



**HUMAN MODELING
AND SIMULATION**
IN AUTOMOTIVE ENGINEERING

PERIPROSTHETIC FRACTURE MODELLING USING A COMBINED FINITE ELEMENT – SMOOTH PARTICLE HYDRODYNAMIC METHOD

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November 16 – 17, 2022

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Introduction

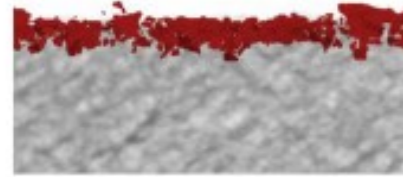
- PFFs are the third most common reason for revision surgeries (Maier, 2015)
- High rate of PFFs during the early postoperative (EP) period (Abdel et al., 2016)
- Due to the lack of bone ingrowth in EP period the interface mechanics is important
- Computer models can aid in understanding EP fractures





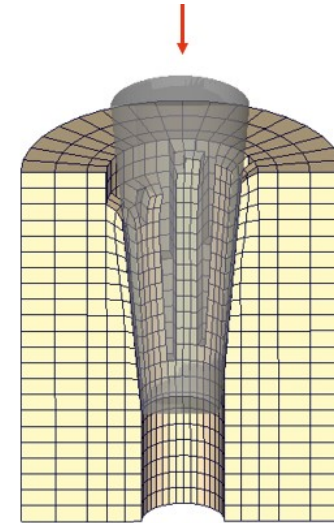
Introduction

- During the stem insertion, highly deformed trabecular bone transforms into bone debris
- Previous studies use element erosion strategy (Miles et al, 2015; Ovesy, 2020).
- Element erosion cause unphysical material loss.



■ Bone Debris

Bone debris formations
(Bätz et al., Clin. Biomech.,
73: 234-240, 2020).



Element erosion

Aim:

Develop and validate a model to simulate stem insertion and predict PPFs using a combined approach based on finite element (FE) and smoothed particle hydrodynamics (SPH) methods



Methods

Numerical method to simulate interface debris

Combined SPH-FE Approach

Interface Validation

Ovesy, 2020, Journal of Biomechanics

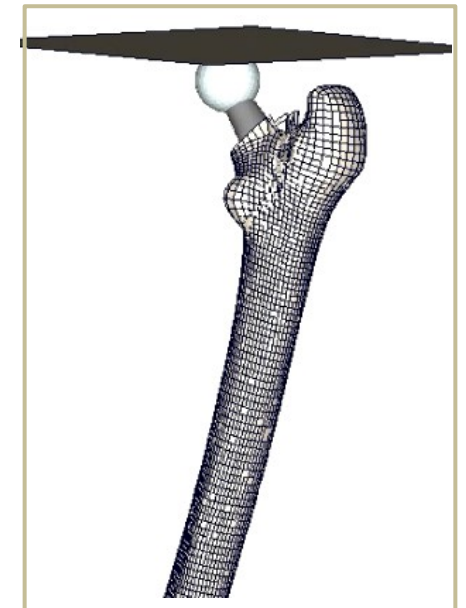
Implanted femur preparation

Parametric Femur models

Surgical Procedure

Broaching
Implanting

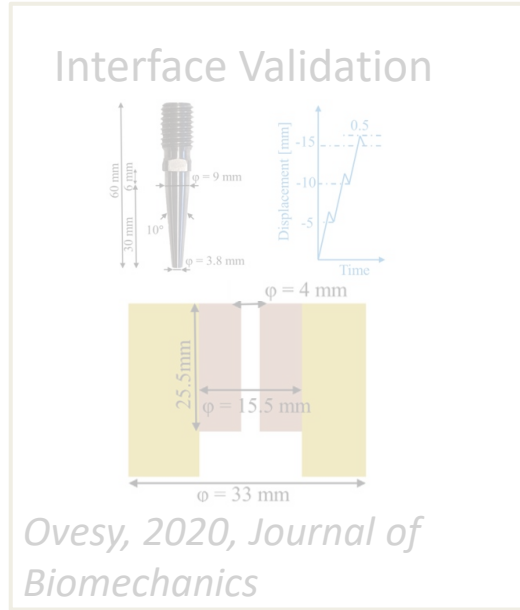
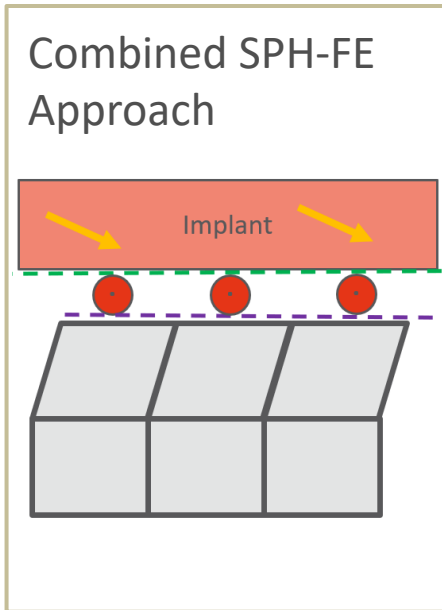
PPF Verification based on experiments



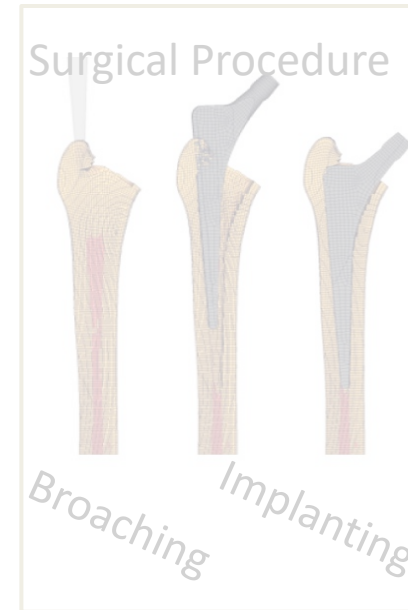


Methods

Numerical method to simulate interface debris



Implanted femur preparation

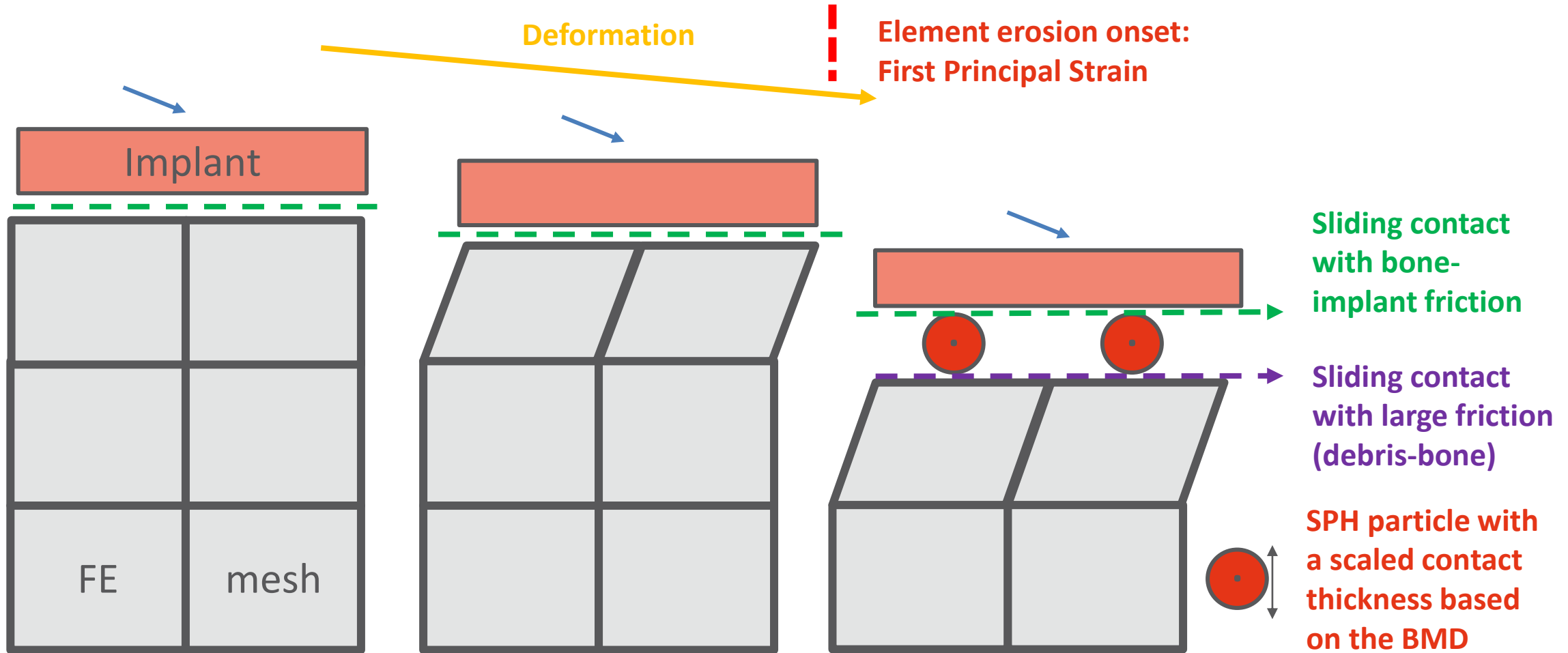


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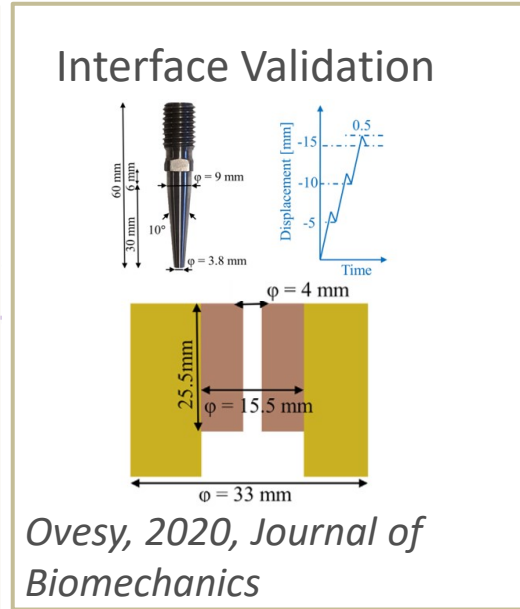
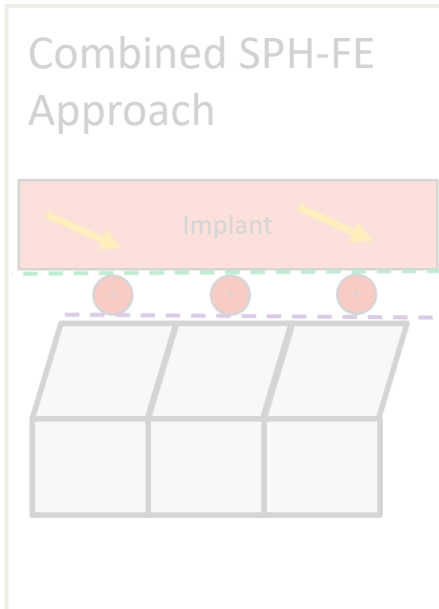
Methods – Combined SPH-FE Approach



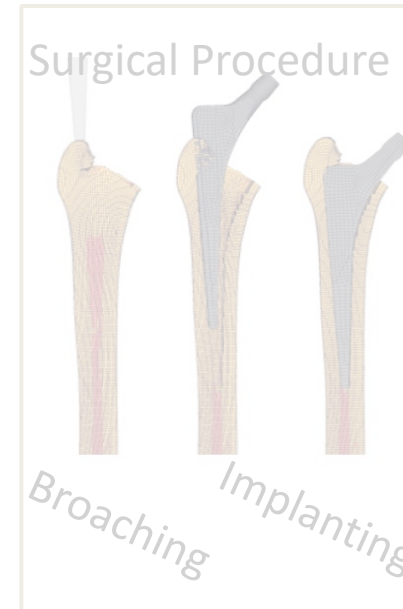


Methods

Numerical method to simulate interface debris



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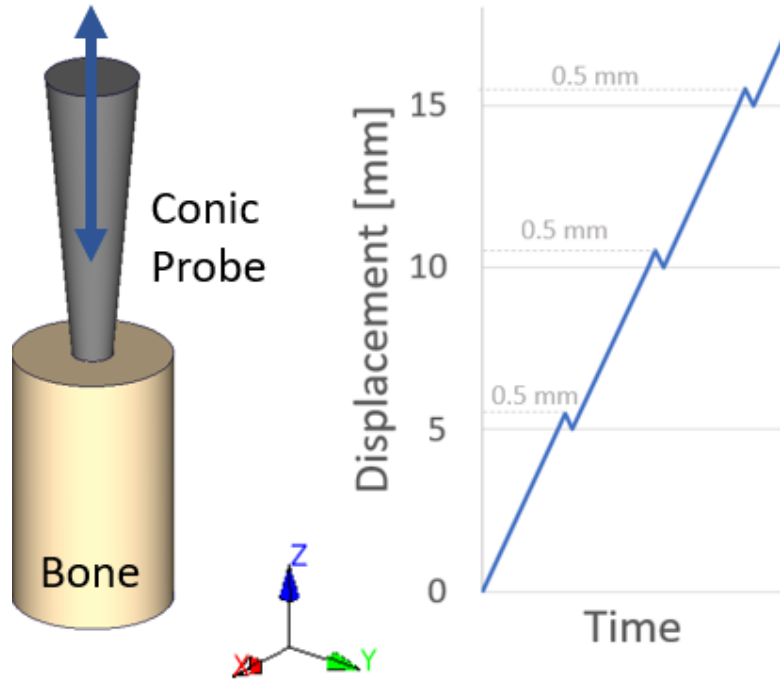
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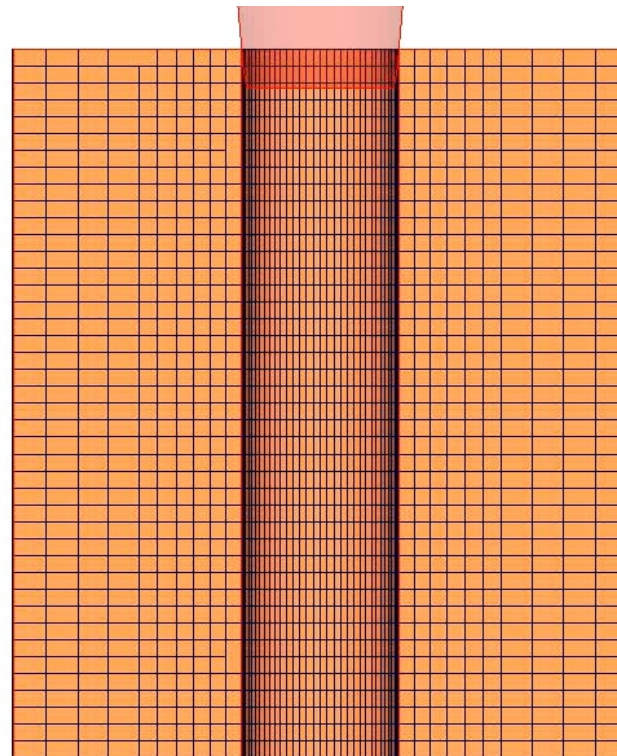
Methods – Interface Validation

Simplified stem insertion experiment presented by Ovesy (2020)



Bone volume / Total Volume: %29.9
 $\mu = 0.20$ (Damm et al., 2015; Grant et al., 2007)

Generated SPH particles with eroded elements



Sensitivity Analysis

Investigated Parameters

Erosion onset:

0.07, 0.13, 0.19 (Jungmann, 2011)

SPH resolution:

None, 1, and 4 SPH particles per eroded element

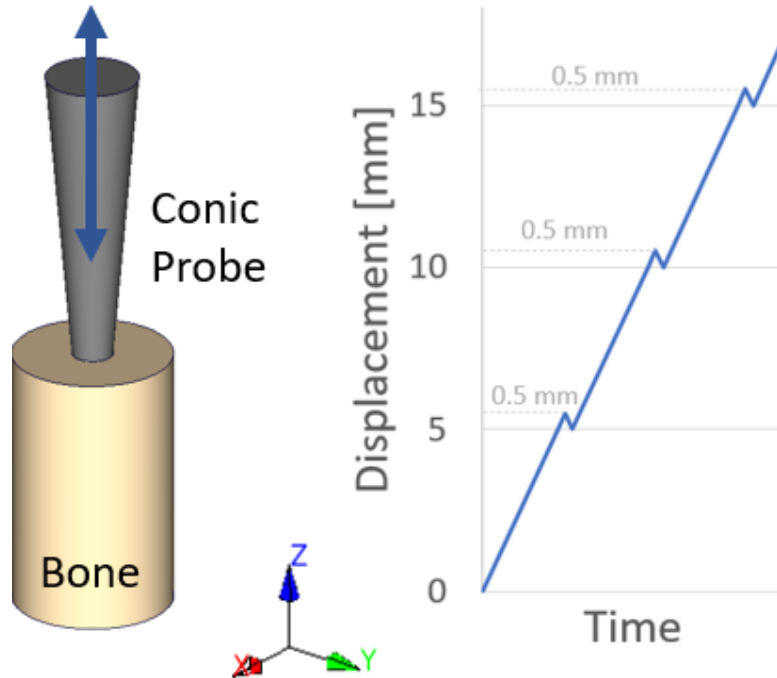
Mesh size:

0.38, 0.76, 1.52 mm



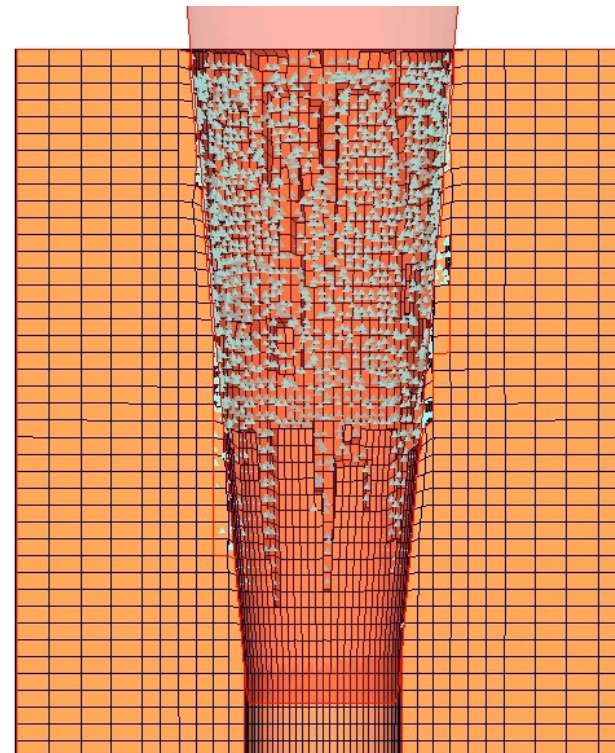
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Animation

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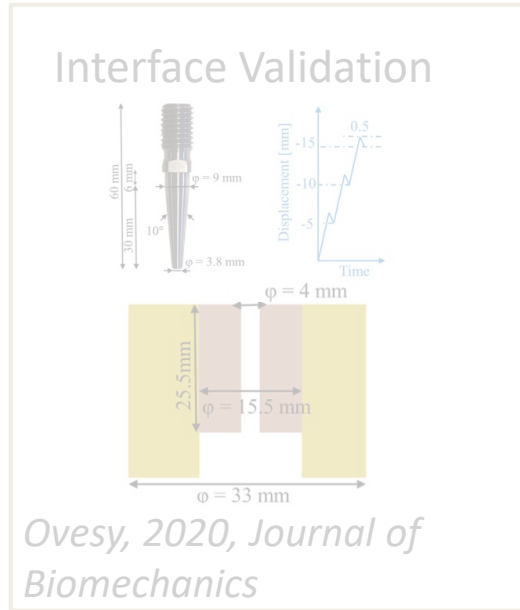
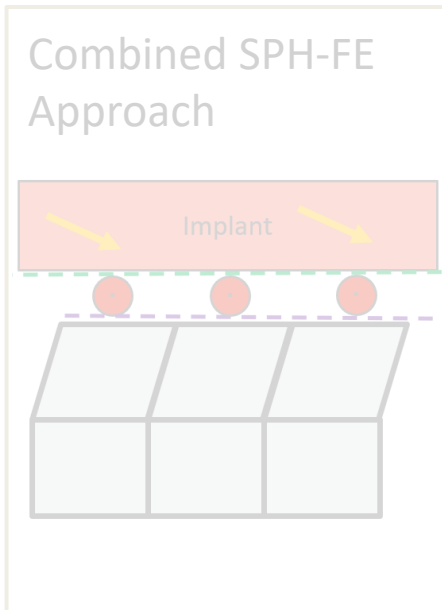
Mesh size:

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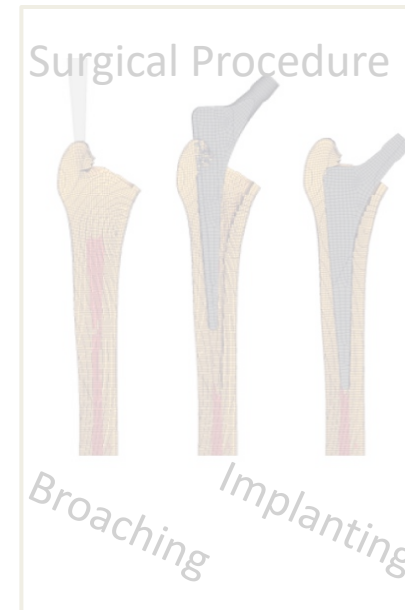
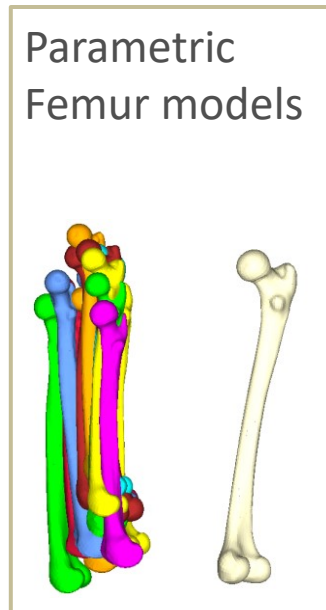


Methods

Numerical method to
simulate interface debris



Implanted femur
preparation



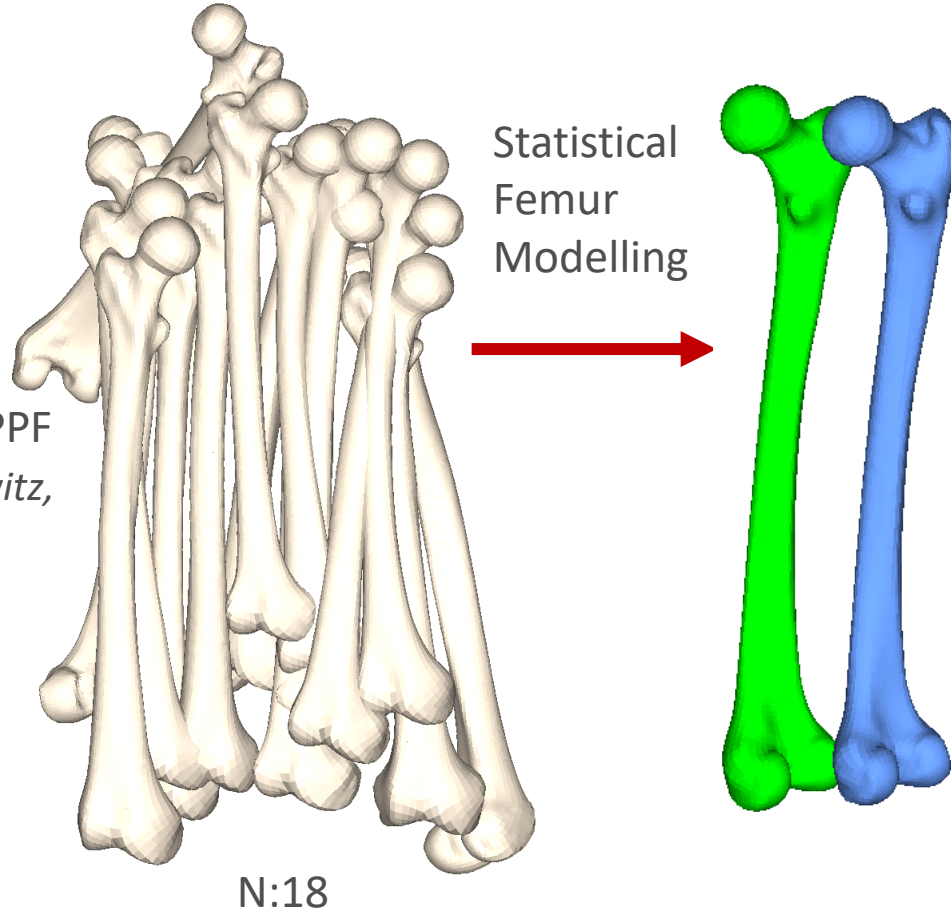
PPF Verification
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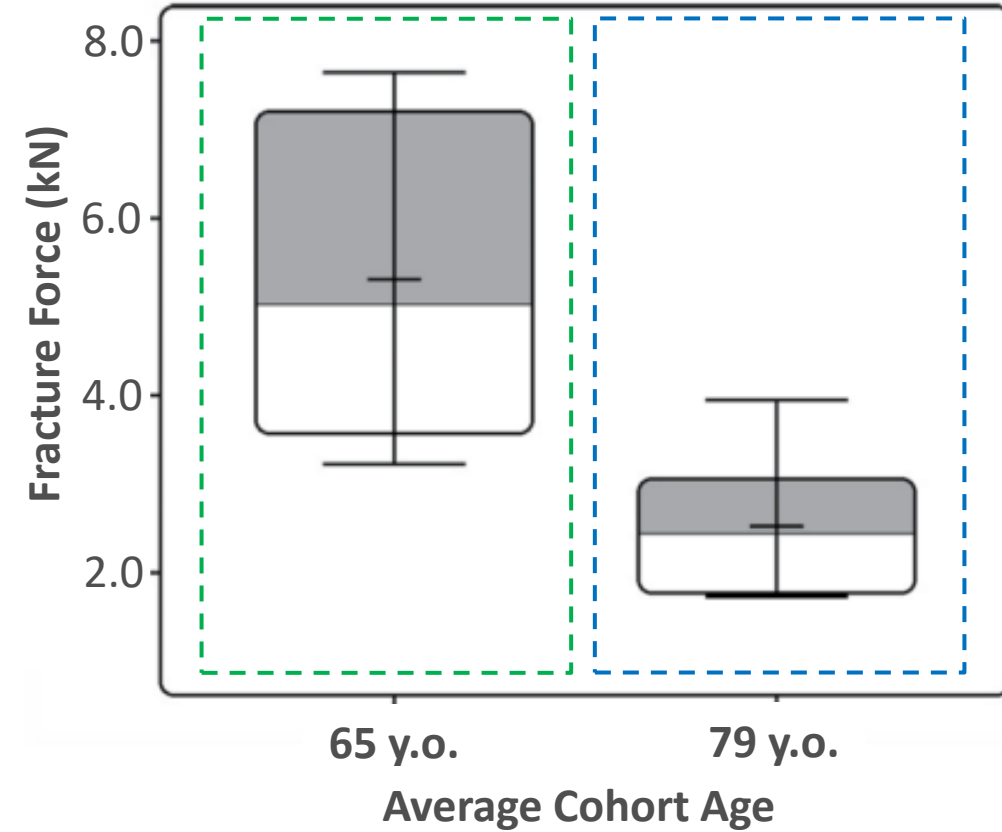


Methods – Parametric Femur models

- Female femurs
- Age: 65 and 79 y.o.
- Cohort averages for PPF experiments (*Jakubowitz, 2009*)



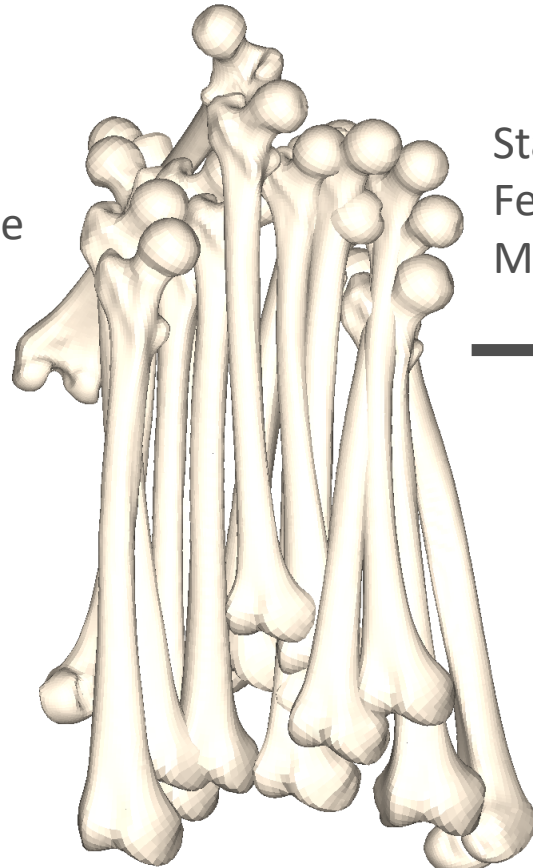
Jakubowitz, Med Sci Monit., (2009)





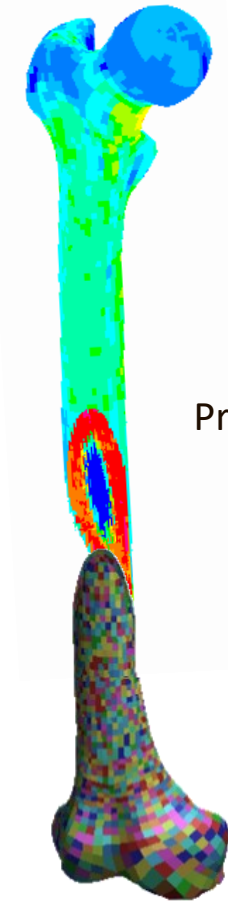
Methods – Parametric Femur models



- Asymmetric Crushable foam -> Trabecular bone
- Asymmetric metal plasticity -> Cortical bone



N:18

Statistical
Femur
Modelling

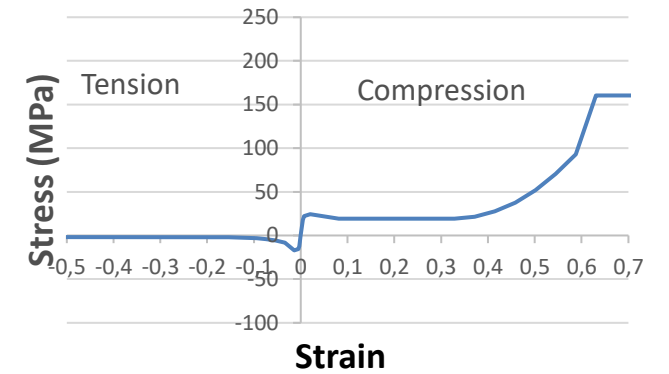


E. Mod.
High 
Low 

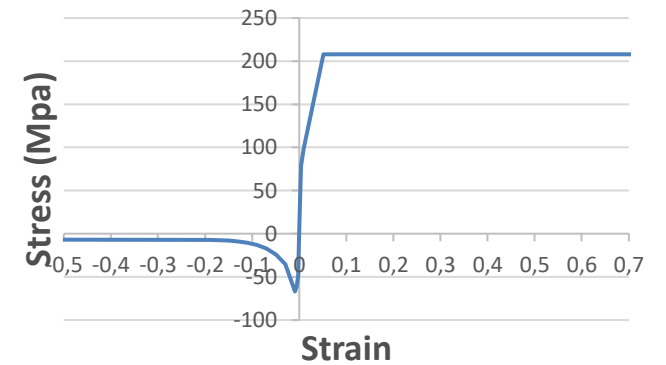
Pre-Processing



Trabecular Bone: Crushable Foam



Cortical Bone: Metal Plasticity

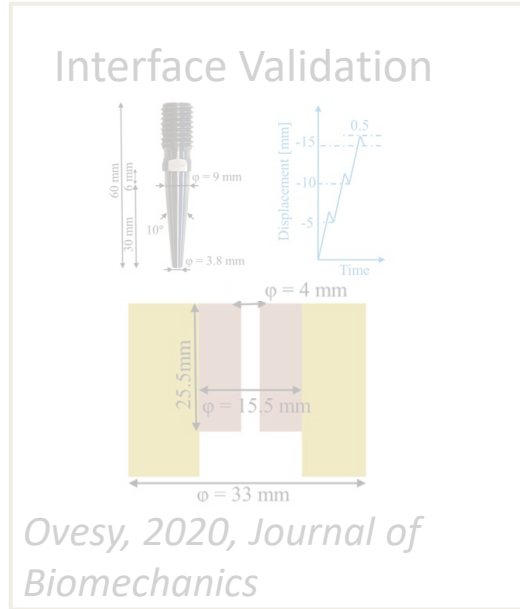
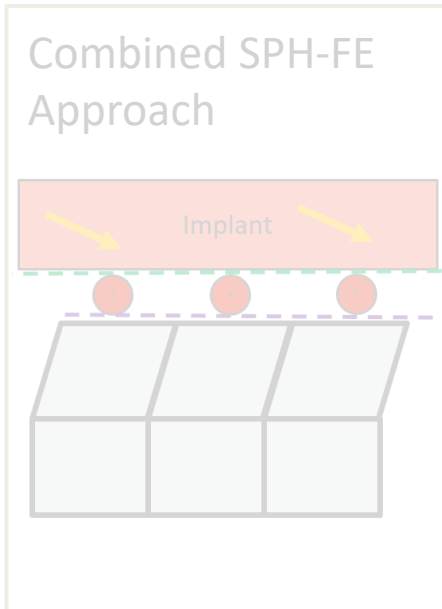


(Ensy-Bray et al. 2018)

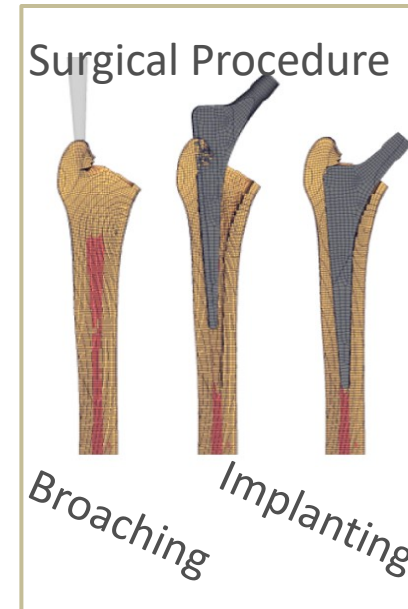


Methods

Numerical method to simulate interface debris



Implanted femur preparation

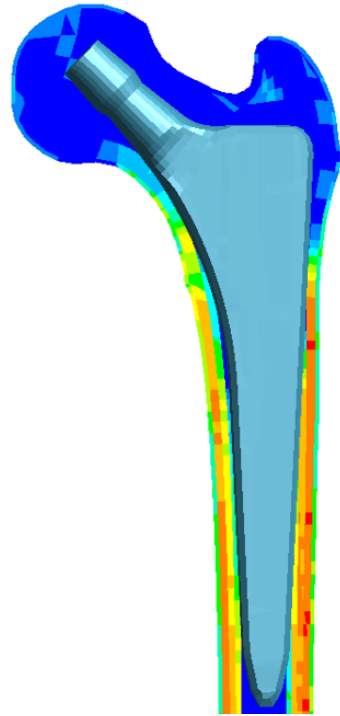


PPF Verification based on experiments





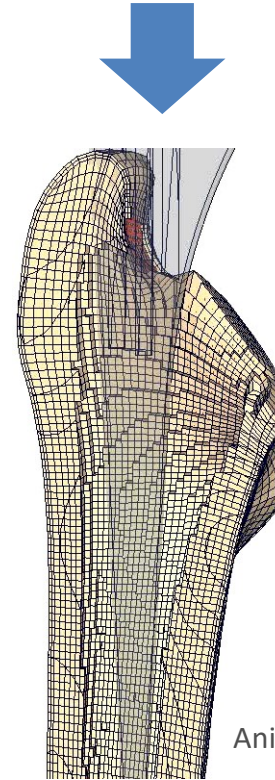
Methods – Virtual Implanting



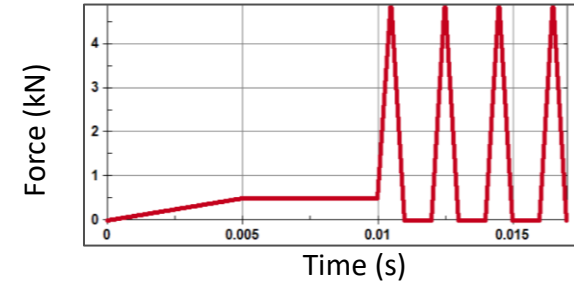
E. Mod.
High ■
Low ■



Animation



Animation



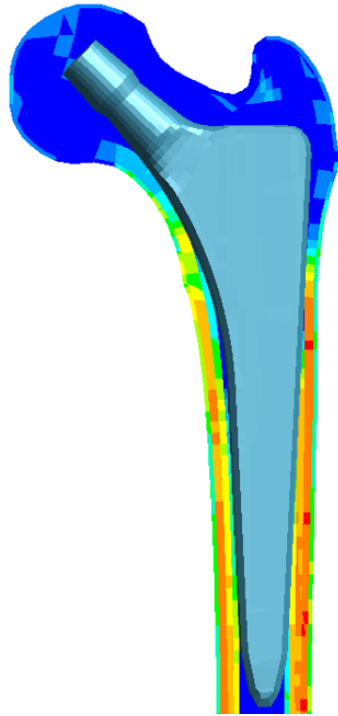
Planning: Stems were positioned considering the cortical fitting and the hip center of rotation.

Broaching: A free-moving broach interacts with the mechanical properties. (Bätz, 2019)

Insertion: Stems were inserted applying the hammering forces from literature. (Tijou, 2018)



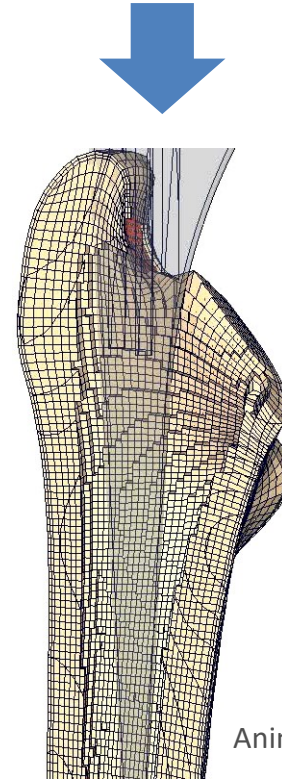
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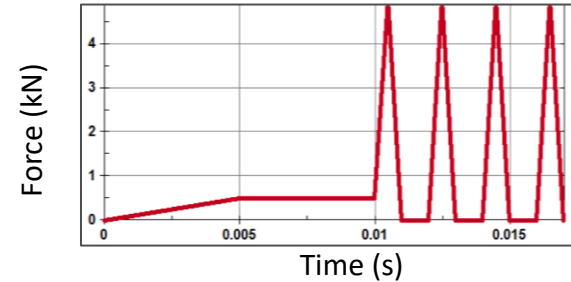
E. Mod.
High ■
Low ■



Animation



Animation



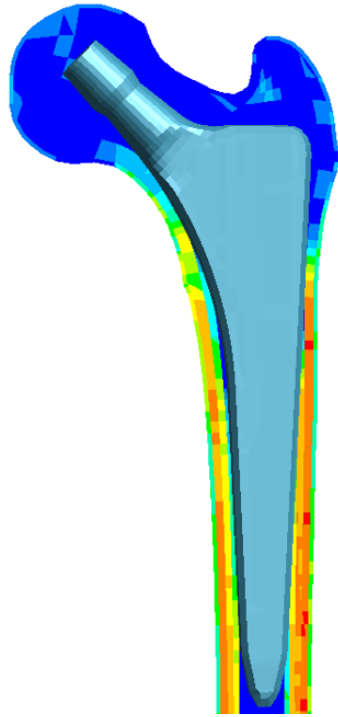
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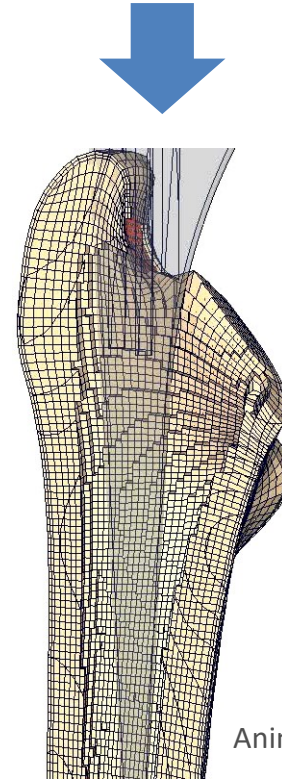
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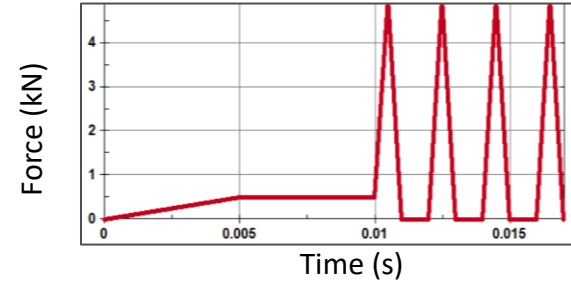
E. Mod.
High ■
Low ■



Animation



Animation



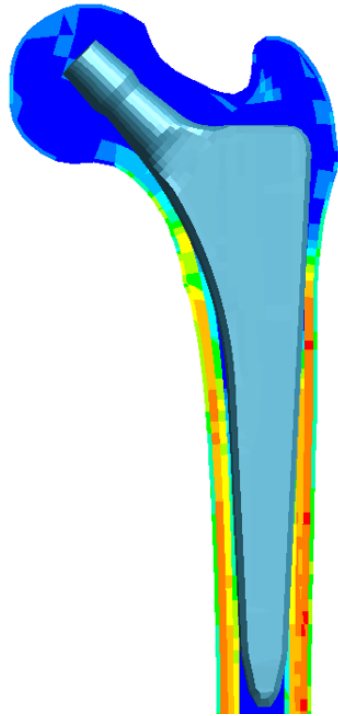
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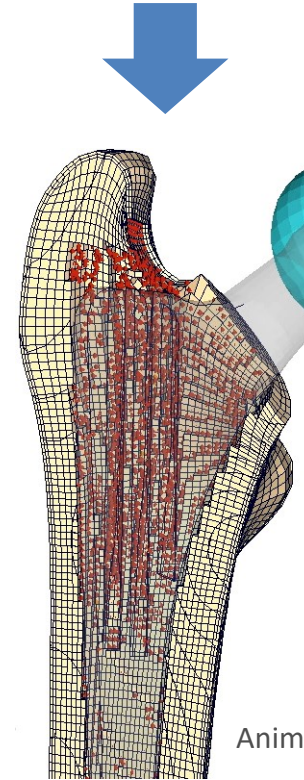
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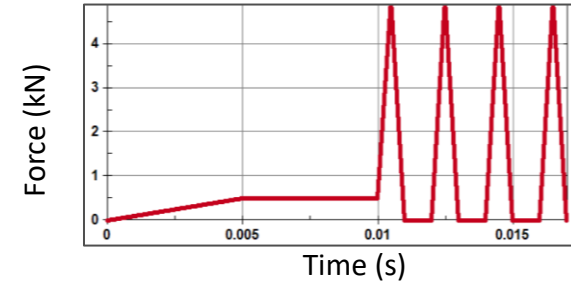
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High ■
Low ■



Animation



Animation



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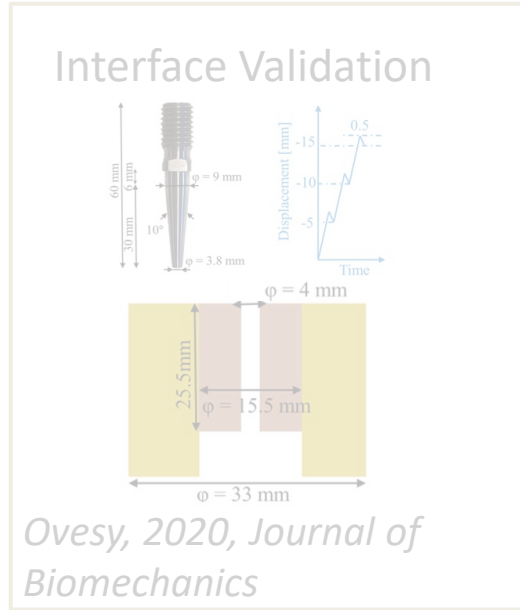
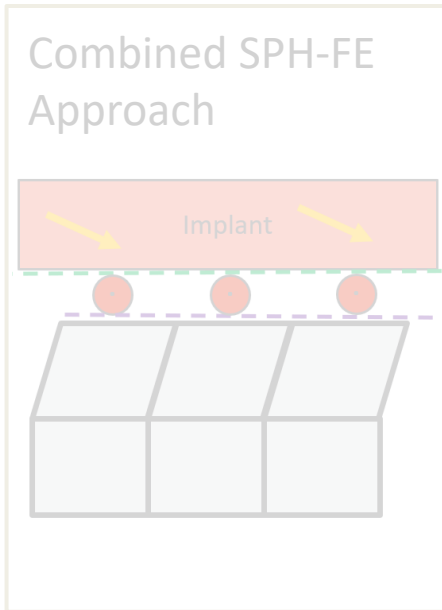
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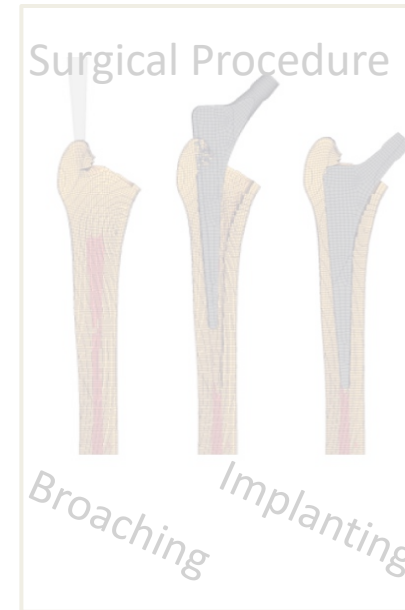


Methods

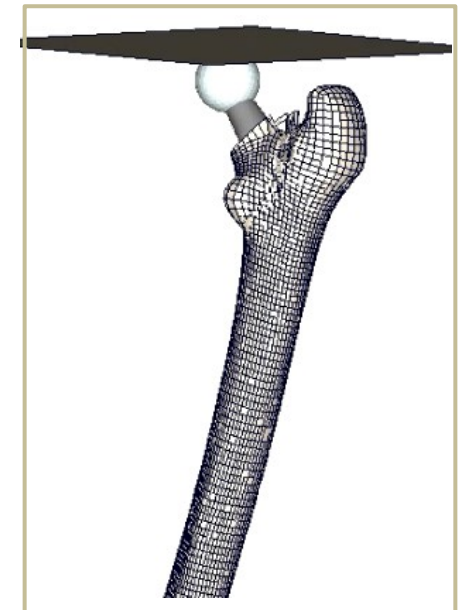
Numerical method to
simulate interface debris



Implanted femur
preparation



PPF Verification
based on
experiments





Methods - PPF Verification

CLS-Spotorno:

Rough blasted micro porous surface
(Aldinger et al., 2009)

Bone-Implant friction:

$\mu = 0.45$ (Gao, 2019)

Titanium:

E Mod.: 100GPa

Yield Stress: 795 MPa

Distal 10 cm



31.8° Internal Rotation
13.1° Adduction

Single run for insertion and loading



Intraoperative stress-strain state



Jakubowitz, 2009



Methods - PPF Verification

CLS-Spotorno:

Rough blasted micro porous surface
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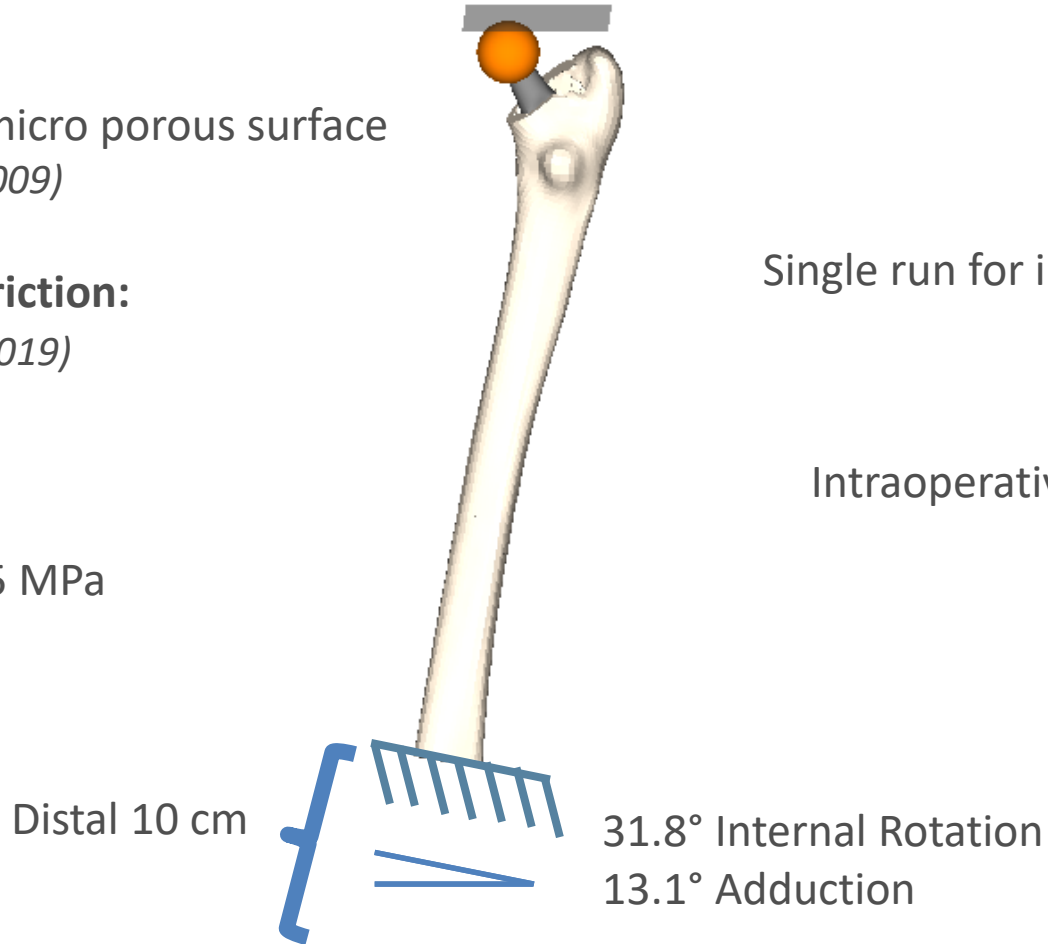
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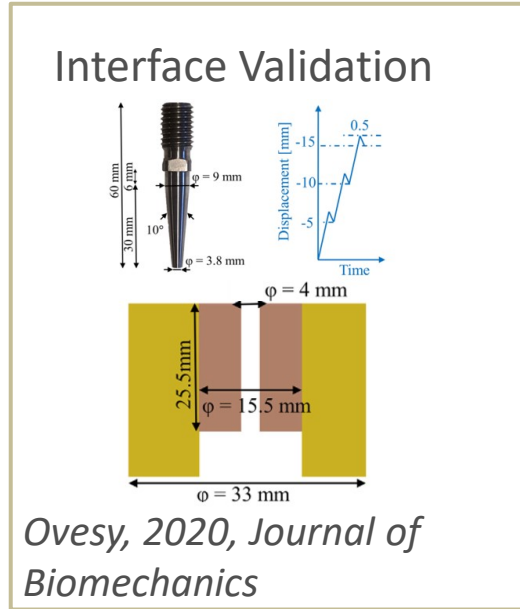
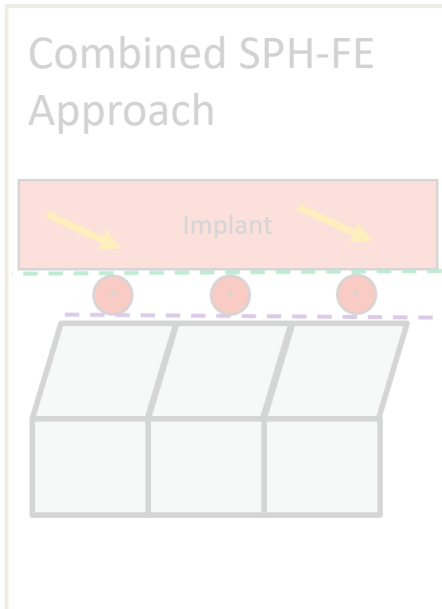
Intraoperative stress-strain state



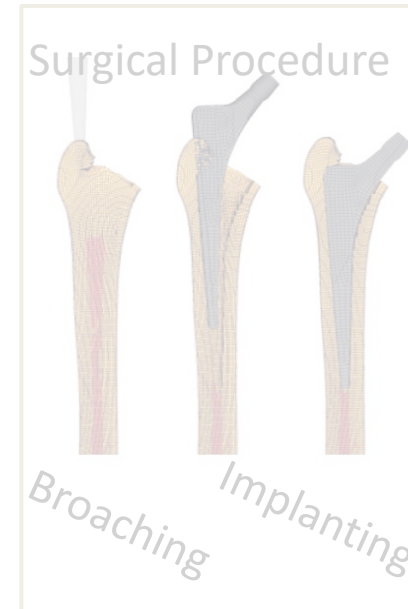


Results

Numerical method to simulate interface debris



Implanted femur preparation

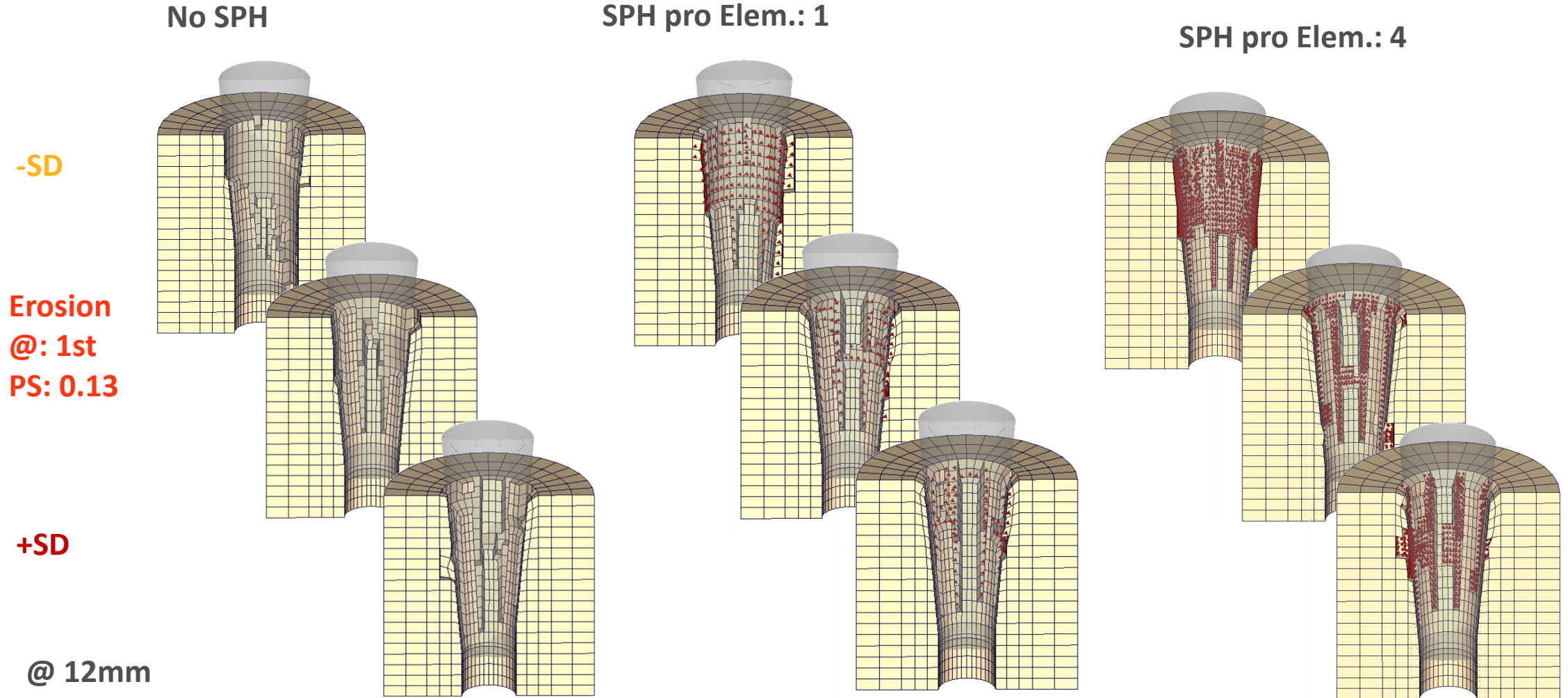


PPF Verification based on experiments





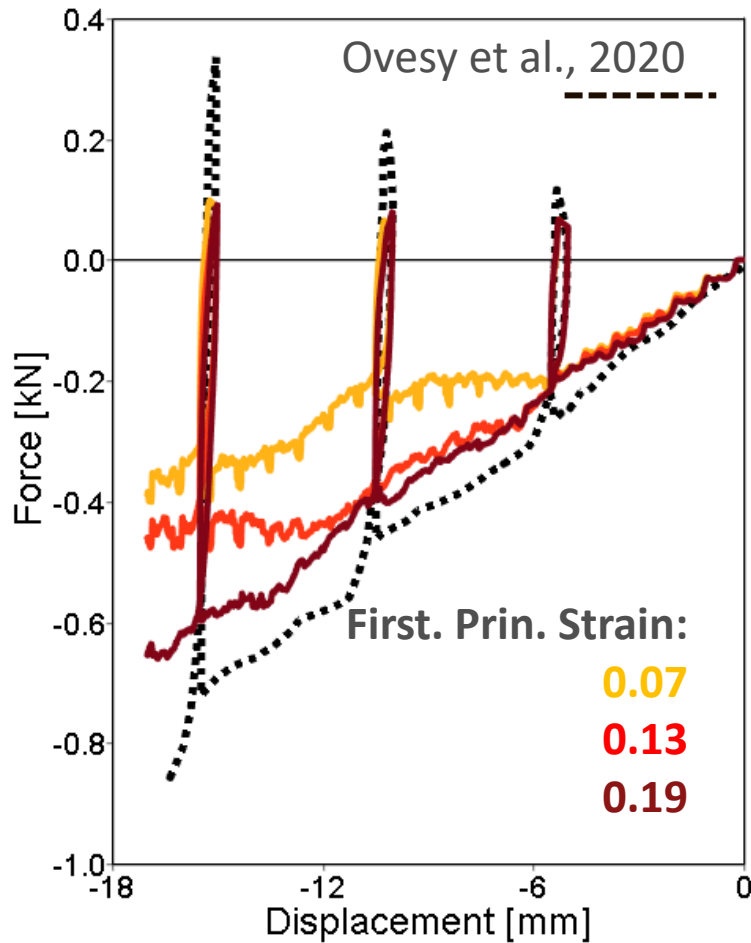
Results - Interface Modeling



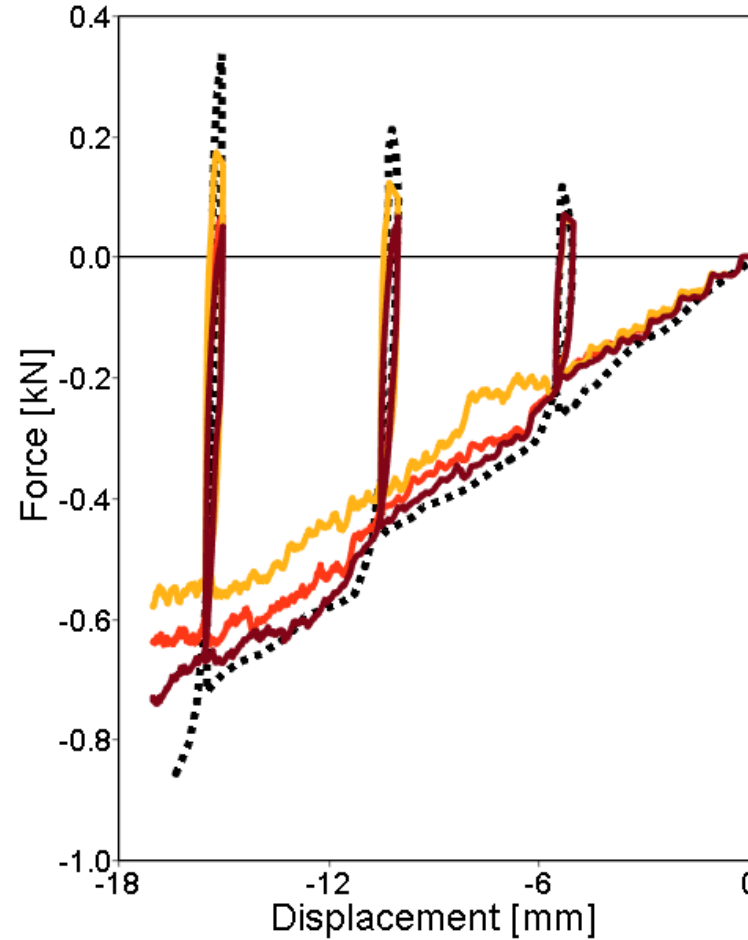


Results - Interface Modeling

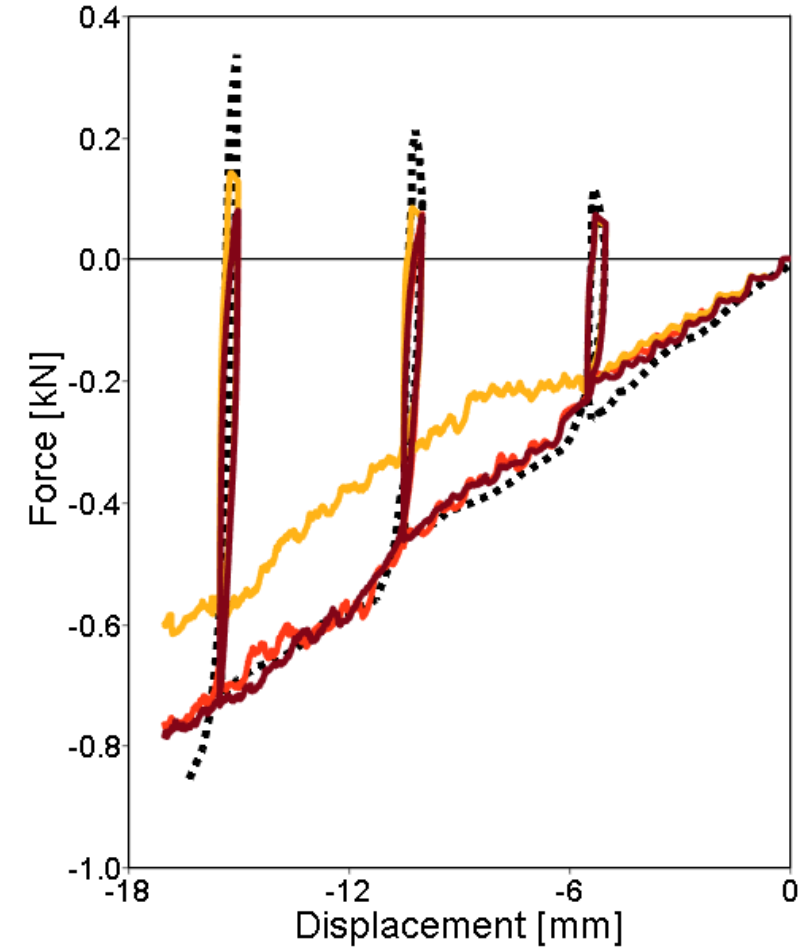
No SPH



SPH pro Elem.: 1



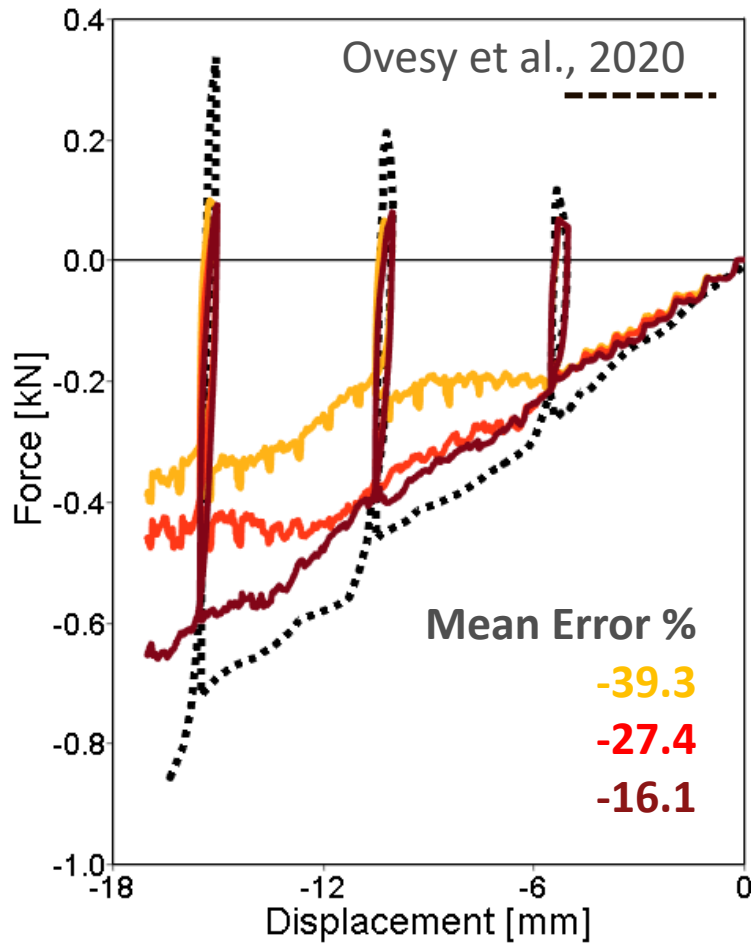
SPH pro Elem.: 4



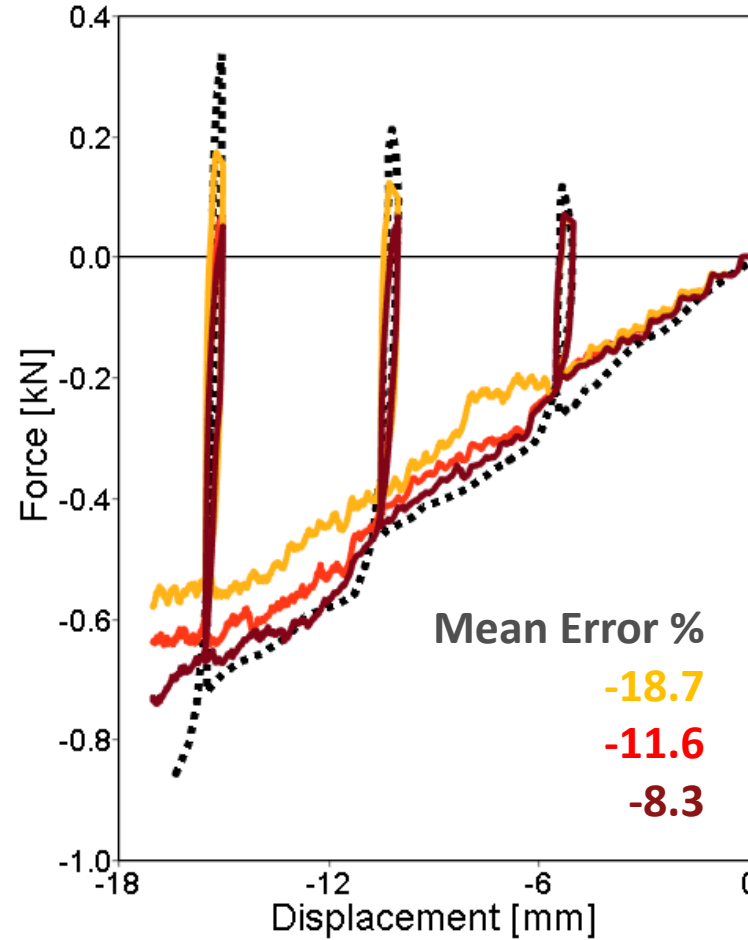


Results - Interface Modeling

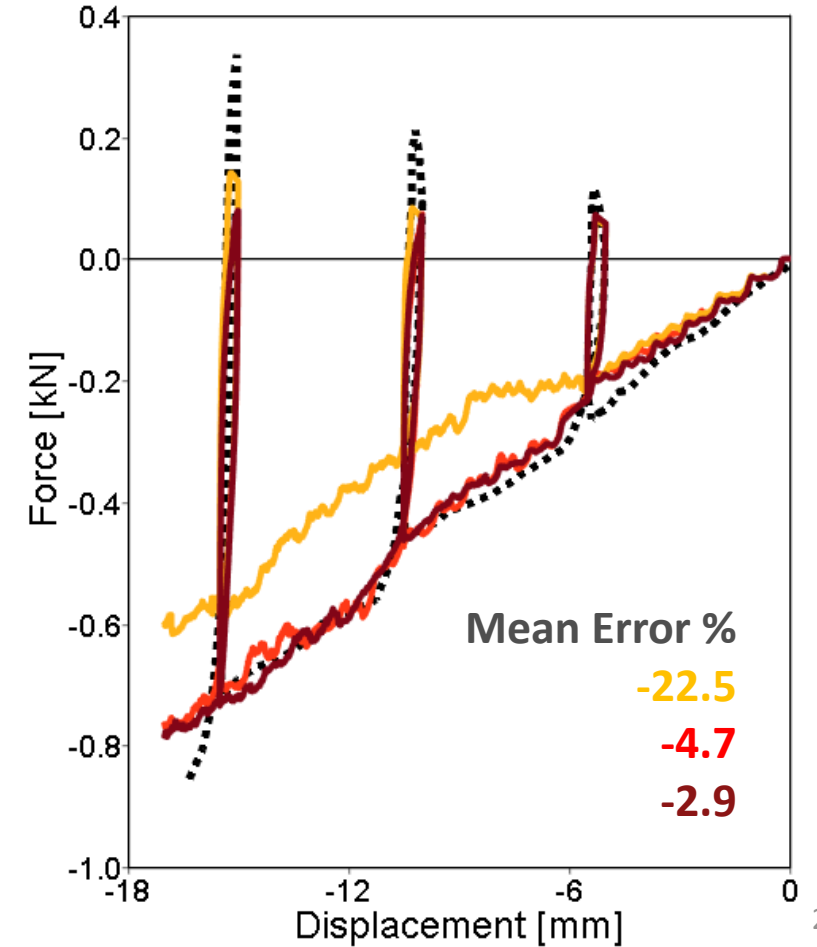
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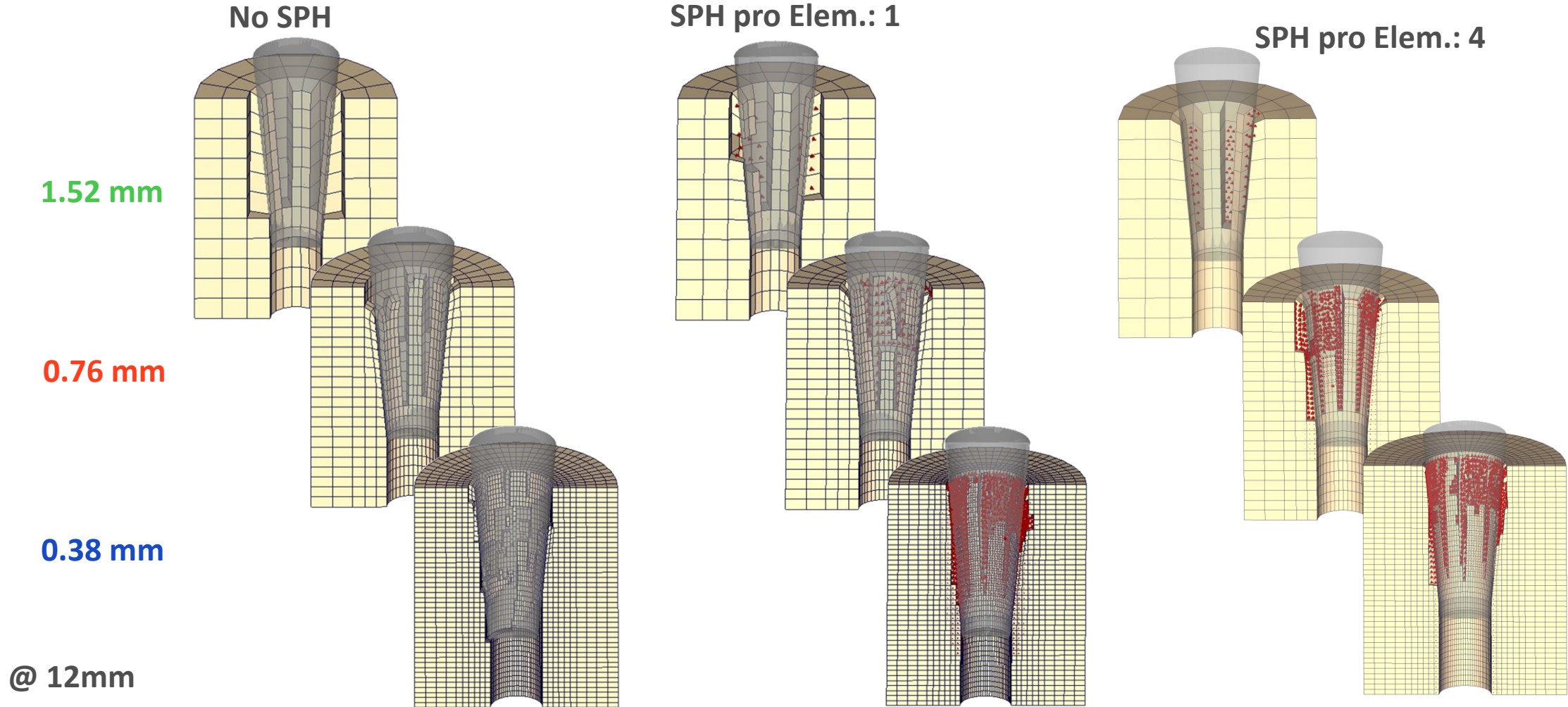


SPH pro Elem.: 4





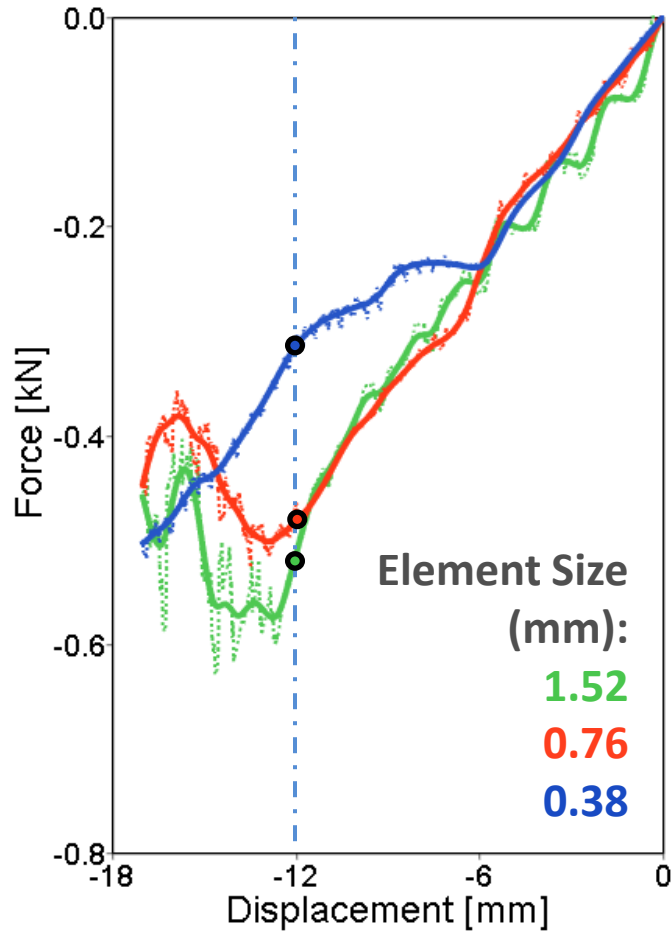
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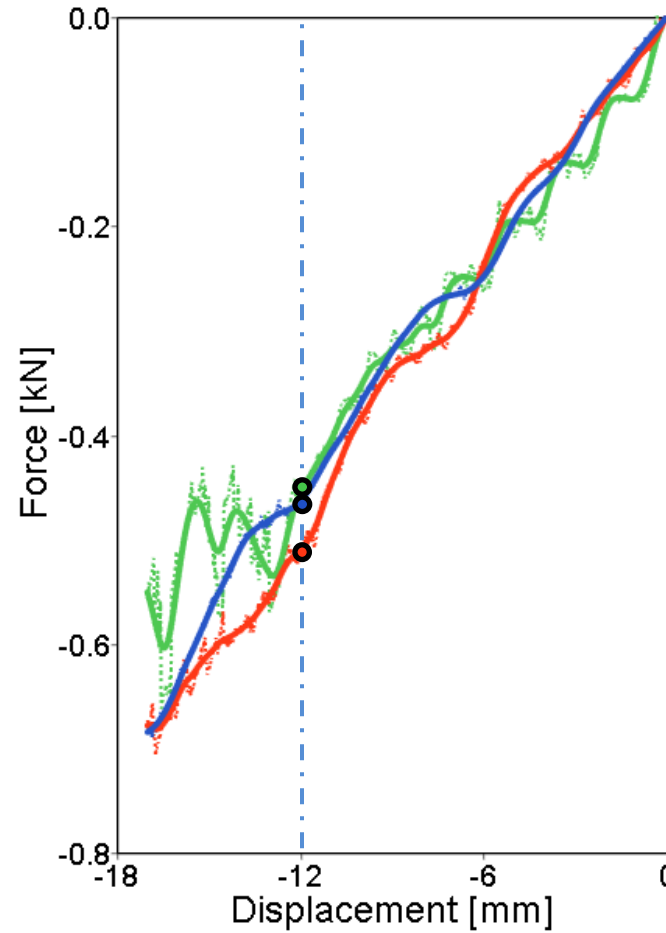


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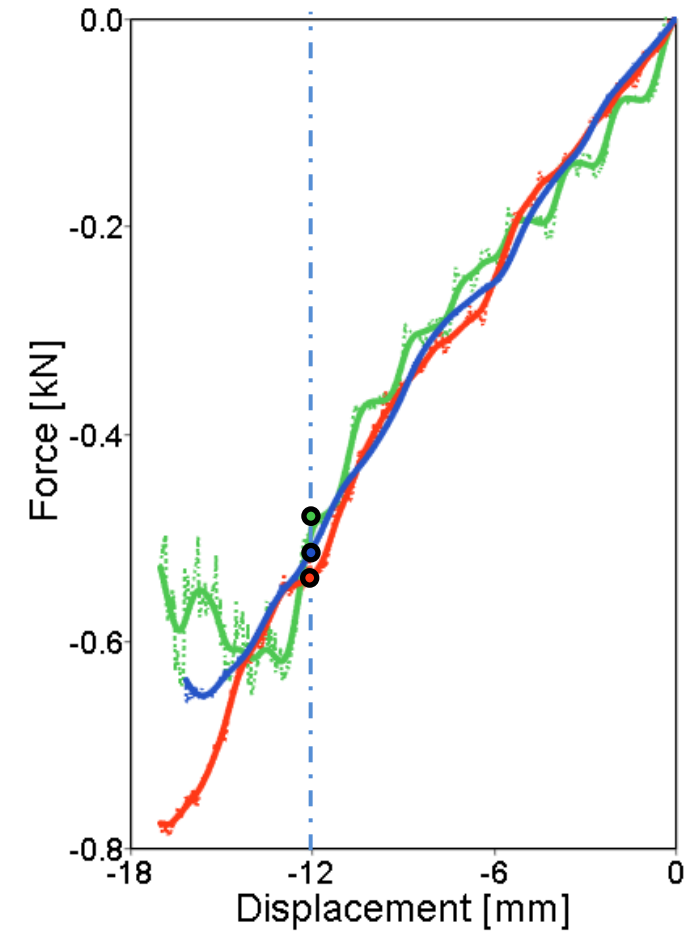
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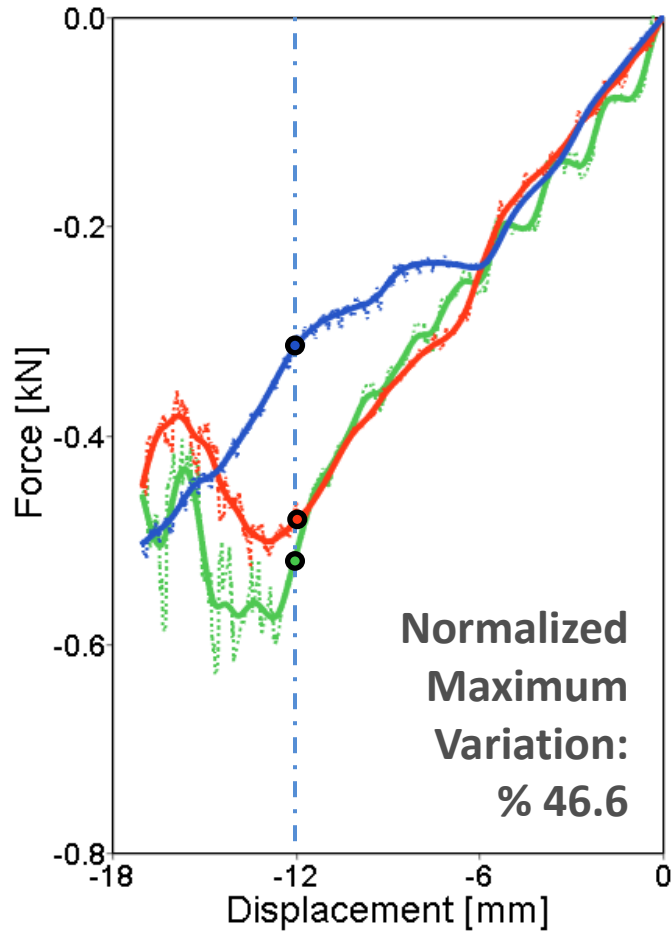
SPH pro Elem.: 4



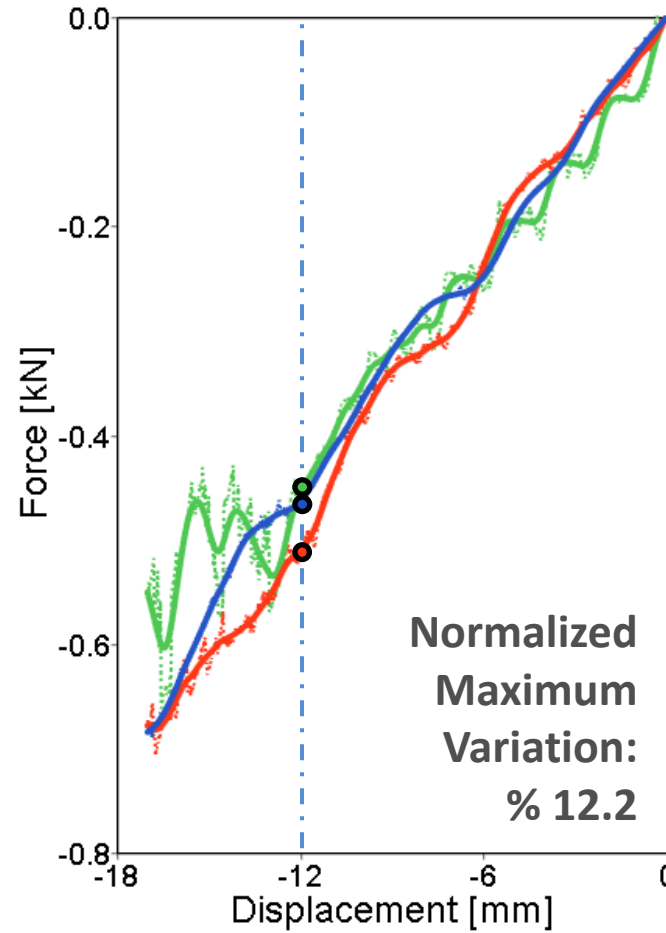


Results - Interface Modeling

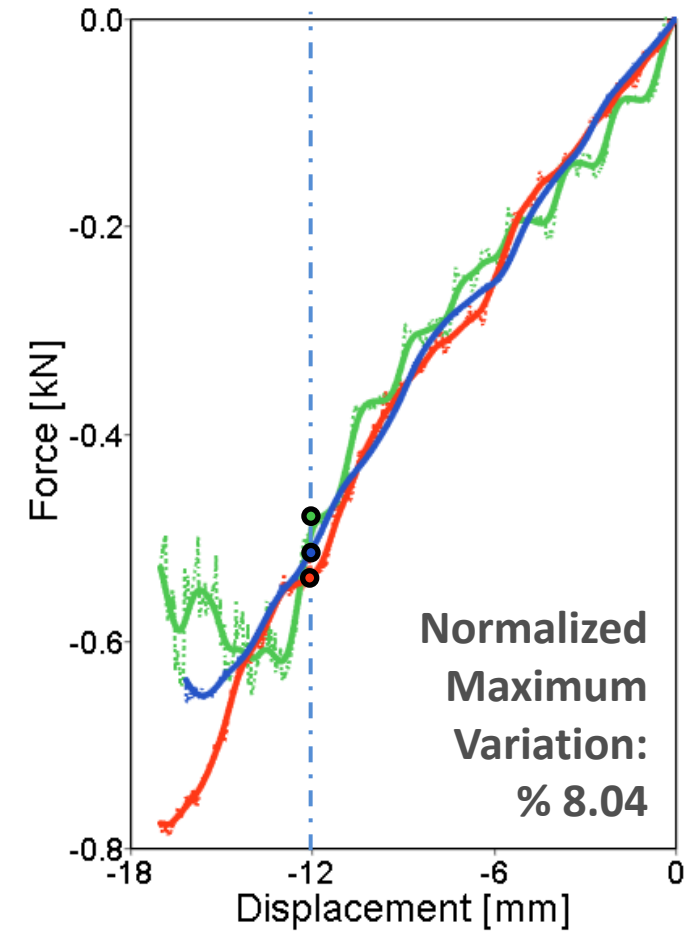
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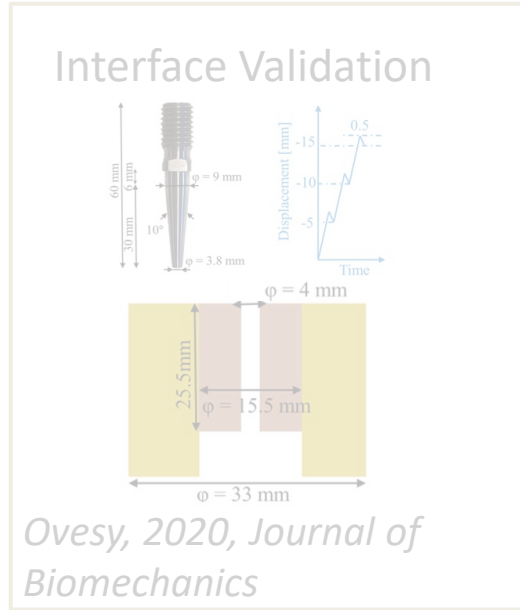
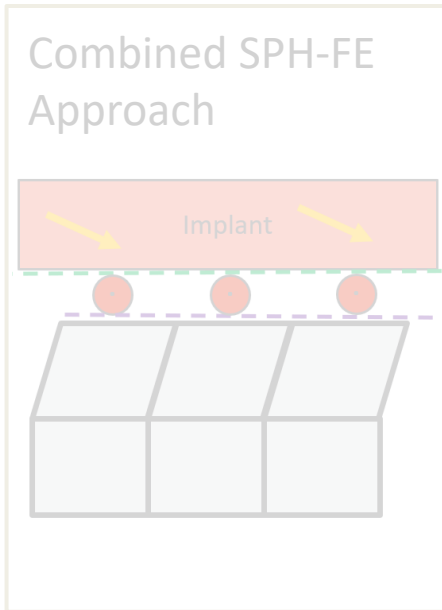
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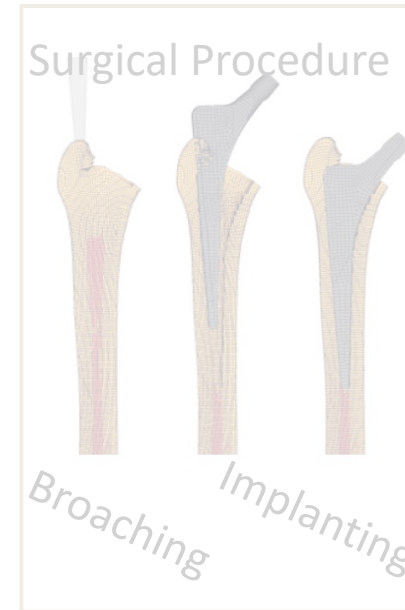


Results

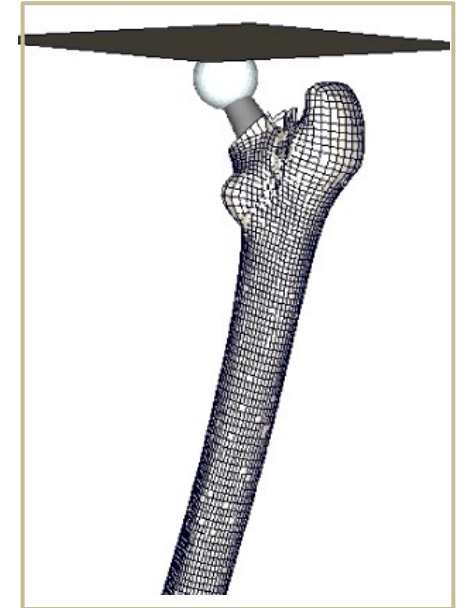
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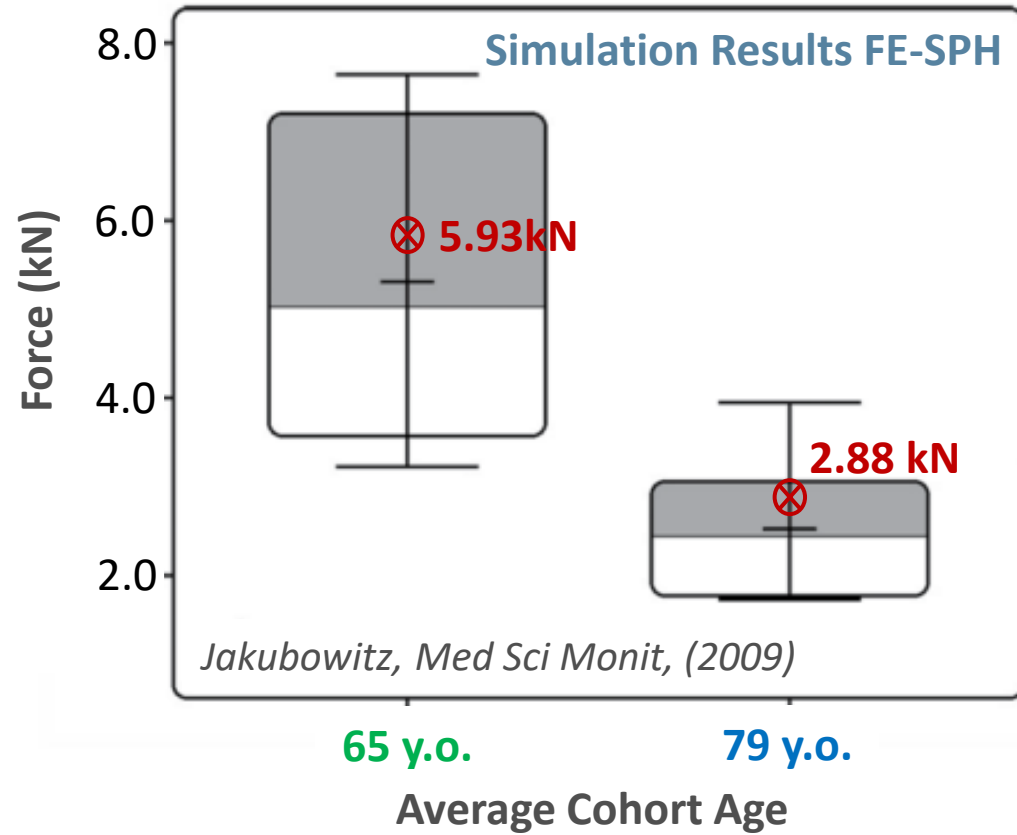
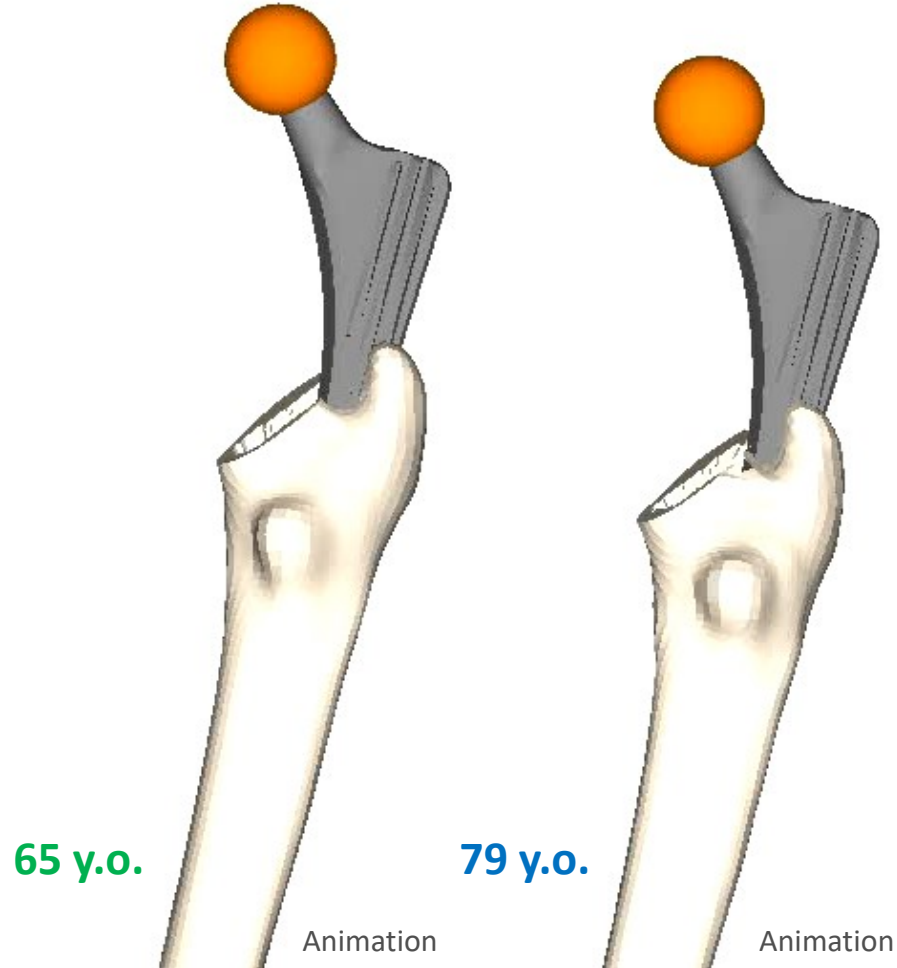


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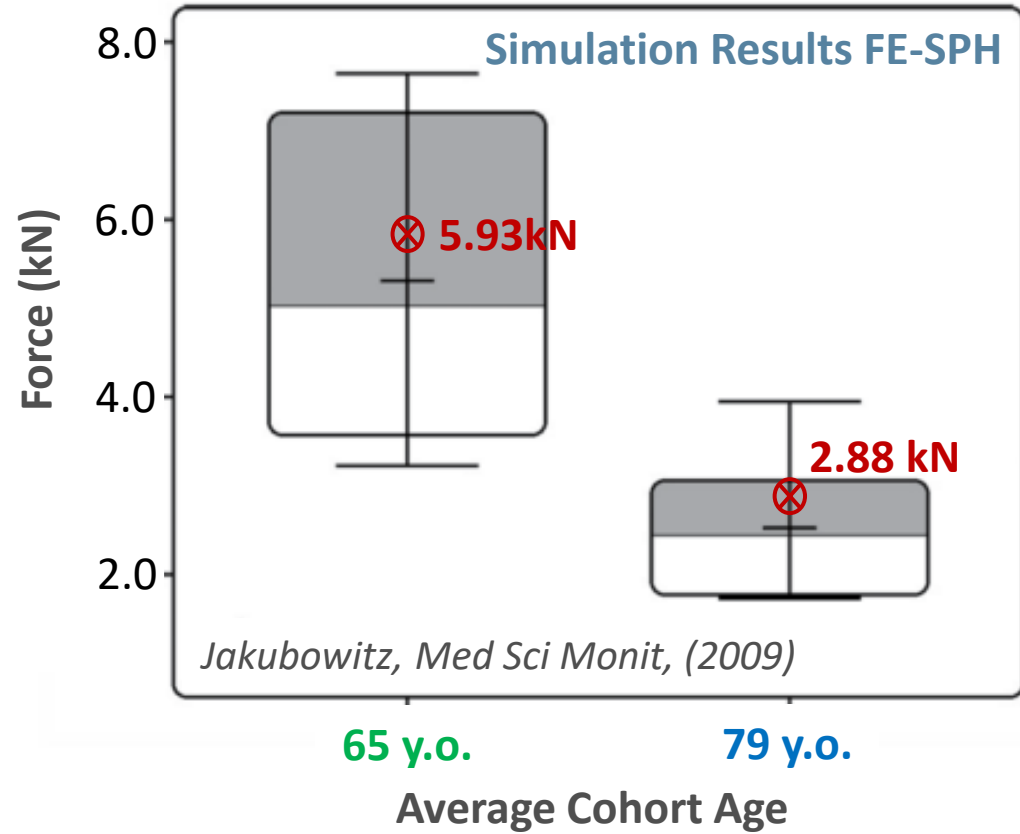
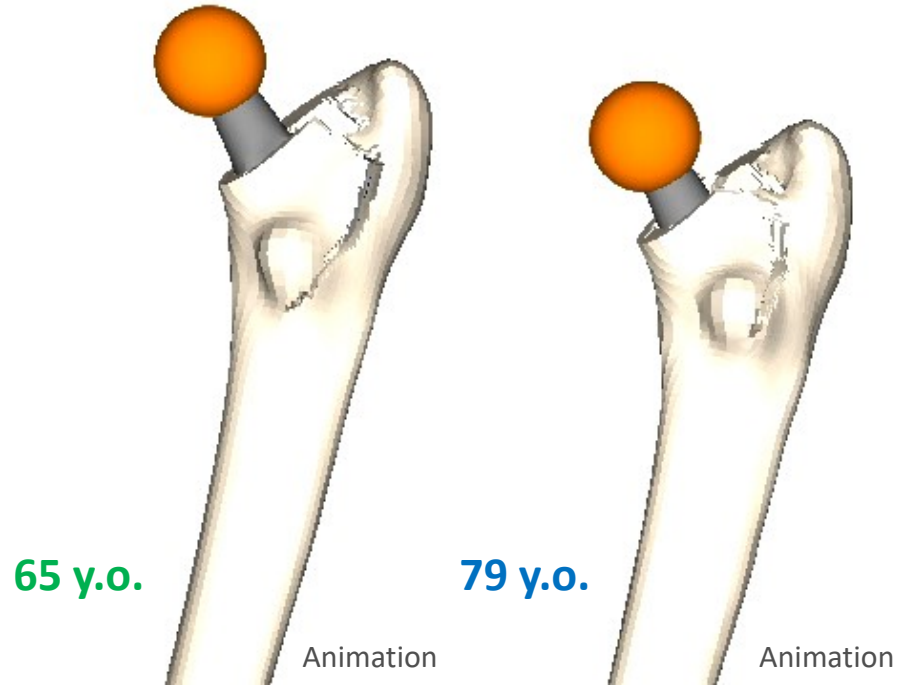
Results- PPF Verification



Age	Experiments (sd.)	Simulation	Error (%)
65 y.o.	5.02 (1.82) kN	5.93 kN	11.98%
79 y.o.	2.42 (0.64) kN	2.88 kN	14.53%



Results- PPF Verification



Age	Experiments (sd.)	Simulation	Error (%)
65 y.o.	5.02 (1.82) kN	5.93 kN	11.98%
79 y.o.	2.42 (0.64) kN	2.88 kN	14.53%



Conclusion and Outlook

- ➔ • Combined SPH-FE approach can represent the stem insertion experiment realistically
- ➔ • Reduced sensitivity on element erosion criteria using the combined SPH-FE approach
- ➔ • Reduced element size sensitivity using the combined SPH-FE approach
- ➔ • PPF simulations provided comparable results with the experiments
- ➔ • Pull out forces were predicted with large error and bone debris mechanics require further research



Conclusion and Outlook

- ➔ • Orthotropic-asymmetric material models will be included for cortical bone
- ➔ • In near future models will be validated based on ex-vivo experiments
- ➔ • In future developed models can be used to optimize stem designs and the intraoperative procedures which might help to mitigate PFFs



**HUMAN MODELING
AND SIMULATION**
IN AUTOMOTIVE ENGINEERING

THANKS FOR YOUR ATTENTION

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1. Maier, C. C. and Waddell, J. P. (2015) Incidence and predisposing factors of periprosthetic proximal femoral fractures: a literature review. *International Orthopaedics (SICOT)*, 39(9): pp.1673–1682.
2. Abdel MP, Houdek MT, Watts CD, Lewallen DG, Berry DJ. Epidemiology of periprosthetic femoral fractures in 5417 revision total hip arthroplasties: a 40-year experience. *Bone Joint J.* 2016 Apr; 98-B(4):468-74.
3. Bätz, J., Syrigos, S., Vorbeck, M. (2019) The influence of broach design on bone friction and osseo densification in total hip arthroplasty, *Clinical Biomechanics*
4. Brad Miles, Elizabeth Kolos, William L. Walter, Richard Appleyard, Angela Shi, Qing Li, Andrew J. Ruys, Subject specific finite element modeling of periprosthetic femoral fracture using element deactivation to simulate bone failure, *Medical Engineering & Physics*, 37 (6), 2015, pp. 567-573
5. Marzieh Ovesy, Marcel Aeschlimann, Philippe K. Zysset, Explicit finite element analysis can predict the mechanical response of conical implant press-fit in homogenized trabecular bone, *Journal of Biomechanics*, Volume 107, 2020.
6. Niklas B. Damm, Michael M. Morlock, Nicholas E. Bishop, Friction coefficient and effective interference at the implant-bone interface, *Journal of Biomechanics*, Volume 48, Issue 12, 2015, Pages 3517-3521,
7. J.A. Grant, N.E. Bishop, N. Götzén, C. Sprecher, M. Honl, M.M. Morlock, Artificial composite bone as a model of human trabecular bone: The implant–bone interface, *Journal of Biomechanics*, Volume 40, Issue 5, 2007, Pages 1158-1164,
8. R. Jungmann, M.E. Szabo, G. Schitter, Raymond Yue- Sing Tang, D. Vashishth, P.K. Hansma, P.J. Thurner, Local strain and damage mapping in single trabeculae during three-point bending tests, *Journal of the Mechanical Behavior of Biomedical Materials*, 4(4), 2011, pp. 523-534
9. Jakubowitz, E., Seeger, E. J., Kretzer, J. P., Heisel, C., Kleinhans, J. A., Thomsen M., (2009), he influence of age, bone quality and body mass index on periprosthetic femoral fractures: A biomechanical laboratory study, *Med Sci Monit*, 15(11): 307-312
10. Enns-Bray, W.S., Bahaloo, H., Fleps, I., Ariza, O., Gilchrist, S., Widmer, R., Guy, P., Pálsson, H., Ferguson, S.J., Cripton, P.A., Helgason, B. (2018), Material mapping strategy to improve the predicted response of the proximal femur to a sideways fall impact. *Journal of the Mechanical Behavior of Biomedical Materials*, 78: pp. 196-205.
11. Tijou, A., Rosi, G., Vayron, R., Lomami, H., Hernigou, P., Flouzat-Lachaniette, C.H., Haïat, G. (2018) Monitoring cementless femoral stem insertion by impact analyses: An in vitro study, *Journal of the Mechanical Behavior of Biomedical Materials*, 88: pp. 102-108.
12. Gao X., Fraulob M., Haïat G. (2019) Biomechanical behaviours of the bone–implant interface: a review. *J. R. Soc. Interface* 16(59).