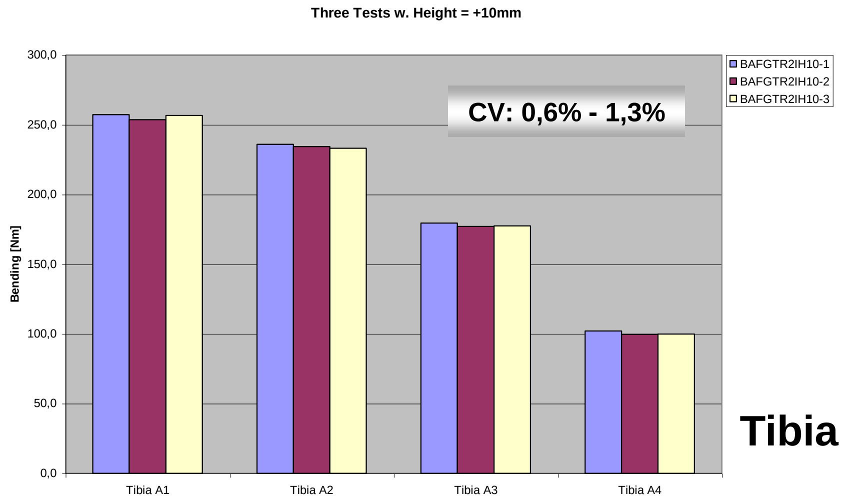
Impact height variation:
Results of three tests with +10mm



Femur bending moments

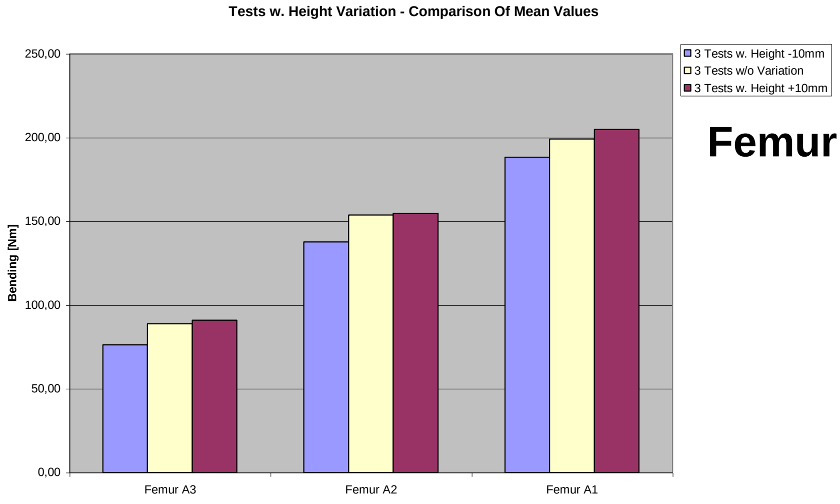


Knee elongations

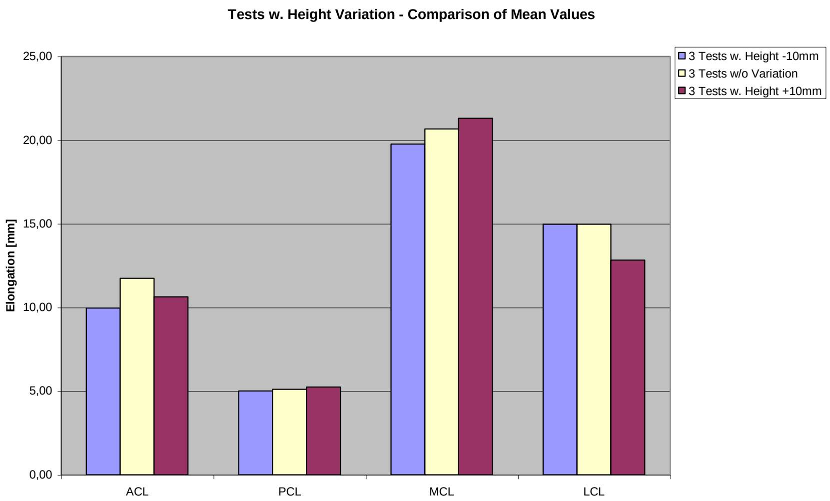


Tibia bending moments

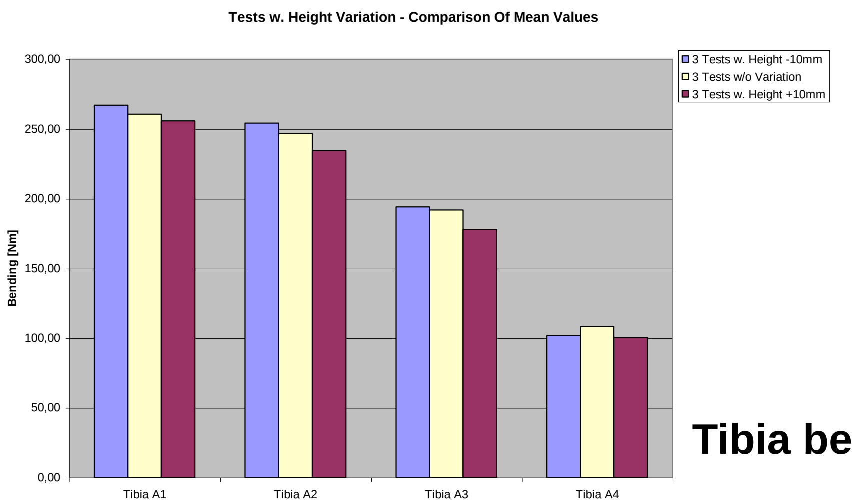
Impact height variation (-10mm, 0, +10mm): Comparison of average values



Femur bending moments

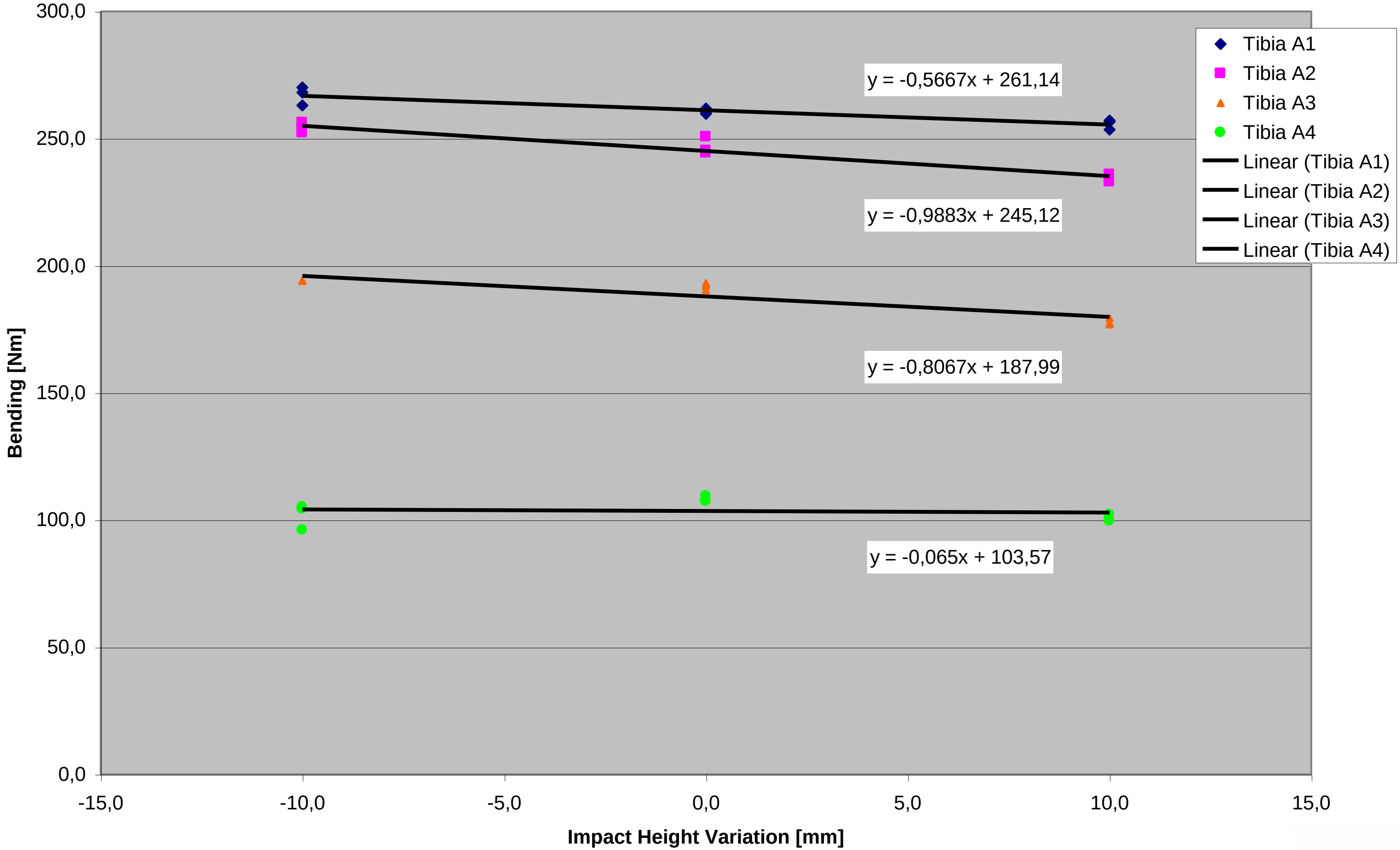


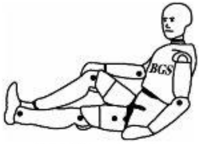
Knee elongations



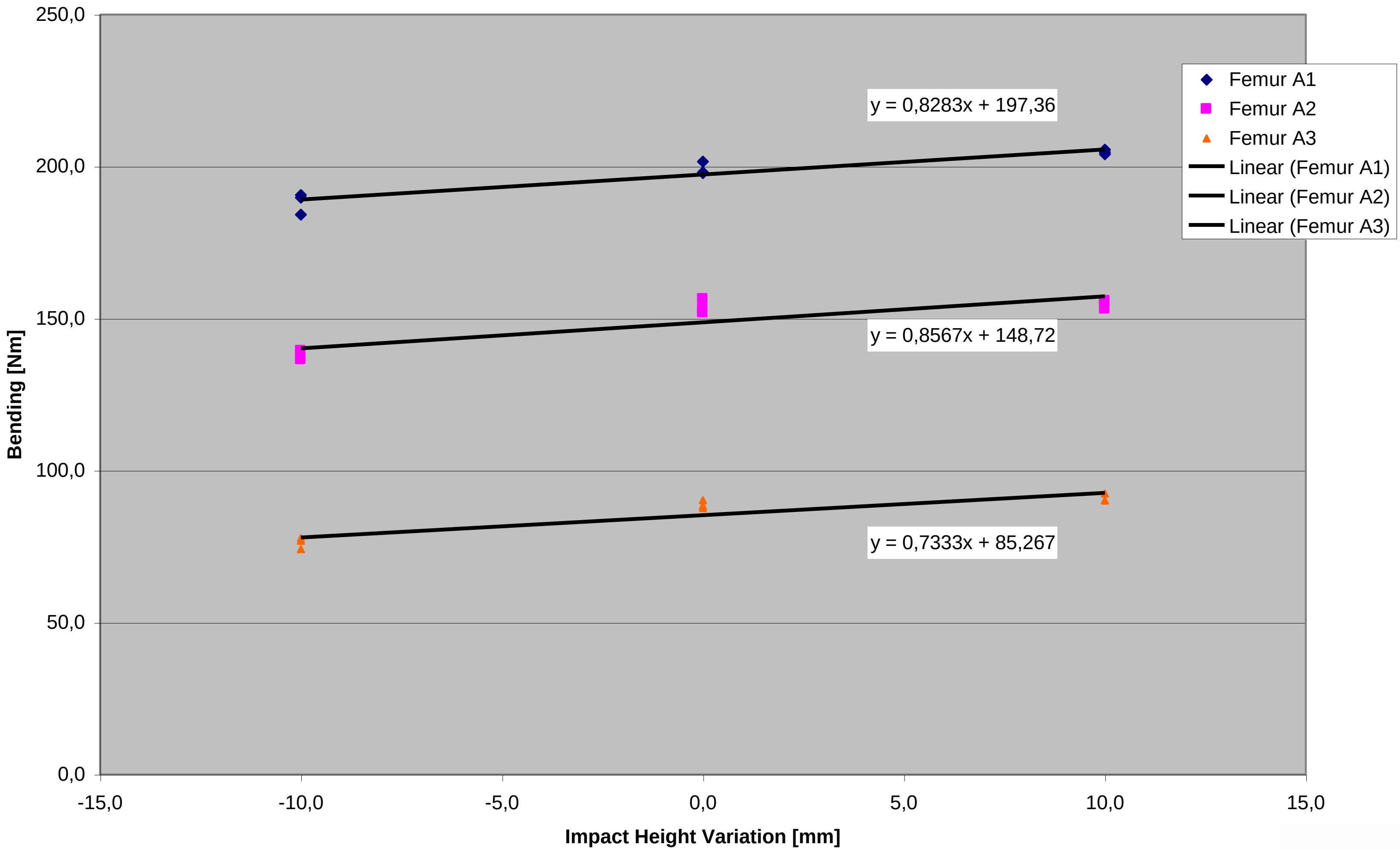
Tibia bending moments

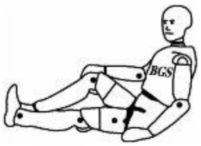
Impact height variation: Tibia Bending Moments





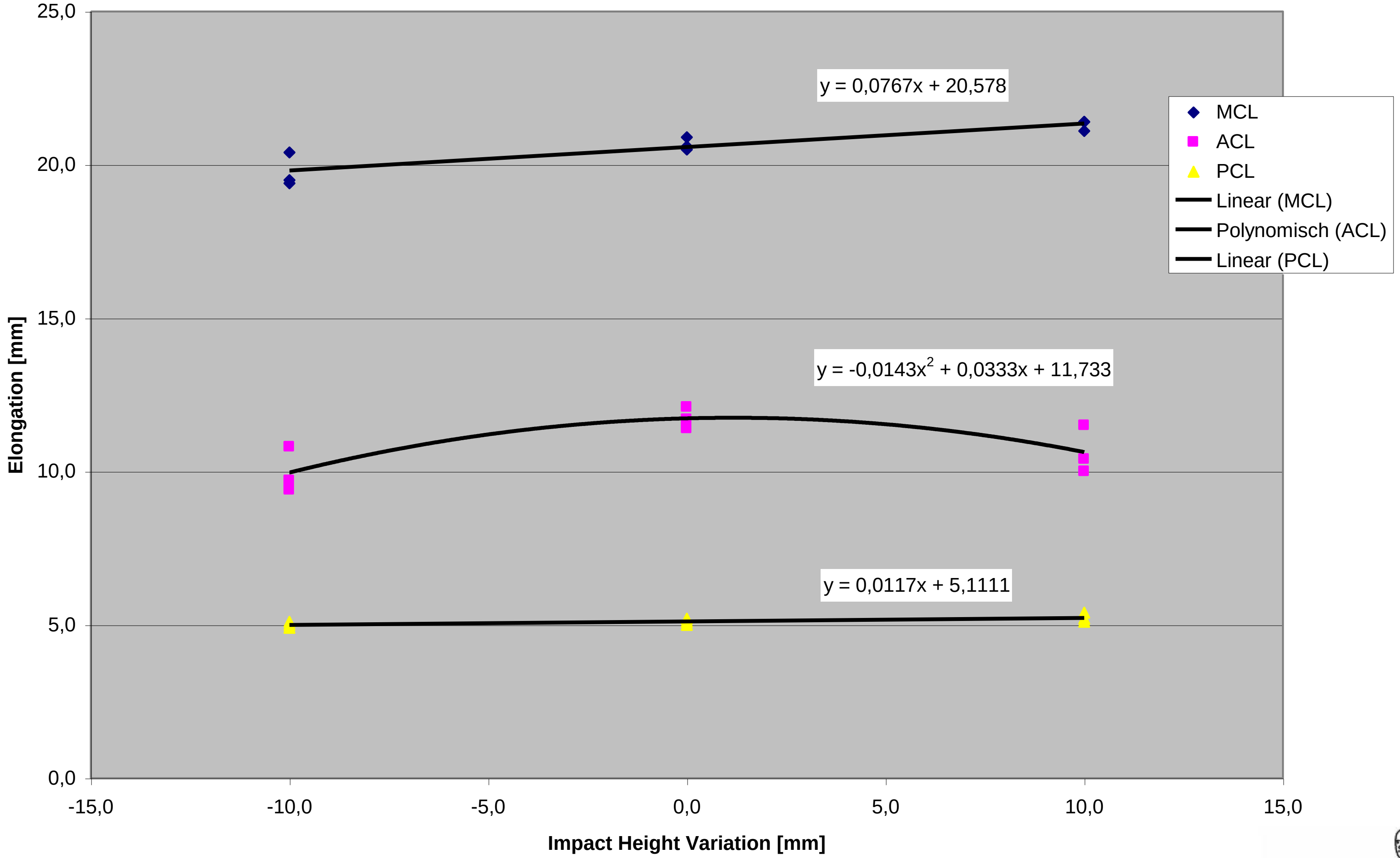
Impact height variation: Femur Bending Moments





Impact height variation: Knee Elongations

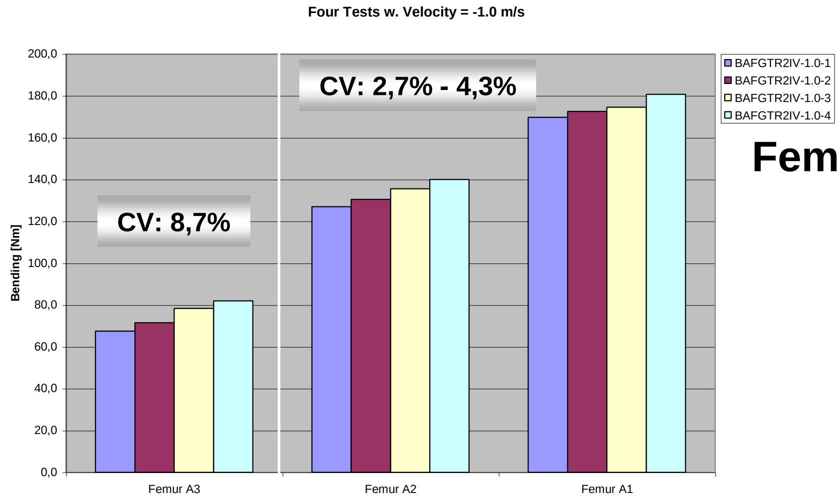
BGS



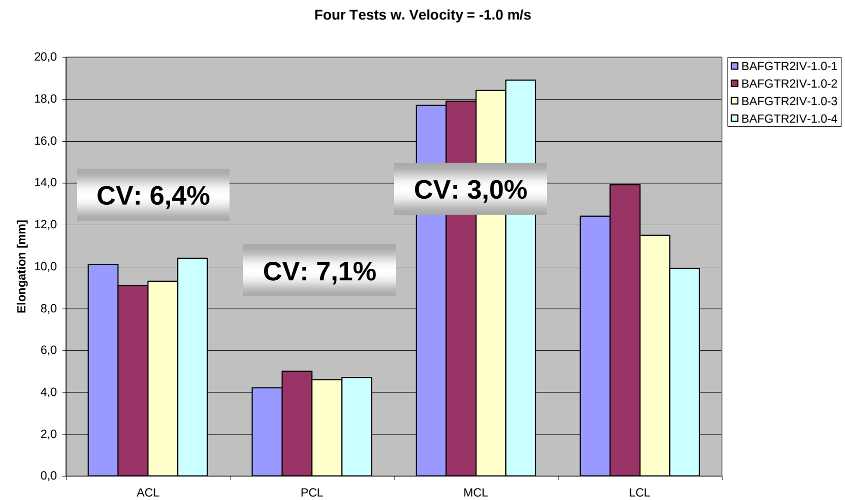
Impact Velocity Variation

- Evaluation Diagrams
  - Results of tests with -1.0 m/s
  - Results of tests with -0.5 m/s
  - Results of tests with +0.5 m/s
  - Results of tests with +1.0 m/s
  - Comparison of average values
  - Quantification diagrams:
    - Tibia moments vs. impact velocity
    - Knee elongations vs. impact velocity

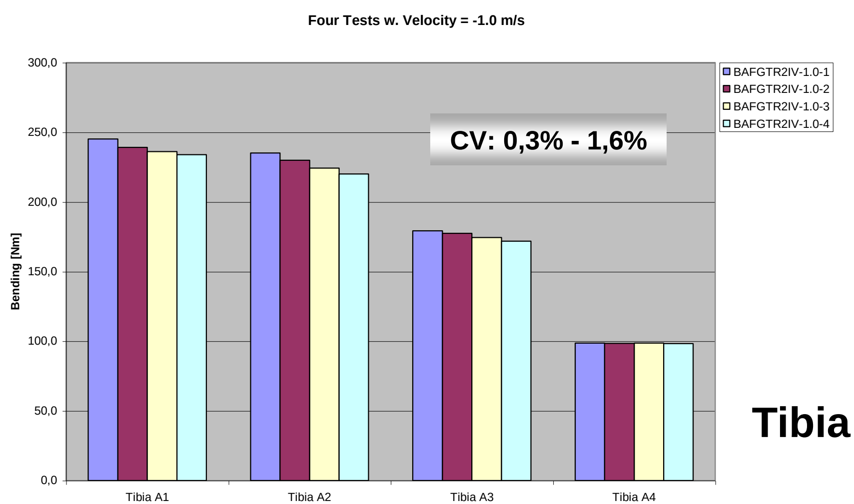
Impact velocity variation:
Results of four tests with –1.0 m/s



Femur bending moments

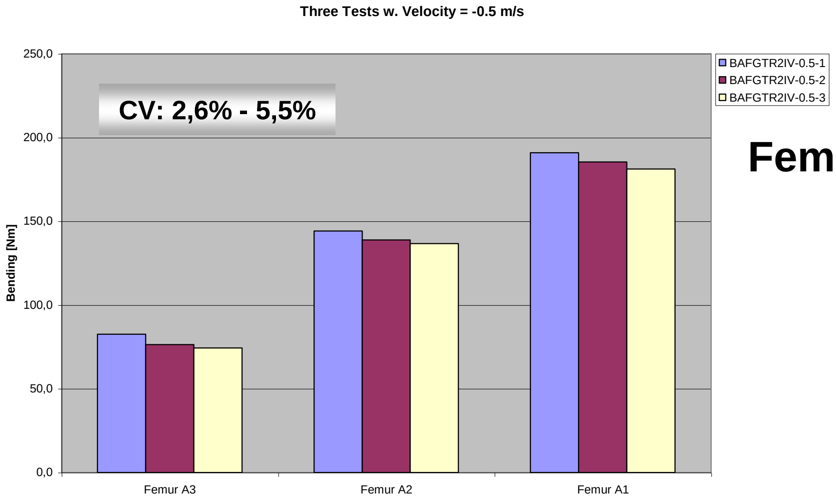


Knee elongations

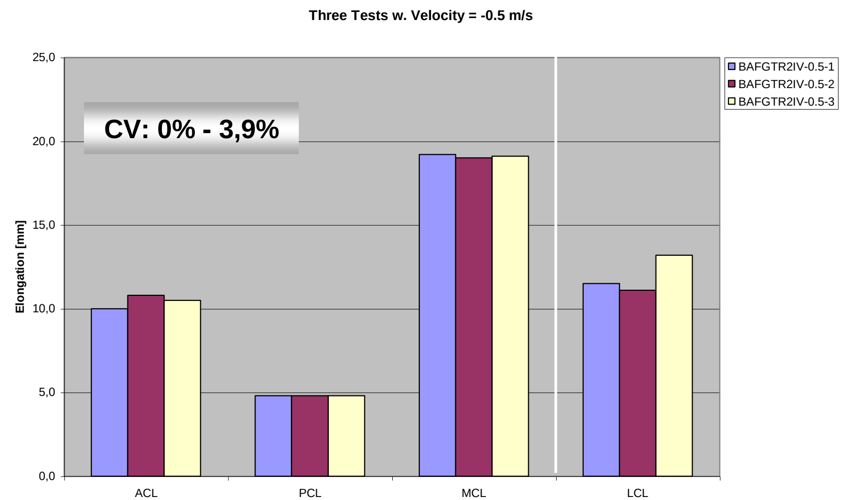


Tibia bending moments

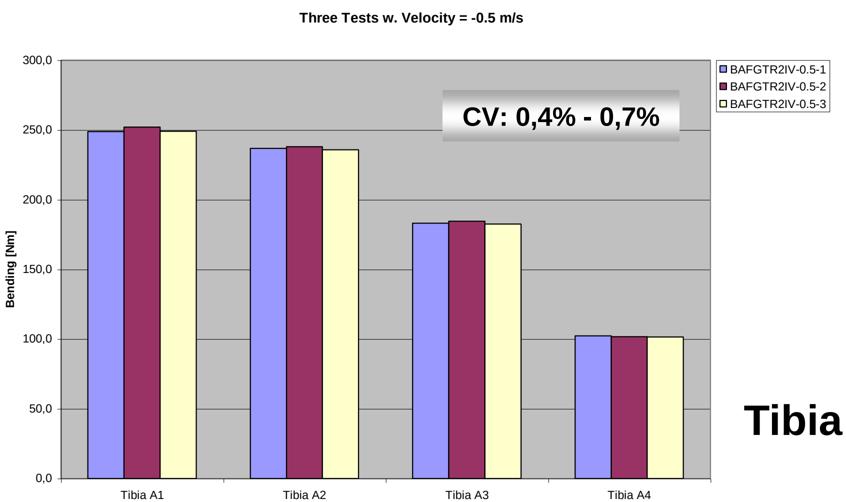
Impact velocity variation:
Results of three tests with –0.5 m/s



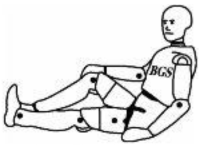
Femur bending moments



Knee elongations



Tibia bending moments



Impact velocity variation:
Results of three tests with +0.5 m/s

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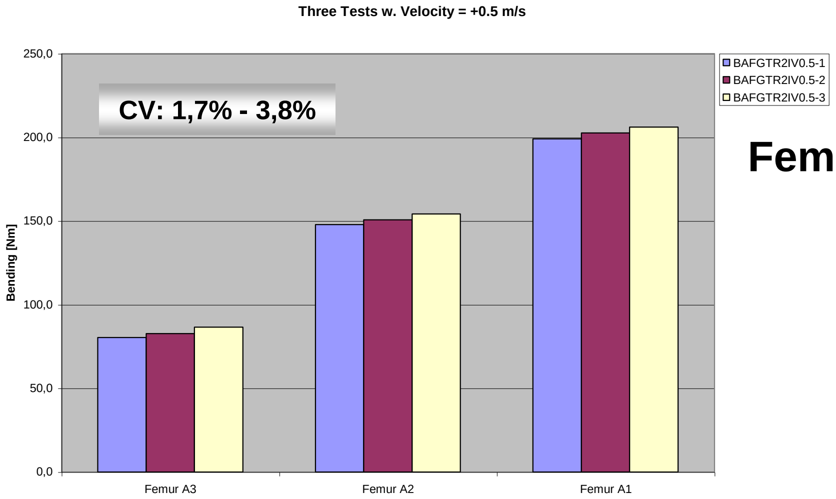
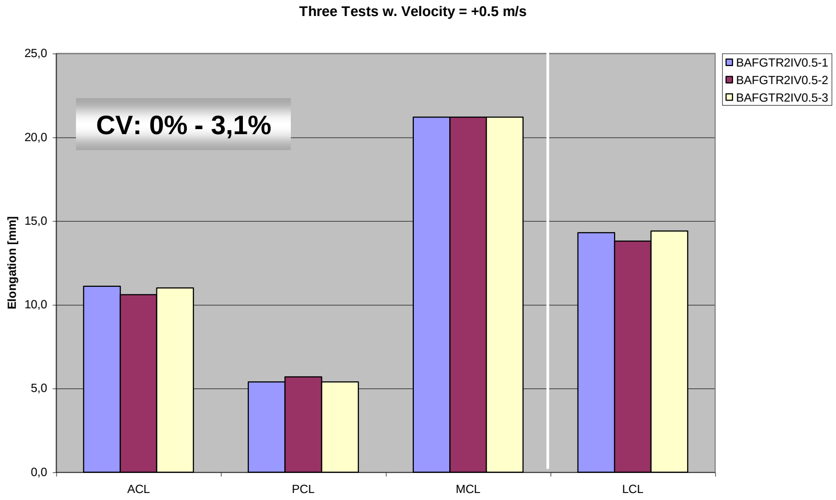
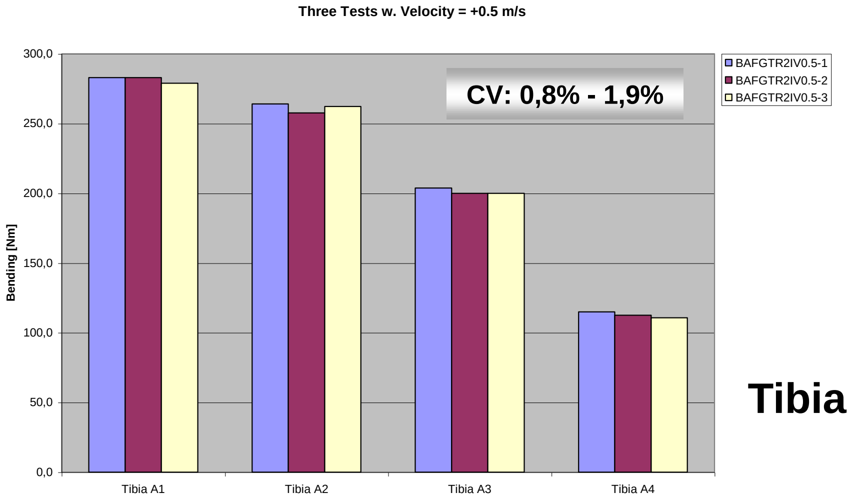


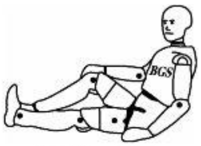
Femur bending moments



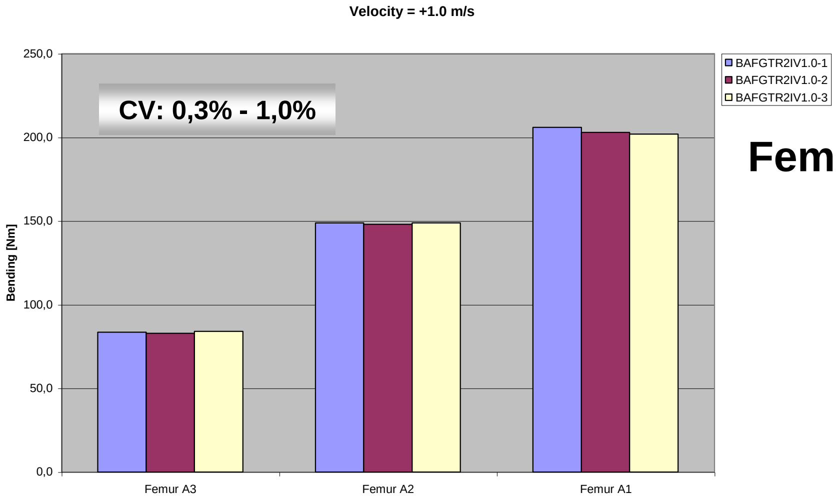
Knee elongations



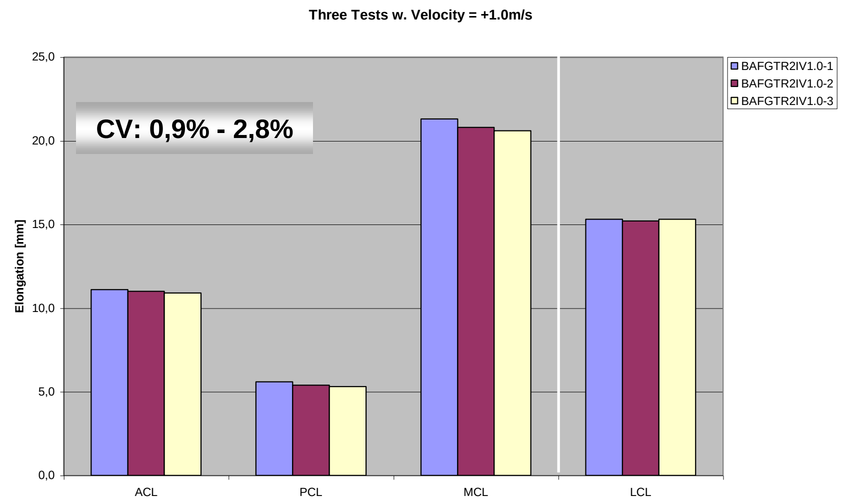
Tibia bending moments



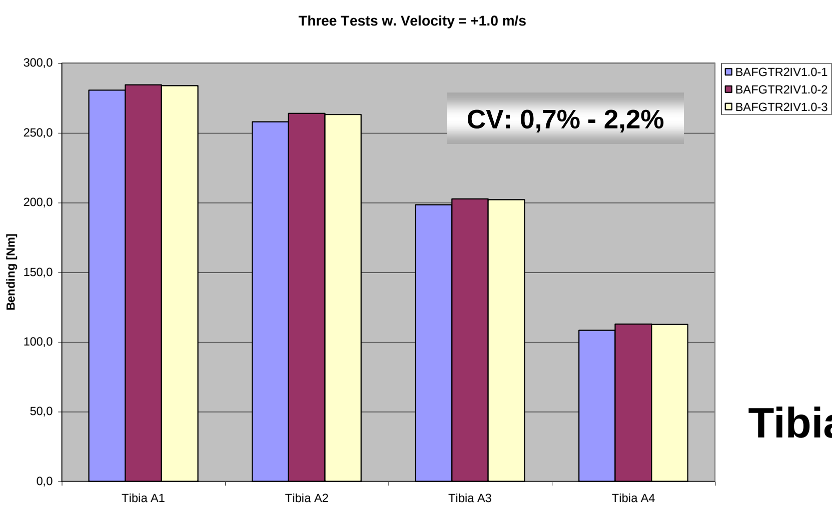
Impact velocity variation:
Results of three tests with +1.0 m/s



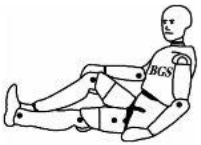
Femur bending moments



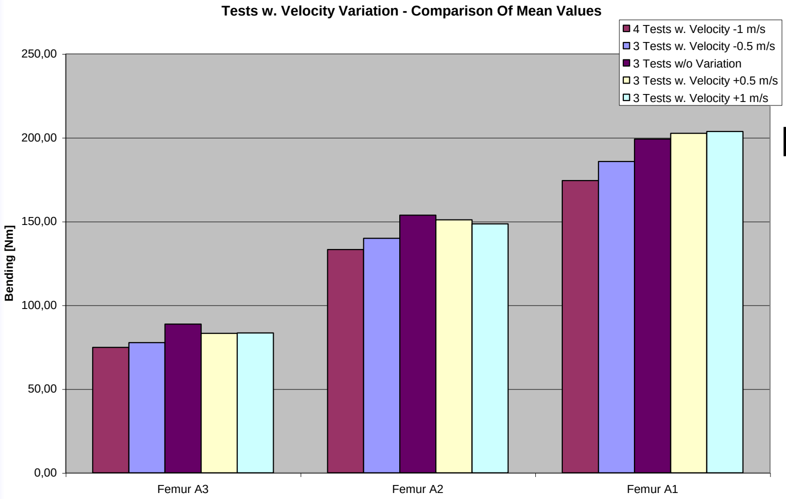
Knee elongations



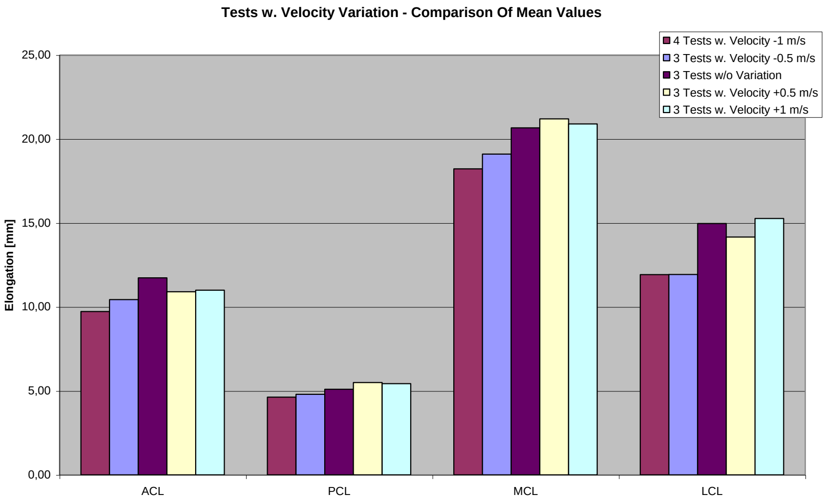
Tibia bending moments



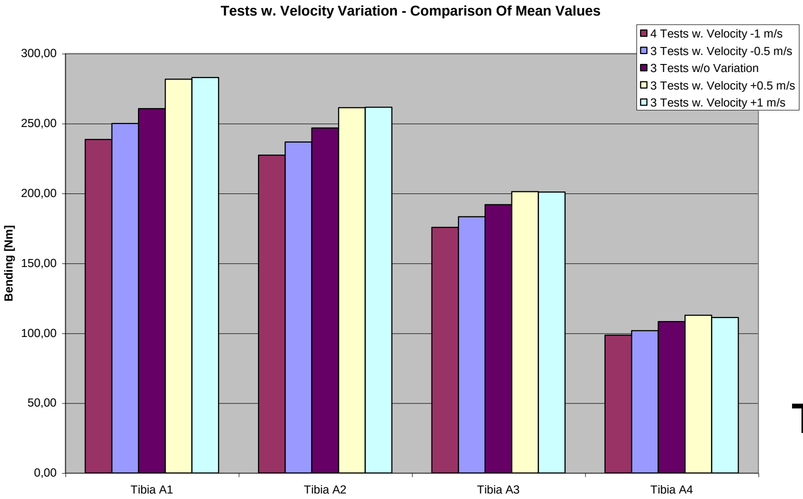
Impact velocity variation (-0.5, -1, 0, +0.5, +1 m/s): Comparison of average values



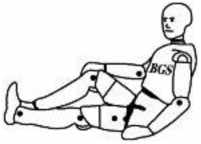
Femur bending moments



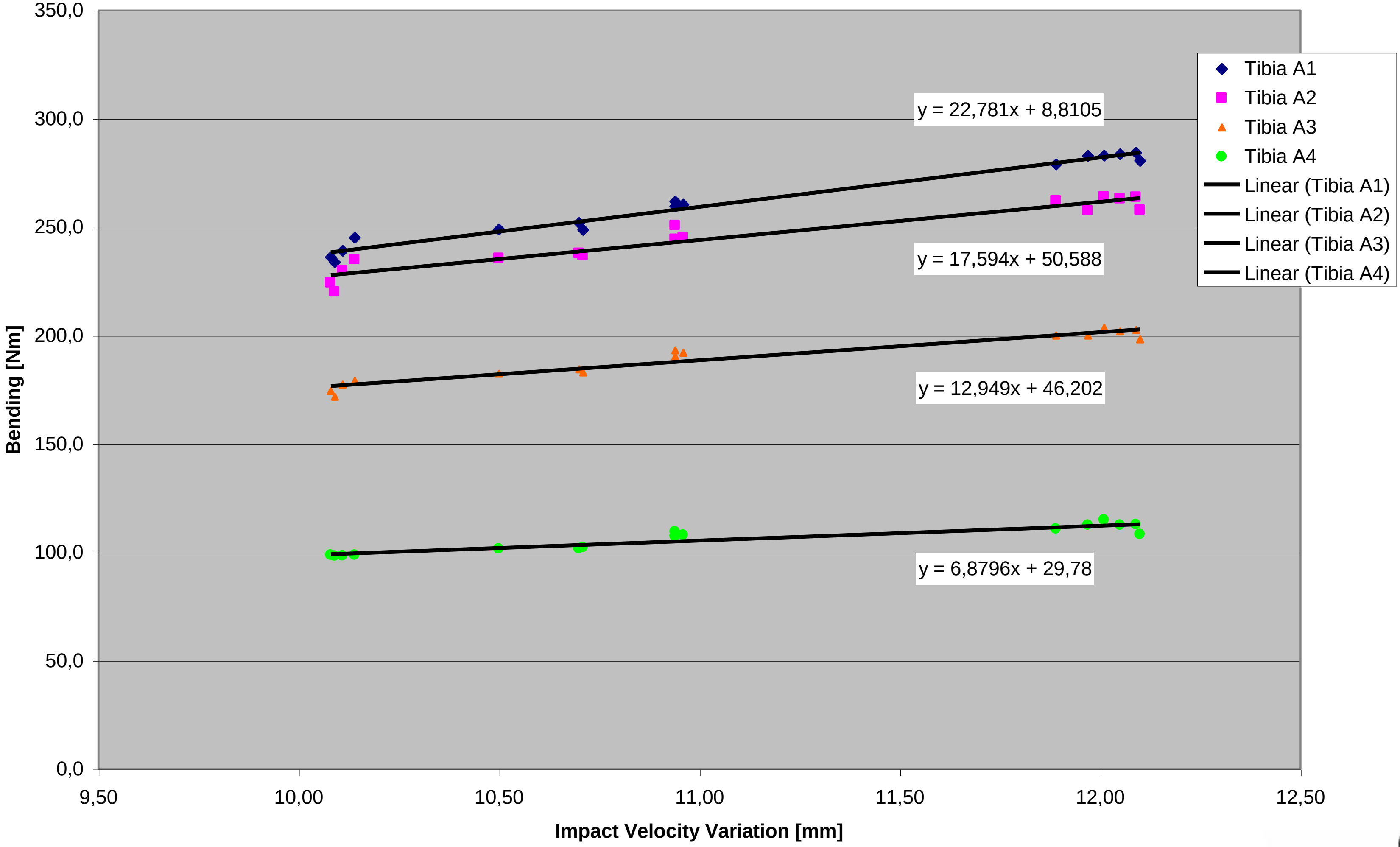
Knee elongations

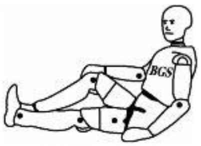


Tibia bending moments

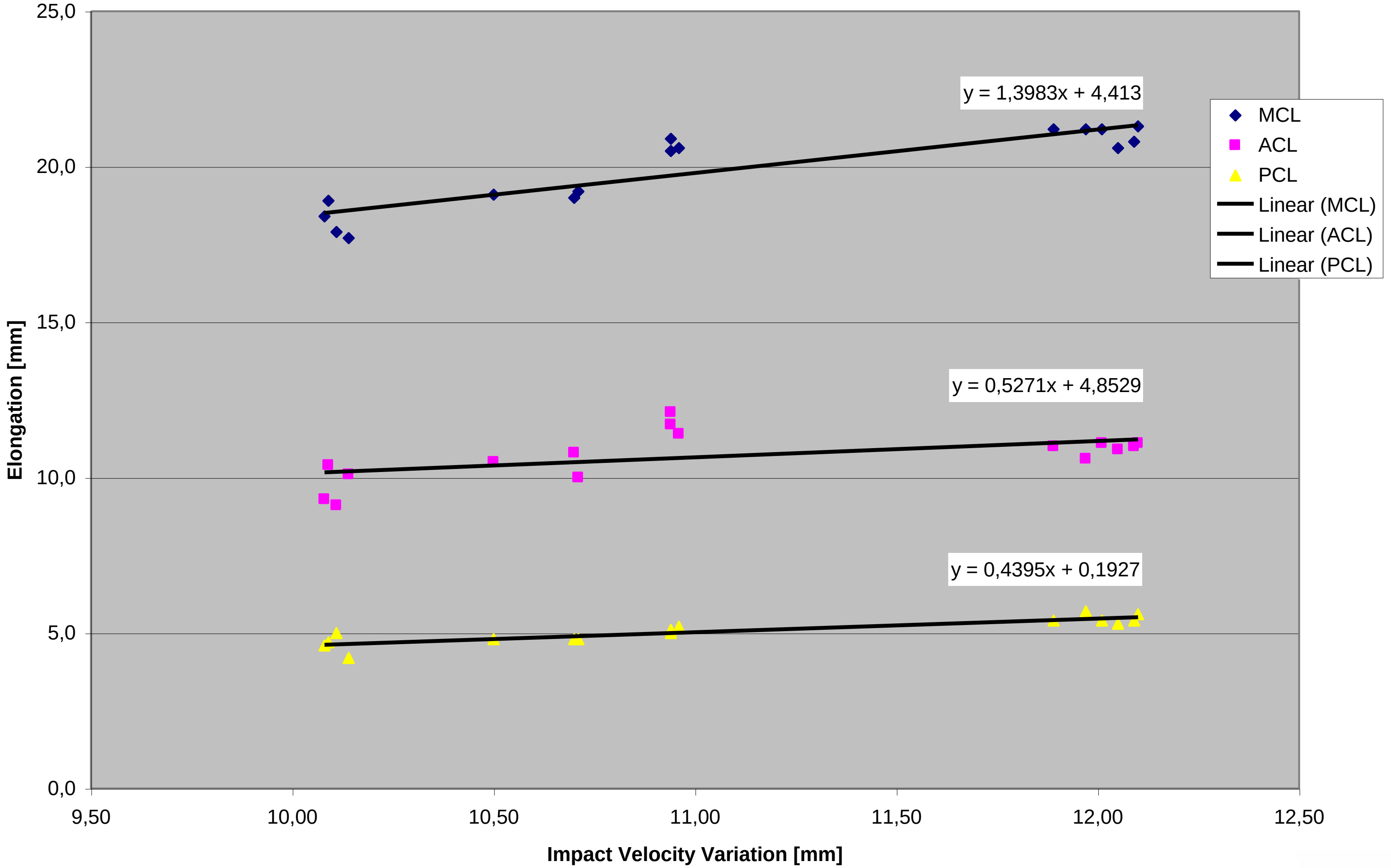


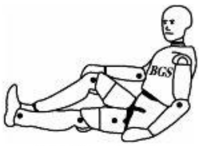
Impact velocity variation: Tibia Bending Moments





Impact velocity variation: Knee Elongations





Summary of Results (1)

- Remarkable general effects due to the parameter variations including tests with higher loadings (velocity) or obligue impact angles:
  - No damages of the legform
  - No unexpected behaviour of the legform
  - No unexpected sensor output (peaks etc.)
  - Reproducibility seems to be good (only three tests each): CV < 5% for Tibia Moments, MCL, ACL and PCL in all cases, except:
    - PCL in tests with Z-rotation -10° (5,3%)
    - ACL in tests with impact height variation (7,4%; 7,3%)
    - ACL and PCL in tests with impact velocity -1 m/s (6,4%, 7,1%)

Summary of Results (2)

- Rotation around z-axis
  - No significant change of the tibia and femur bending moments due to rotations of +10° or -10°
  - No significant change of PCL either
  - MCL and ACL decrease during tests with rotations around z-axis of +10° and -10°:
    - Z-rot. = -10° => ACL = -15%
    - Z-rot. = -10° => MCL = -6%
    - Z-rot. = +10° => ACL = -8%
    - Z-rot. = +10° => MCL = -5%
    - (The reason for the differences with +10° or -10° is not obvious and should be further investigated)

Summary of Results (3)

- Impact height variation (1)
  - The tibia bending moments decrease with increasing impact height while the femur bending moments increase :
    - Femur A3: +0,7 Nm / mm
    - Femur A2: +0,9 Nm / mm
    - Femur A1: +0,8 Nm / mm
    - Tibia A1: -0,6 Nm / mm
    - Tibia A2: -1,0 Nm / mm
    - Tibia A3: -0,8 Nm / mm
    - Tibia A4: -0,1 Nm / mm
    - Obvious reason: With increasing impact height the legform loading goes from tibia top upwards towards the femur

Summary of Results (4)

- Impact height variation (2)
  - MCL increases with increasing impact height:
    - MCL: +0,8 mm / mm
    - Obvious reason: With increasing impact height the legform loading goes from tibia top upwards to the knee. (The maximum MCL value is expected in tests when the middle axis of the honeycomb is aimed to the centre of the knee)
  - ACL decreases when changing the impact height in either direction:
    - -10 mm => ACL = -15%
    - +10 mm => ACL = -9%
    - Obvious reason: The original configuration (upper edge of honeycomb aims at centre of knee) introduces the maximum shear loading between upper and lower part of the knee. (Reason for the differences between +10 mm and -10 mm not obvious)
  - No significant change of PCL due to the impact height variations

Summary of Results (5)

- Impact velocity variation (1)
  - Generally, all measurements increase at least slightly with increasing impact velocity:
    - Tibia A1: +2,3 Nm / 0,1 m/s
    - Tibia A2: +1,8 Nm / 0,1 m/s
    - Tibia A3: +1,3 Nm / 0,1 m/s
    - Tibia A4: +0,7 Nm / 0,1 m/s
    - MCL: +0,14 mm / 0,1 m/s
    - ACL: +0,05 mm / 0,1 m/s
    - PCL: +0,04 mm / 0,1 m/s
    - Obvious reason: The higher velocity applies a higher load to the legform.
  - The effect on ACL as well as on Femur A2 and Femur A3 is not entirely clear because in spite of the above mentioned tendency the maximum values were observed in the tests without velocity variation.

Conclusions (1)

- Generally the effects of the investigated parameter variations occurred as expected.
- The quantifications have to be seen with respect to the particular test configuration used in this study
- Some details require further investigations:
  - Rotation around z-axis:
    - Reason for different deviations with +10° and -10°
    - Effect in tests up to +/- 30° rotation
  - Impact height variation:
    - Effect on the measurements when impacting further upwards (e.g. centre of honeycomb in line with centre of knee or higher)
  - Impact velocity variation:
    - Effect on ACL because the highest value was not in the test with the highest velocity

Conclusions (2)

- The influence of other test parameters was not tested and should be investigated in a subsequent project:
  - Rotation around x-axis
  - Rotation around y-axis
  - Temperature
  - Combination of parameter variations (e.g. impact height and impact velocity)

Thank you!

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