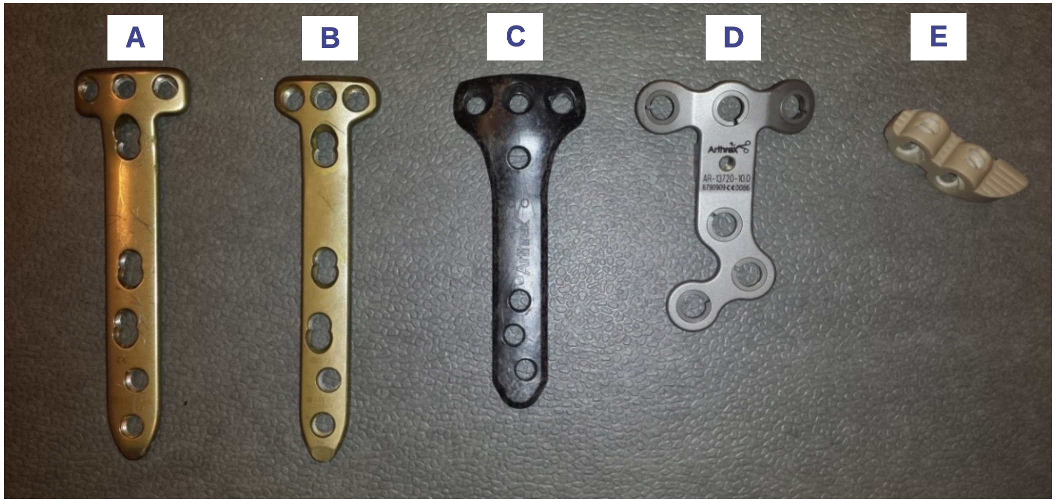
Biomechanical testing of osteotomy plates

Stefan Maas, Arnaud Diffo Kaze, Engineering Sciences, University of Luxembourg

How to analyze biomechanics of High Tibial Osteotomy (HTO) plates

a) by experiment (SAWBONE) ?

b) by simulation ?



Some tested implant for HTO: (A) TomoFix Standard, (B) plaque TomoFix “small”, (C) plaque PEEKPower HTO, (D) Plaque Contour Lock HTO et (E) implant iBalance HTO.

Artificial compositeTibia

(4th generation Sawbones)

Conflict of Interest

Disclosure of **C**onflict **O**f **I**nterest (COI) /Funding

☒ No COI to disclose

References

PhD thesis of Arnaud Diffo Kaze
https://www.shaker.de/de/content/catalogue/index.asp?lang=de&ID=8&ISBN=978-3-8440-4599-4

Biomechanical properties of five different currently used implants for open-wedge high tibial osteotomy, A. Diffo Kaze, S. Maas et al.
https://www.ncbi.nlm.nih.gov/pubmed/26914882

Static and fatigue strength of a novel anatomically contoured implant compared to five current open-wedge high tibial osteotomy plates, A. Diffo Kaze, S. Maas et al., JEO-ESSKA,
https://jeo-esska.springeropen.com/articles/10.1186/s40634-017-0115-3

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Requirements for the testing procedure: it should

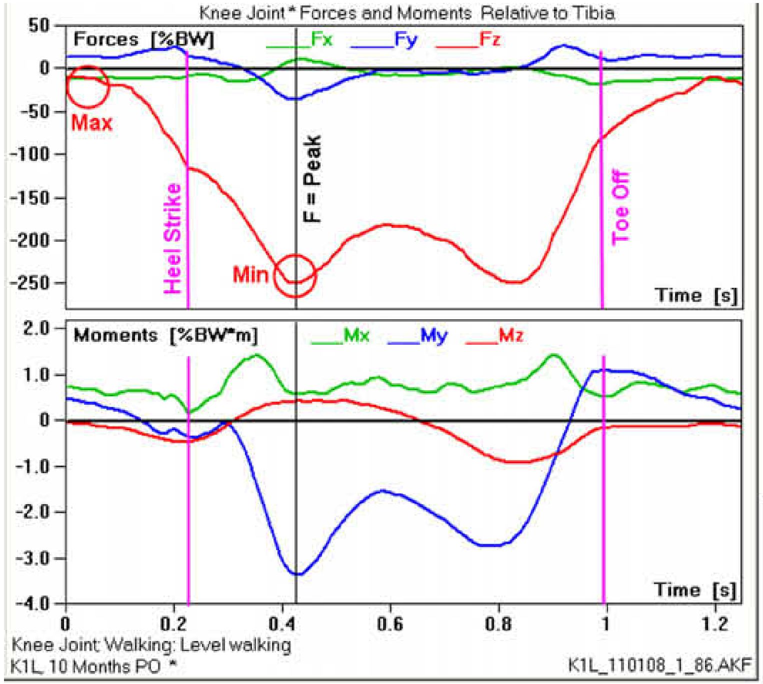
a) be as close as possible to known standards
b) investigate static strength
c) analyze cyclic or fatigue strength
d) be as simple as possible to implement in experimental set-up
e) be standardized & repeatable
f) define precise failure criteria
g) assess correction loss
h) reflect real loading of implant and tibia during slow walking

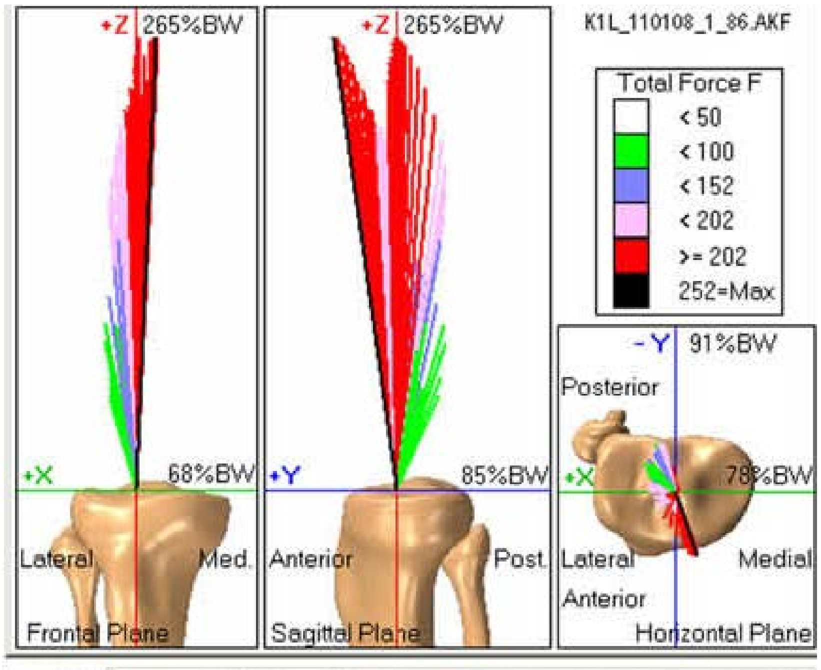
➔ Design of experiment

Contact Forces during Slow Walking

Bergmann et al.

Knee Loads during Level Walking (In Vivo Measurements, www.ortholoads.com)



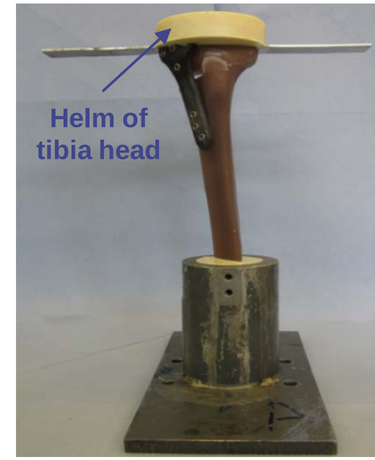


➔ **Vertical forces are dominating**

➔ Vertical contact forces of **250 % - 400 % x Body-Weight due to muscles actions**

Standardised specimens' preparation

(a) (b) (c) (d)



(a) Middal Open Wedge High Tibial Osteotomy performed by an experienced surgeon

(b) Tibia was cut (300 mm from tibial plateau) and positioned in cylindrical mould

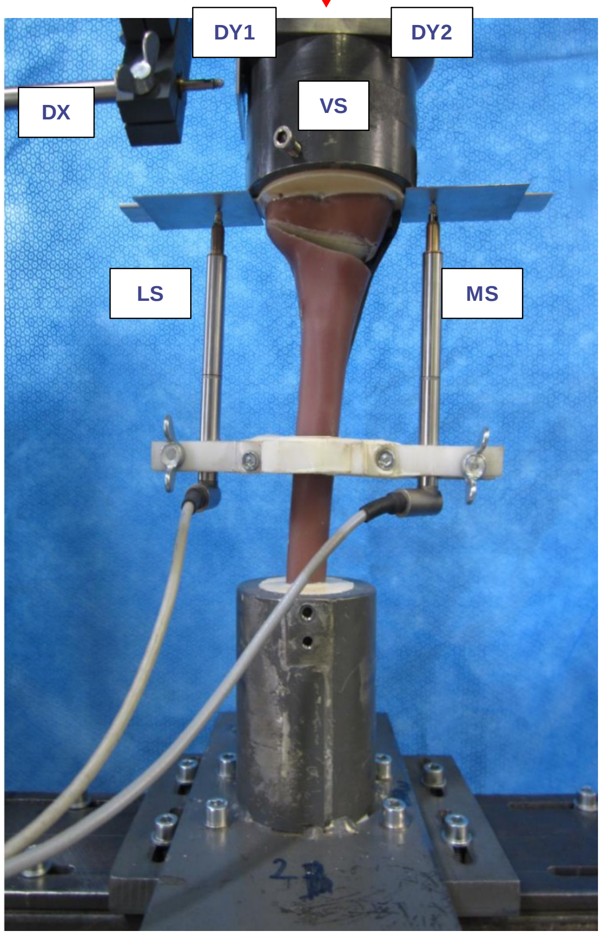
(c) Fixation by 2-component (Isocyanate + polyol in a 1:1 volume ratio) polyurethane resin (FC 52)

(d) Helm of tibia plateau by casting with pre-insertion of sensor attachments

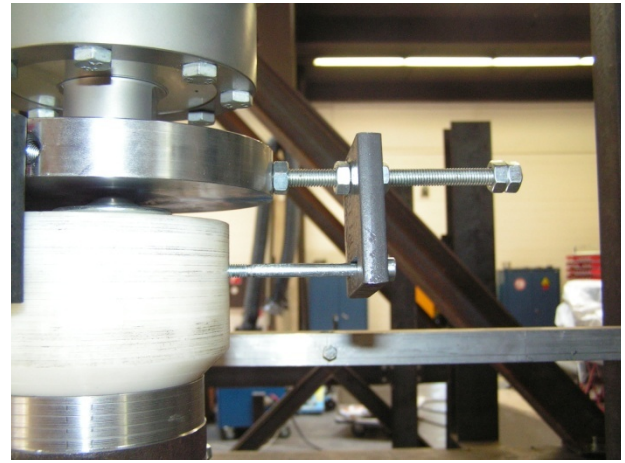
Hydraulic test bench

Vertical displacement

x-direction, y-directions



Horizontal free move of support

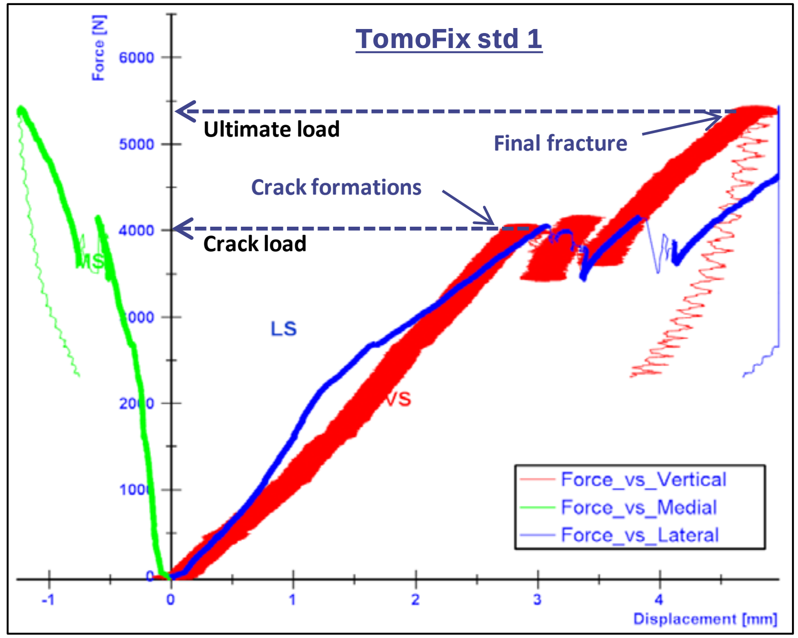


Failure criteria

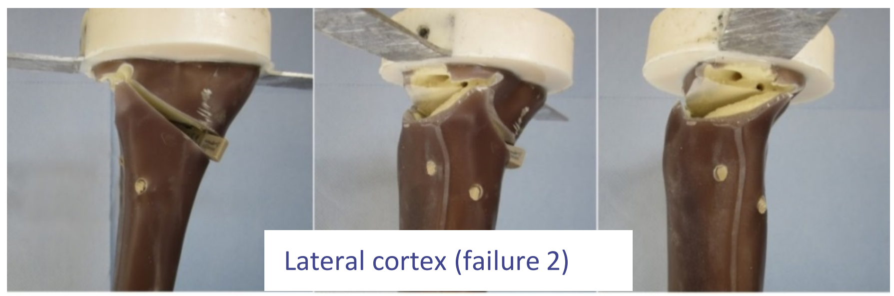
Failure type	Criteria
1	Medial or lateral displacements of the tibial head in relation to the tibial shaft of **more than 2 mm**. This criterion can only be checked in the unloaded condition (“**correction loss**”)
2	Visible **collapse of lateral cortex**. Small hairline cracks are not considered as failure.
3	Maximal displacement range of more than 0.5 mm within one hysteresis loop in the case of cyclic testing only (“**stability**” or “**degree of wobbling**”)
4	Cracks of the **screws** of more than 1 mm

Static testing

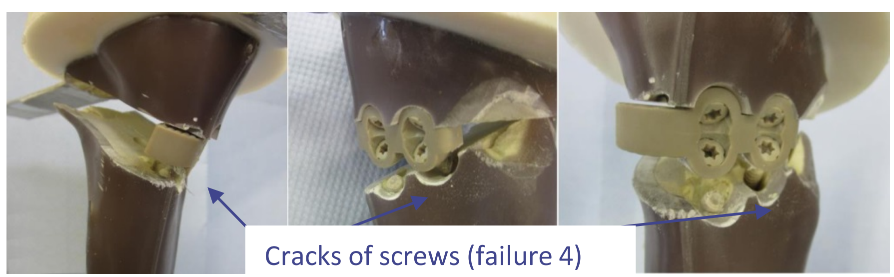
Force vs. displacements



Failure 2


Lateral cortex (failure 2)

Failure 4


Cracks of screws (failure 4)

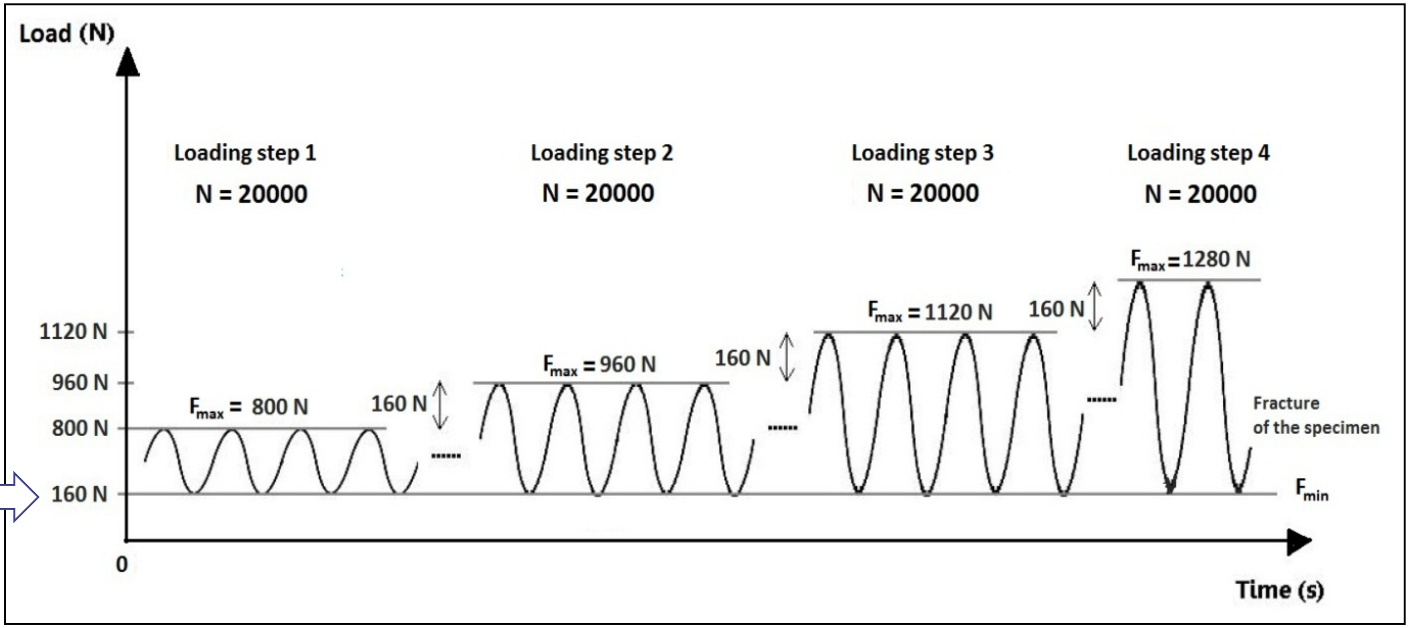
Experimental cyclic testing

No standard found! Definition of own procedure similar to testing protocol for hip implants (ISO 7206). Stepwise increased compression with sinusoidal forces (5Hz)

Load-controlled pulsating cyclical charging until failure

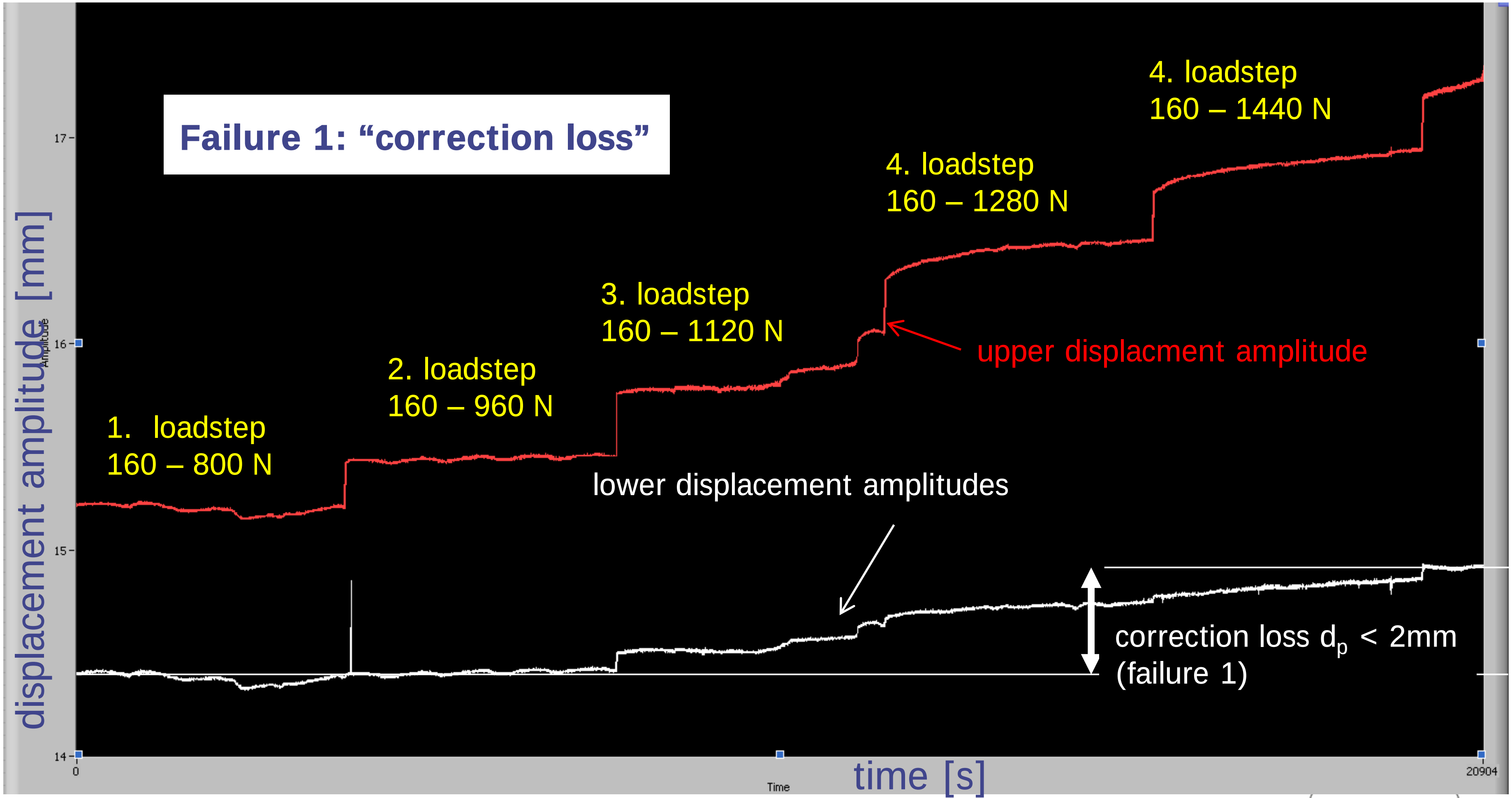
small lower load to avoid backlash

R< 0.2 ≈ 0



Experimental cyclic testing

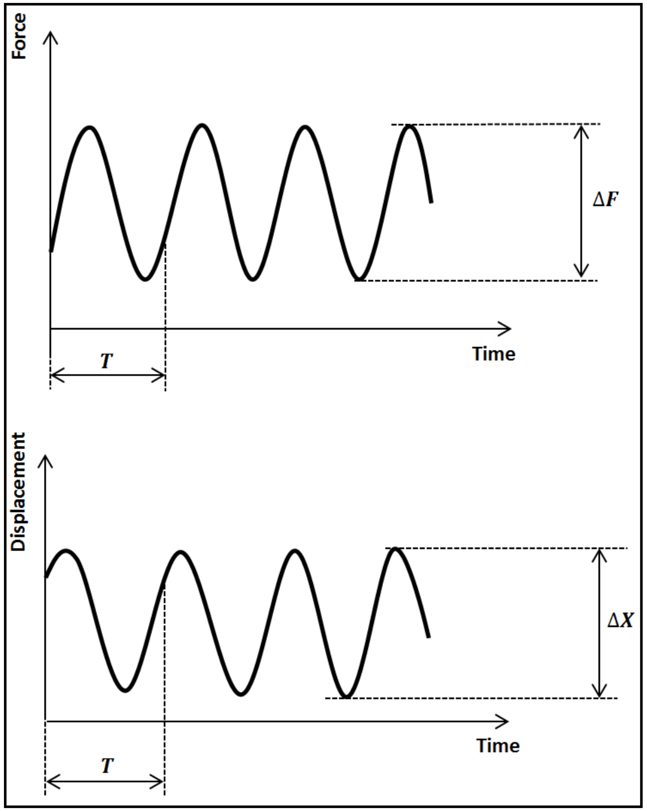
Measured displacement amplitudes (force control, 20 000 cycles per step)



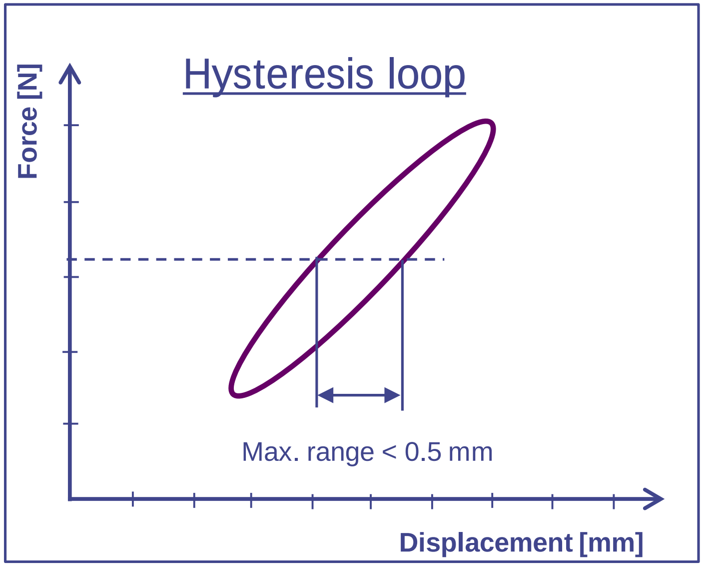
Experimental cyclic testing

Failure 3: stiffness & wobbling, stability

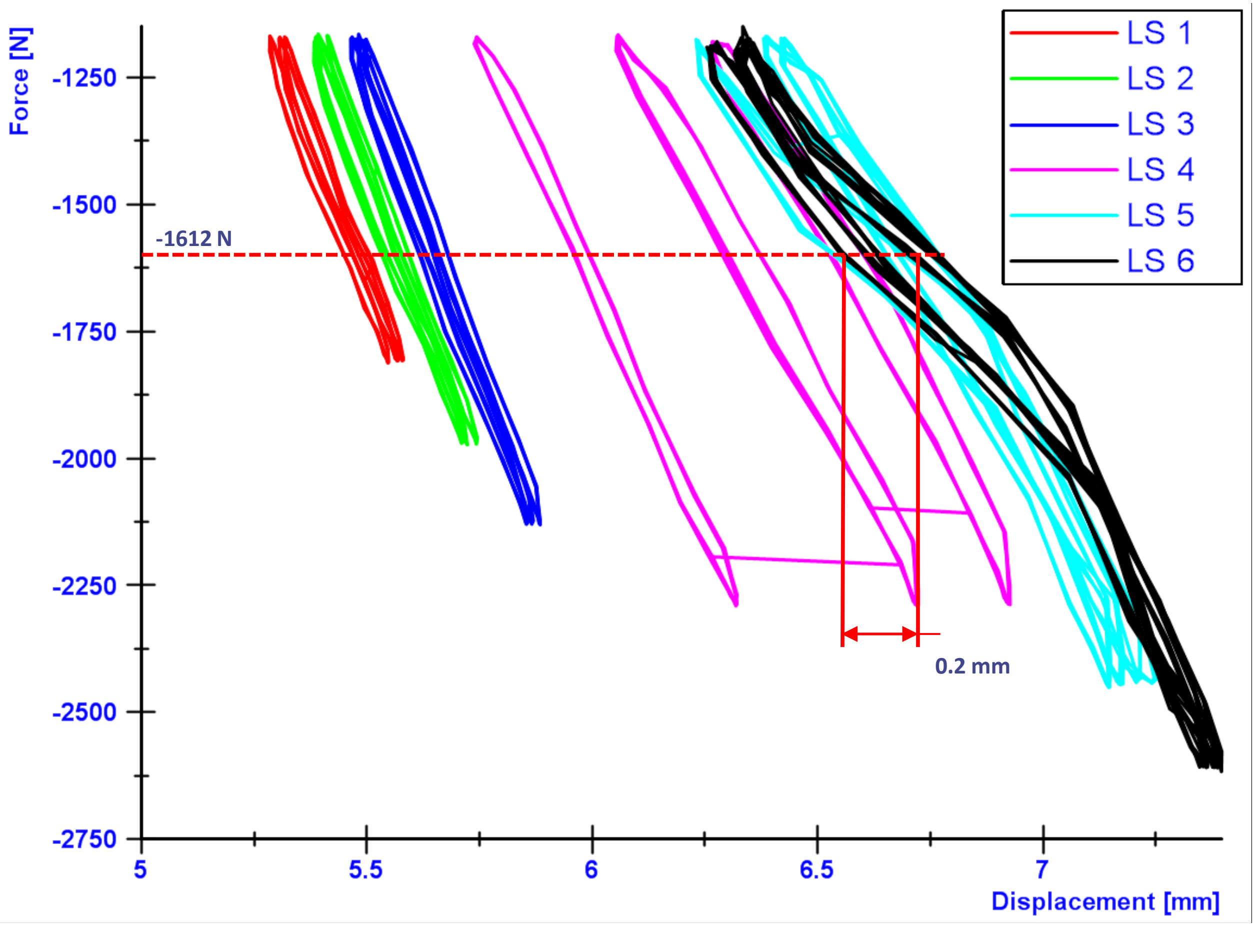
Decrease of stiffness k= ΔF/ΔX
→ indicator for crack growth



Maximal displacement range > 0.5mm
➔ failure 3 (stability, wobbling)



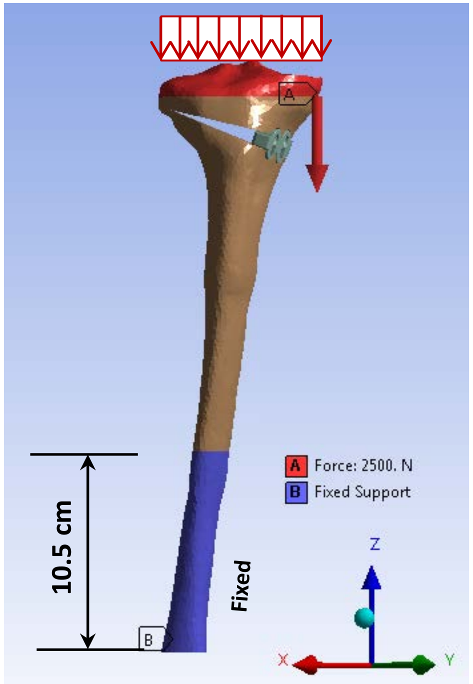
Measured hysteresis during cyclic testing



Here, below threshold for Failure 3

Numerical studies

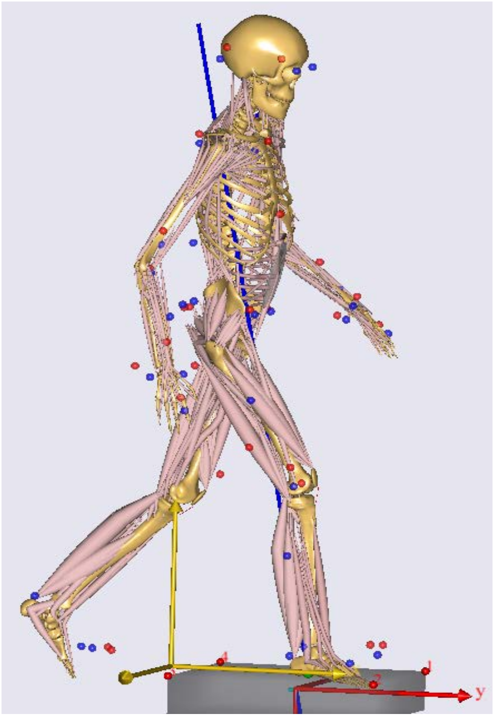
Does our experimental testing reflect slow walking?



Simplified pure vertical loading up to 400% x Body Weight = 2500N

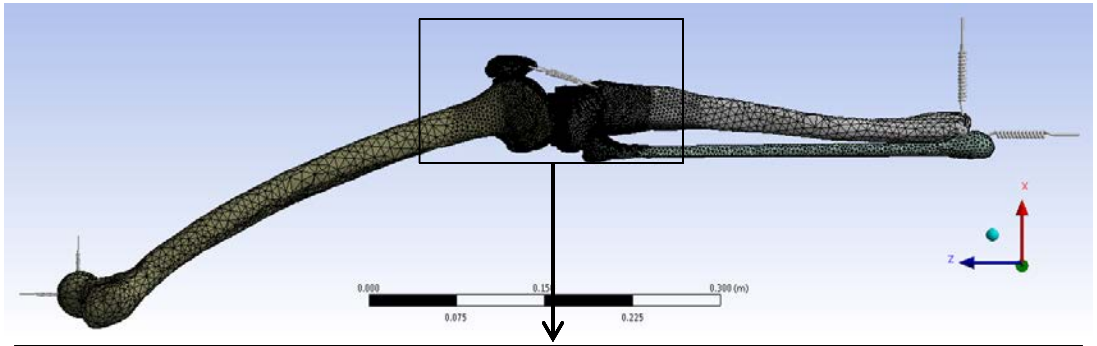
Numerical studies

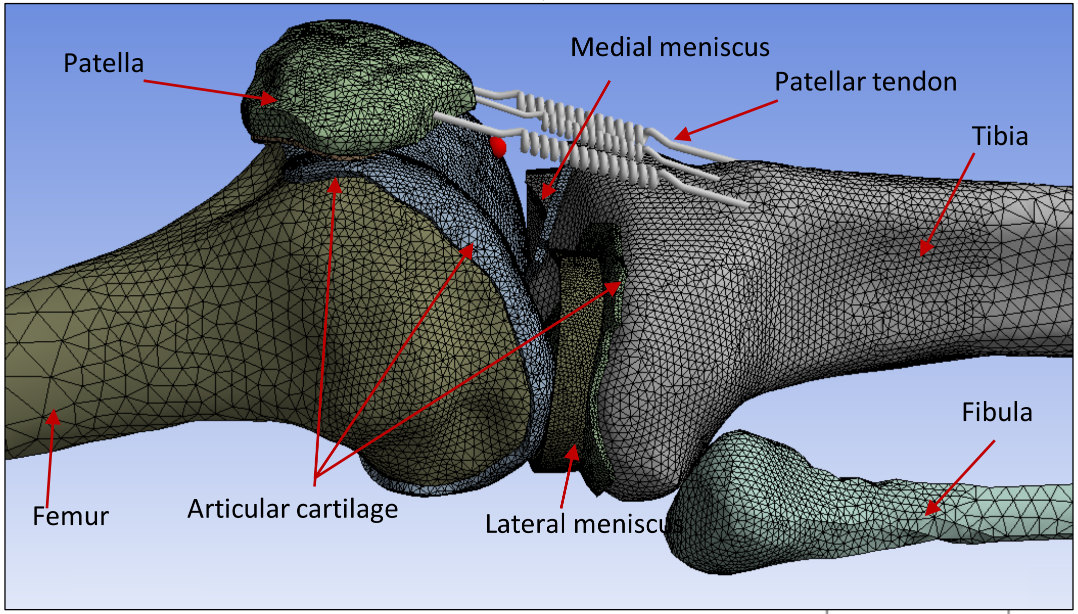
Musculoskeletal model for inverse dynamics **AnyBody**



Muscle forces

Finite Element model of the lower limb **ANSYS**





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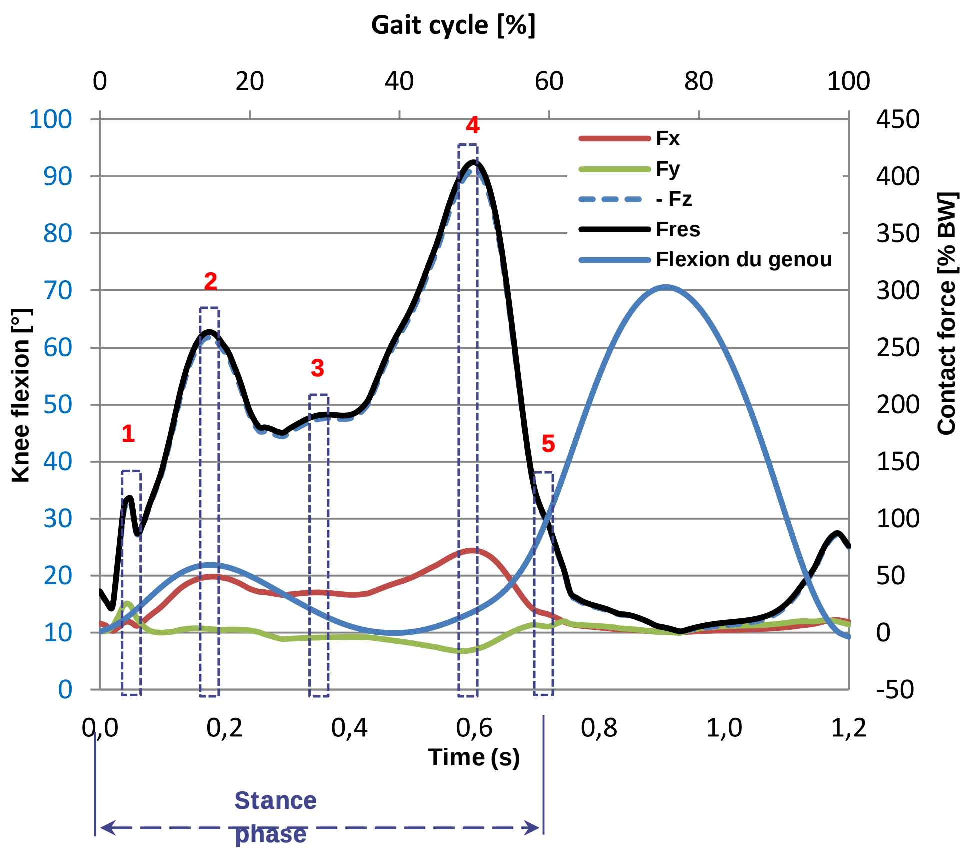
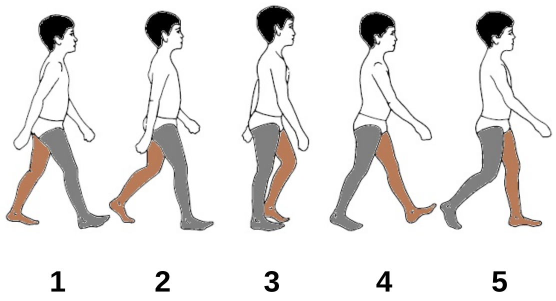
Numerical studies

Consideration of **33 muscle forces** at 5 different positions of level walking in software AnyBody





Export of **muscle forces** into Finite Element software ANSYS for strength assessment

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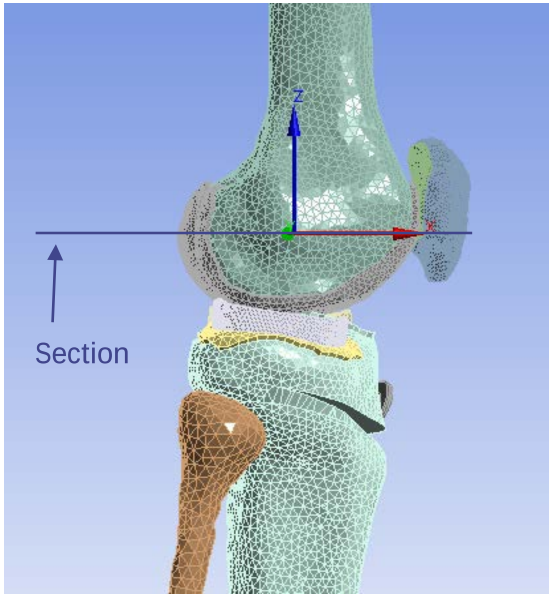
Numerical studies

Comparison of AnyBody & ANSYS

for verification

	Section forces at the femoral head		
	AnyBody	**ANSYS**	**Rel. Diff.**
Position 1	765 N	873 N	14%
Position 2	1498 N	1566 N	4.5%
Position 3	998 N	1054 N	5.6%
Position 4	2077 N	2095 N	0.8%
Position 5	586 N	678 N	15.7%



Section passing through the transepicondylar axis of the femur

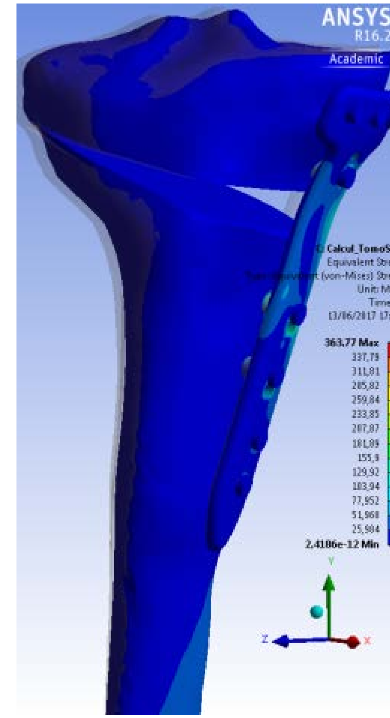
→ **Section forces in the knee are approx. the same in ANSYS and AnyBody**

→ **Inertia forces are negligible for slow daily motions**

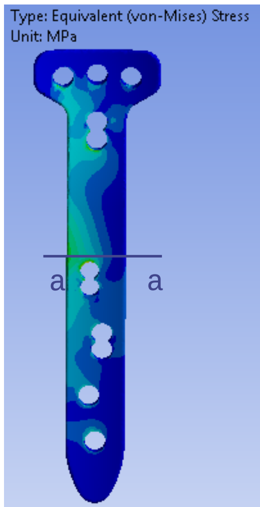
Numerical studies

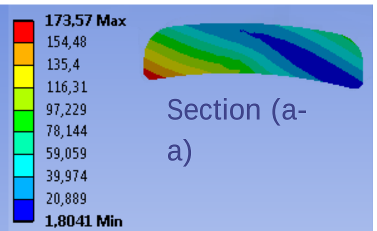
Stresses in the implants (ANSYS)

Plate TomoFix Small



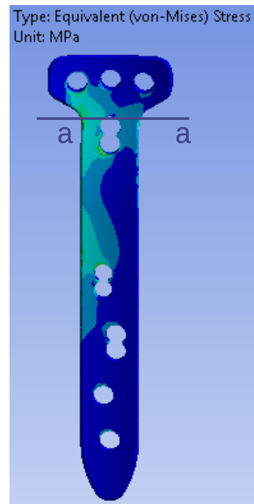
Simplified experimental loading

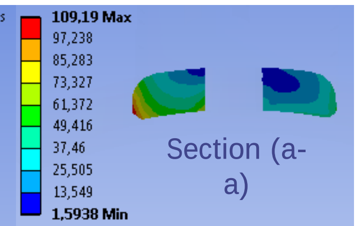




σ_{max}= 174 MPa (160%)

Muscles included (position 2)





σ_{max}= 109 MPa

(+): similar stress distribution, stresses below material strength

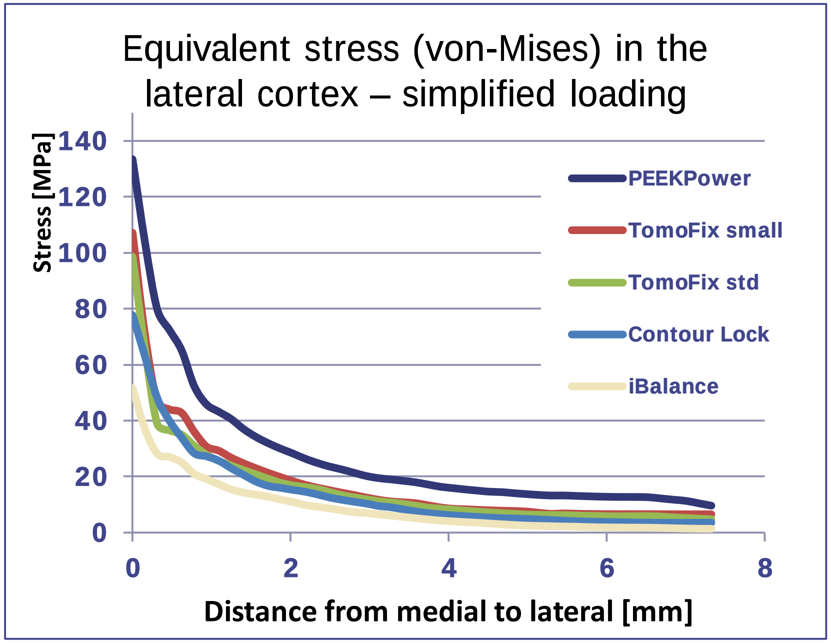
(-): higher stresses in simplified case due to muscles attached at tibia head, section forces above tibia head = 400% BW in position 4

➔ our experimental testing procedure is conservative, i.e. on safe side

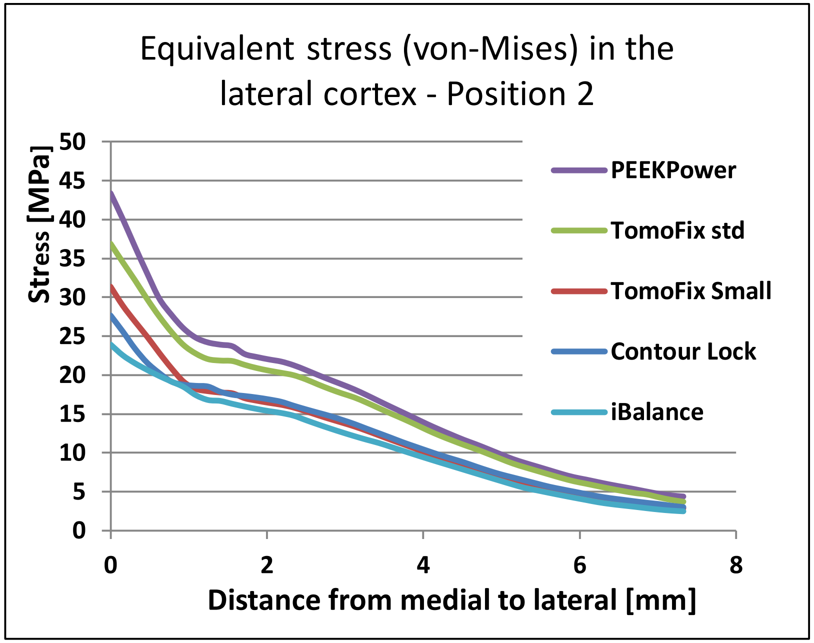
Numerical studies

Stresses in the lateral cortex of tibia head

Experimental loading



Realistic loading with 33 muscles (position 2)

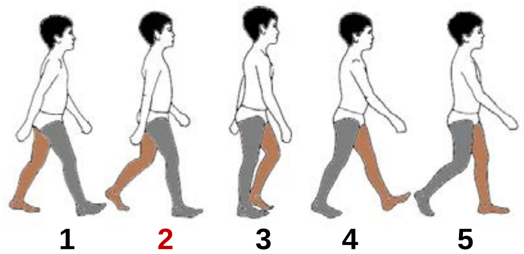


+ : same ranking of implants

- : 3 x higher stresses (200%-300%) in experimental case due to muscles attached at tibia head

➔ our experimental testing is **conservative, i.e. on the safe side!**

Numerical studies vs. experimental testing



Conclusions

All failure criteria confirmed by static and cyclic testing

Combined musculoskeletal & finite elements simulations were used to prove our approach and to verify that our simplified experiments are on safe side

➔ Experimental testing with purely vertical loading makes sense in this case

Thank you ! Questions ?

Université du Luxembourg
Faculté des Sciences, de la Technologie et de la Communication
Campus Kirchberg
Prof. Dr.-Ing. Stefan Maas
Applied Mechanics and Energy Efficiency
6, rue Coudenhove-Kalergi
L-1359 Luxembourg

Tél. : +352-466644-5222

Email: stefan.maas@uni.lu
URL : http://www.uni.lu