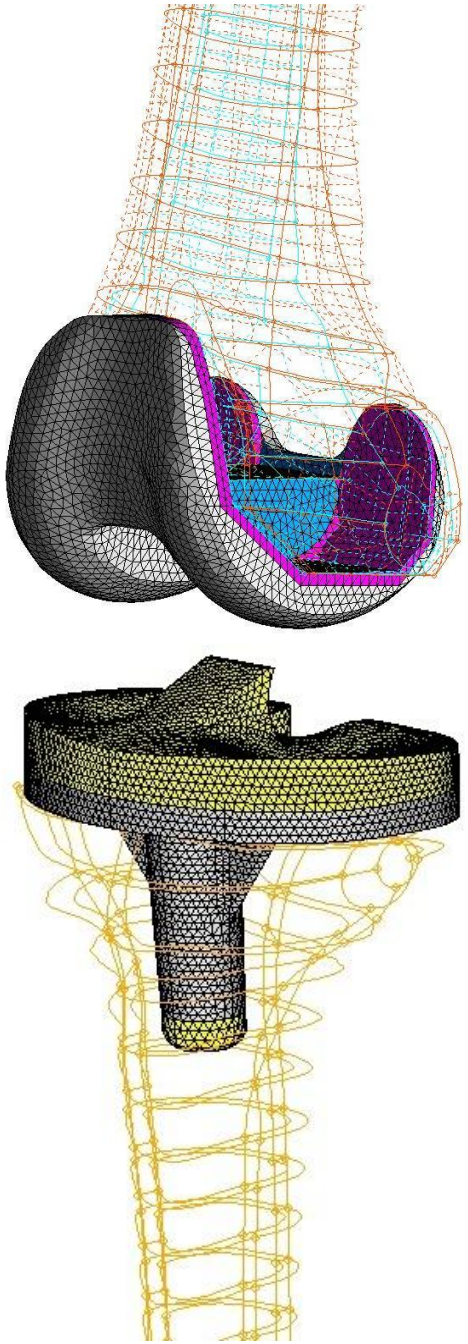
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)



Fernando Fonseca, MD PhD

Hospitais da Universidade de Coimbra

Faculdade de Medicina / Universidade de Coimbra

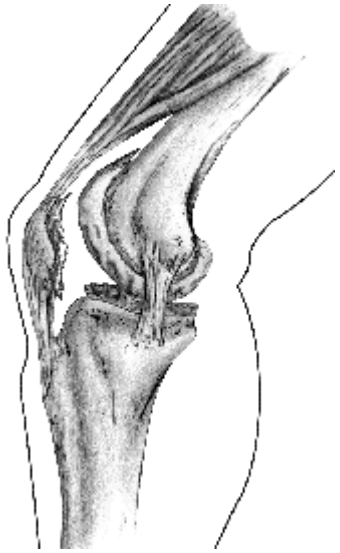
Faculdade de Ciências da Saúde / Universidade da Beira Interior

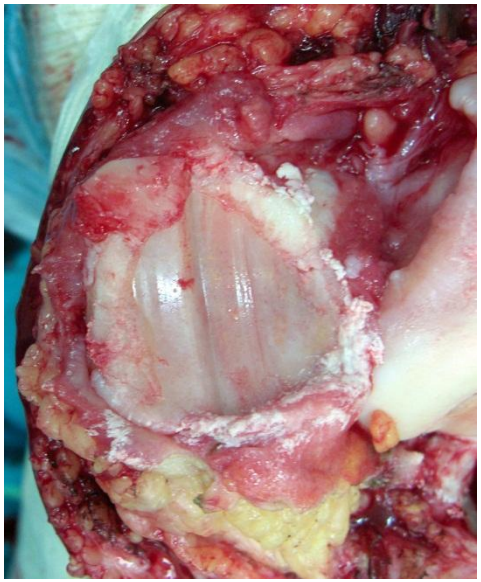
pereirafonseca@gmail.com

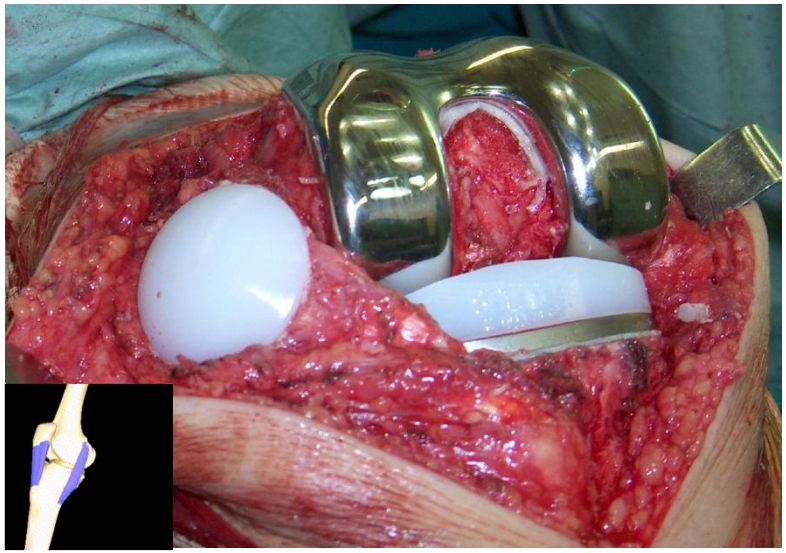
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

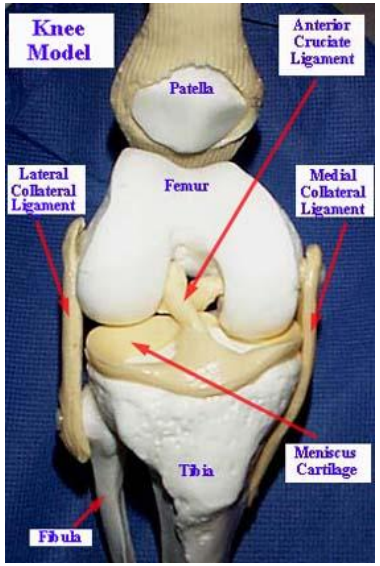
KNEE ARTHROPLASTY

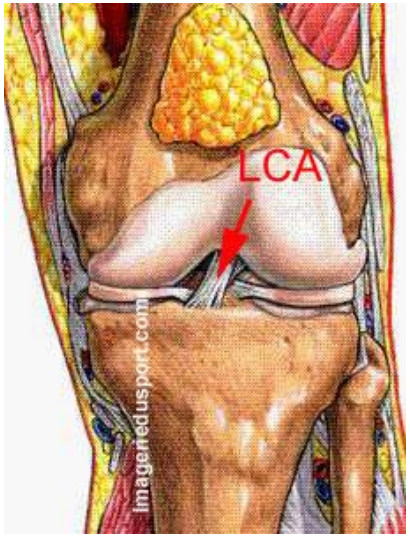
Why do knee fail?







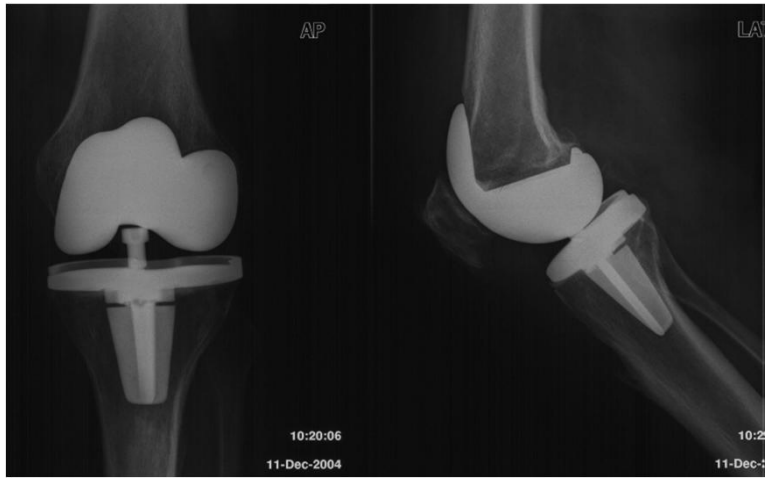




Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

KNEE ARTHROPLASTY

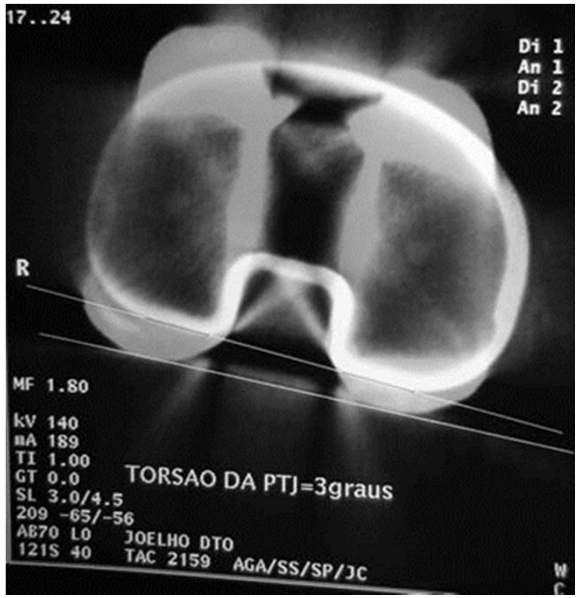
Why do knee fail?



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

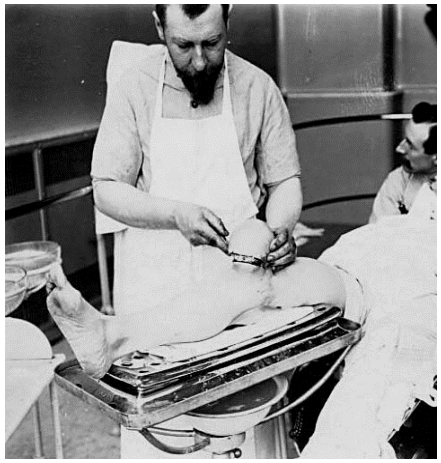
KNEE ARTHROPLASTY

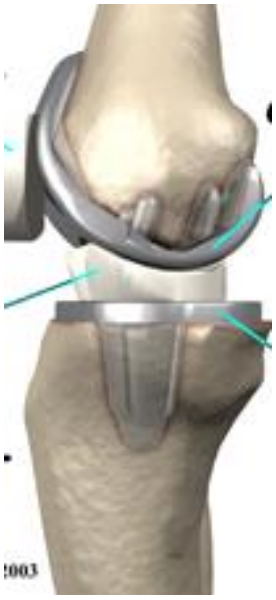
Why do knee fail?

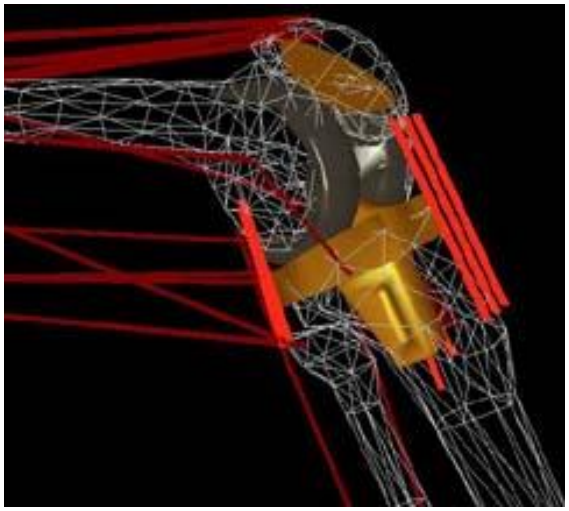


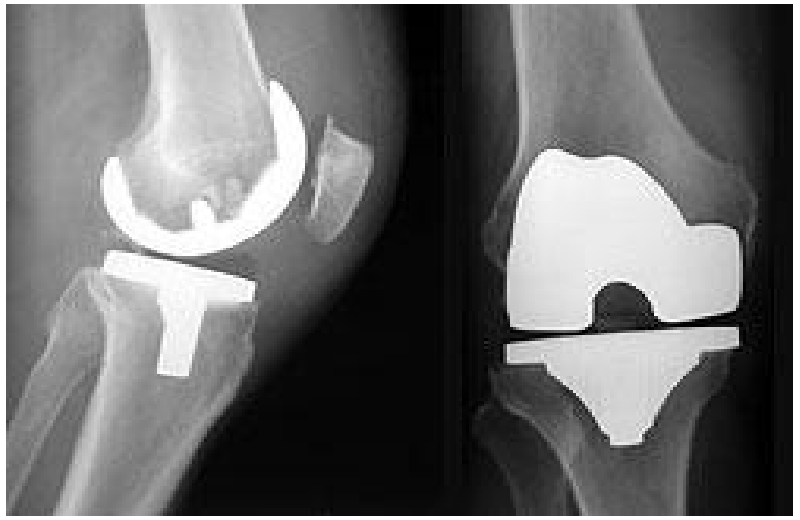
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

KNEE PROSTHESIS_What are the clinical solutions?





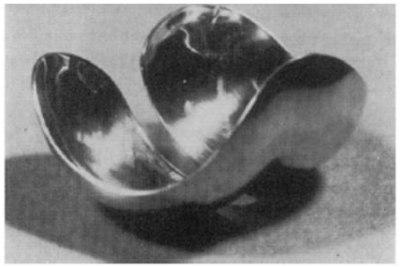




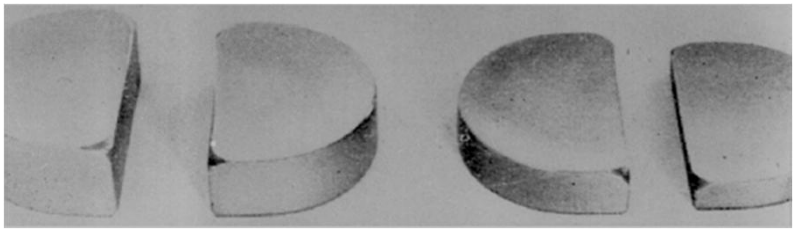
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

HISTORICAL EVOLUTION OF THE KNEE DESIGN

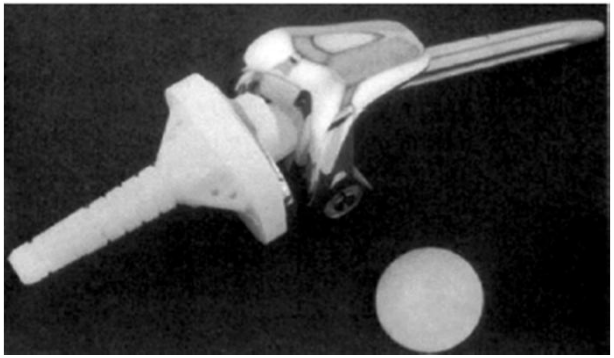
1958 – Shier prosthesis



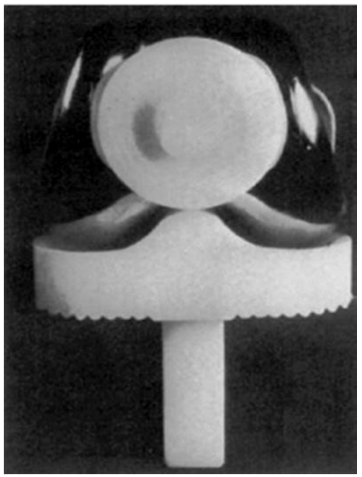
1972 - Smith-Petersen FEMORAL INTERPOSITION



1966 - Macintosh HALF TIBIAL PLATES



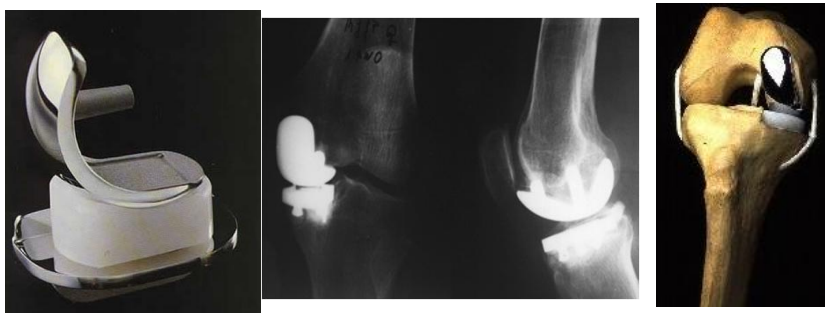
1980 - KINEMATIC II



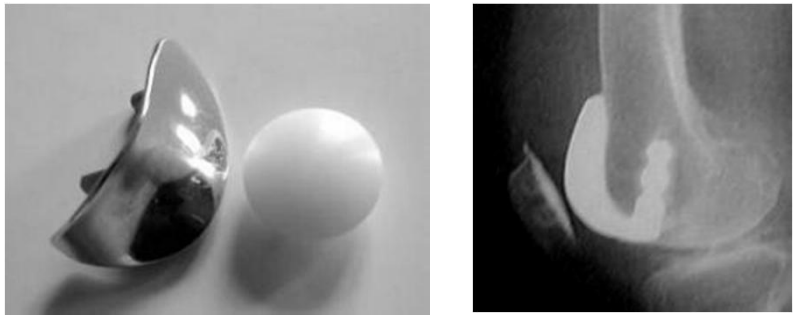
1974 – Insall TOTAL CONDYLAR PROSTHESIS

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

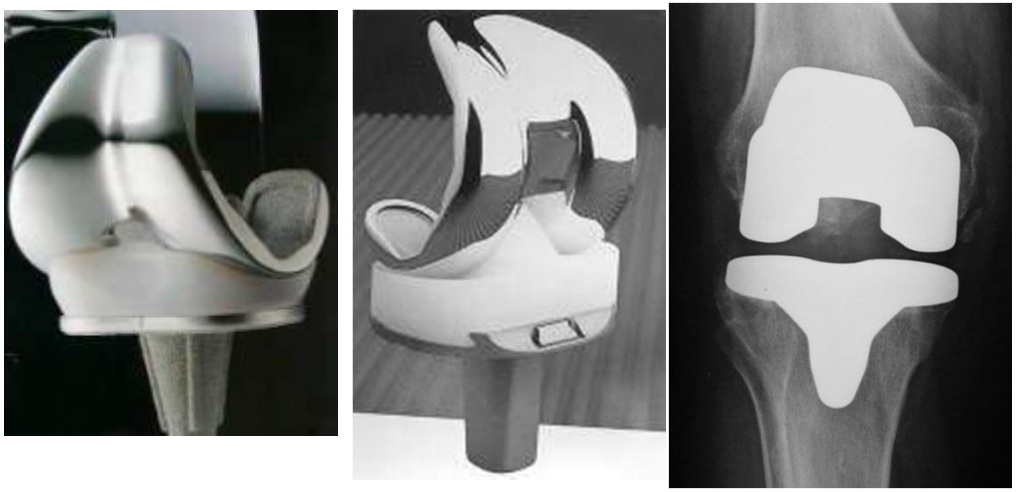
NOWADAYS KNEE PROSTHESES



UNICOMPARTIMENTAL



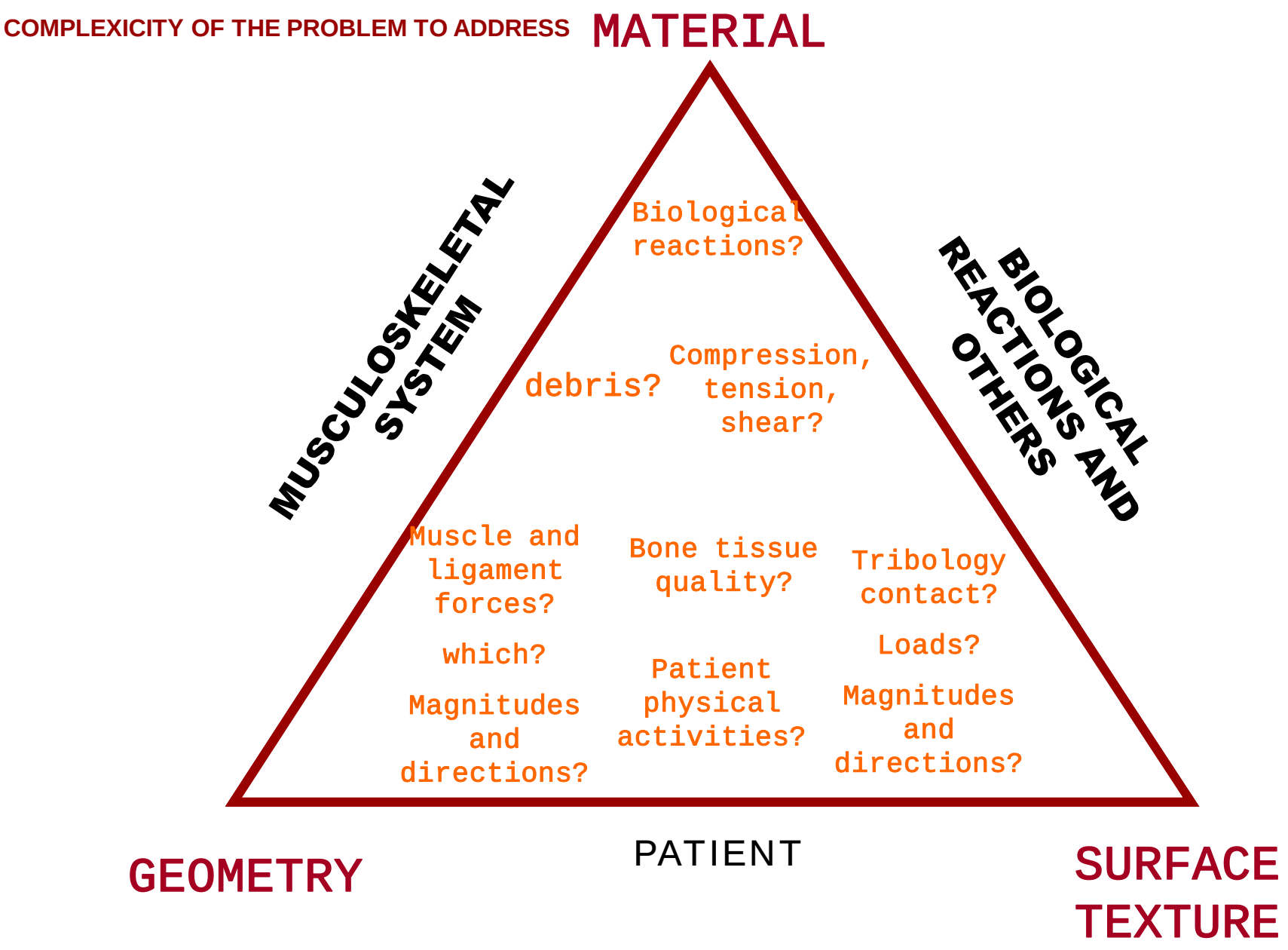
PATELLO-FEMORAL



SLIDING TOTAL KNEE PROSTHESIS

Hinge prosthesis

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

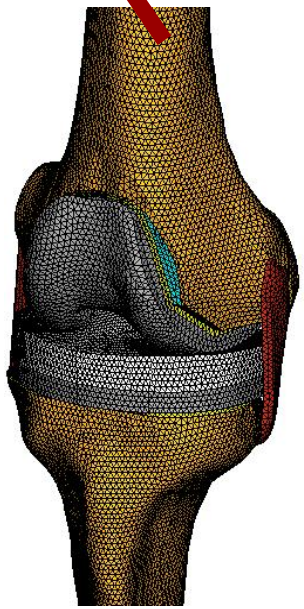
REALITY OF SIMULATION

CLINICAL STUDIES

Radiographs

Periodic patient evaluations

RSA, Others…



EXPERIMENTAL STUDIES

Strain gauges

3D and 2D photoelasticity

Optical methods

Others…

NUMERICAL SIMULATION

Finite elements

Finite differences

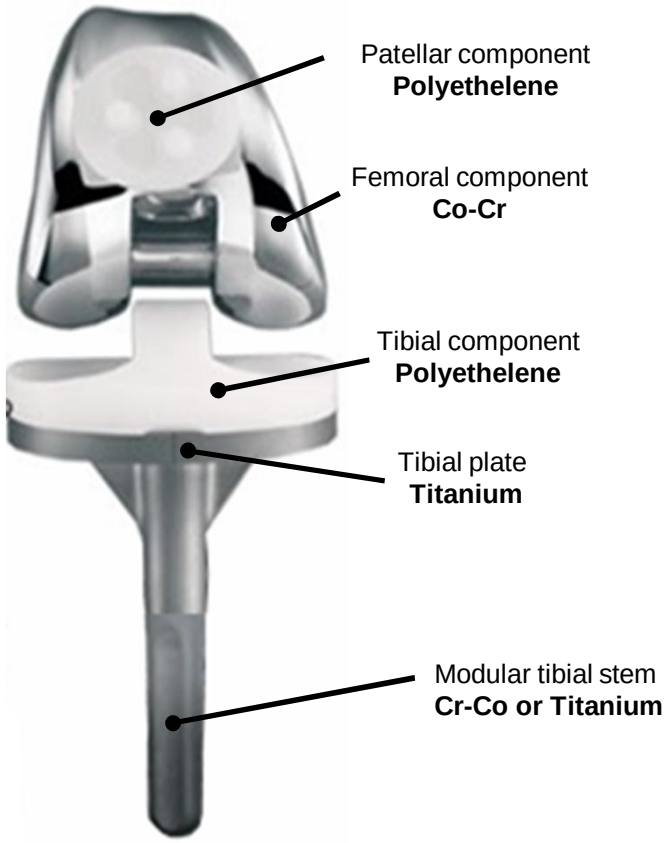
Boundary elements

Others…

SIMULATION CONTROL

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

THE MATERIALS OF KNEE PROSTHESES



Total Knee Prosthesis

First prosthesis were made of Stainless Steel.

Cobalt-Chrome (Co-Cr) is wear resistant and produces less debris, which are not well tolerated and induce loosening

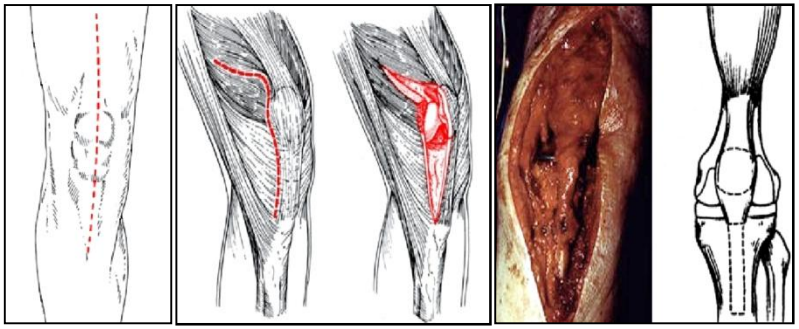
Titanium alloys are used for metallic tibial trays

The sliding components are of ultra high density polyethelene (patella component and tibial tray)

Ceramic femoral components

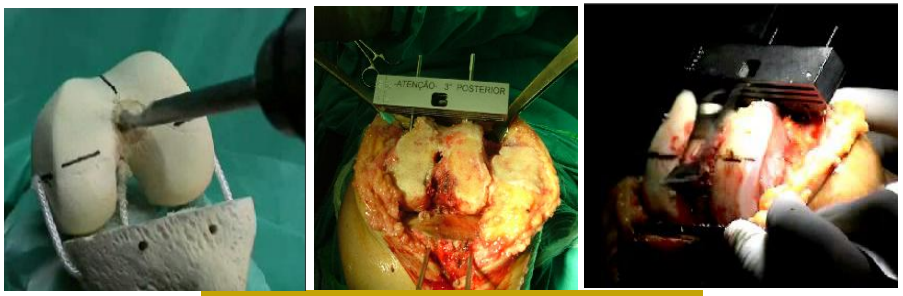
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

TOTAL KNEE PROSTHESIS - SURGERY



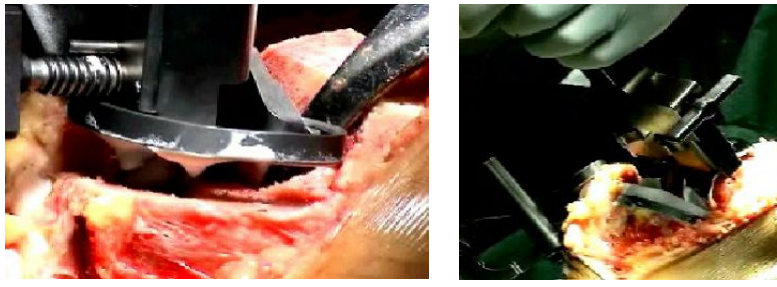
1- Approach

2 Proximal tibial osteotomy

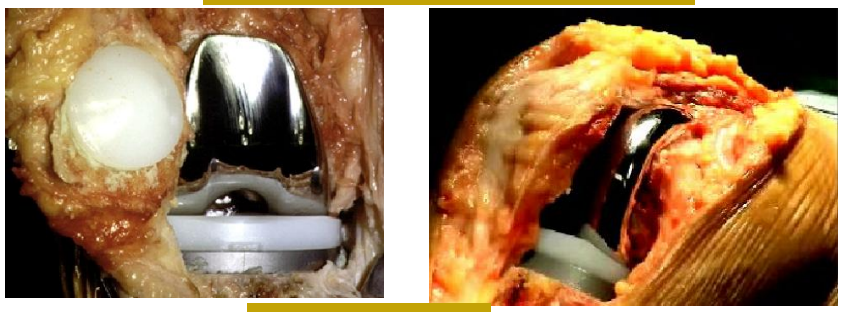


3 Femoral Osteotomy

4 Ligamentar balance



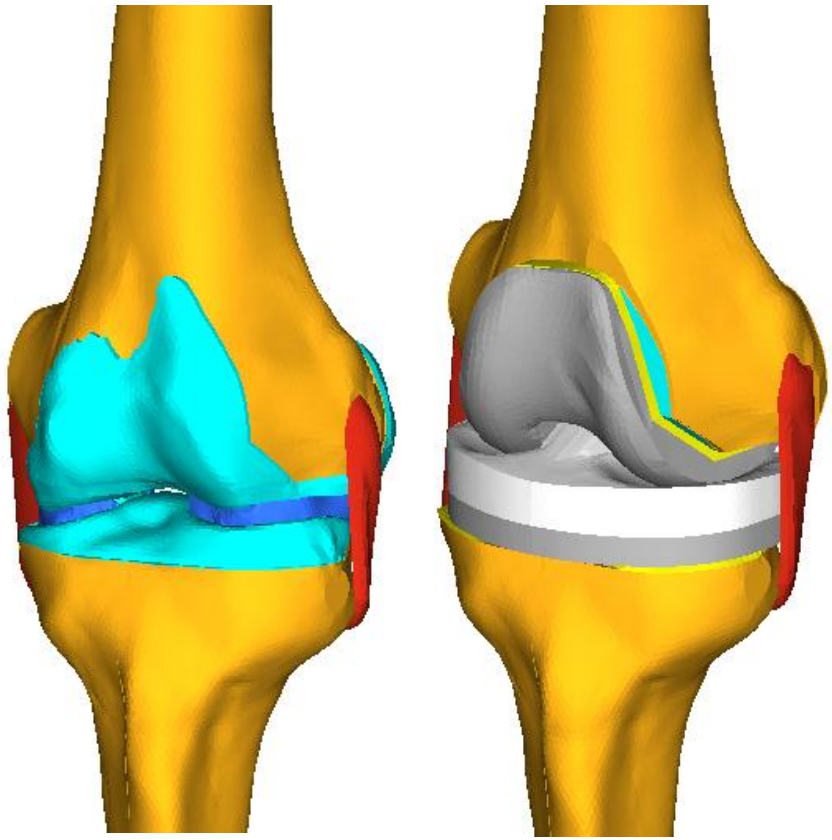
5 Definitive implants



6 Closing

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

KNEE PROSTHESIS_complications



Pain
Infection
Wear
Loosening / instability

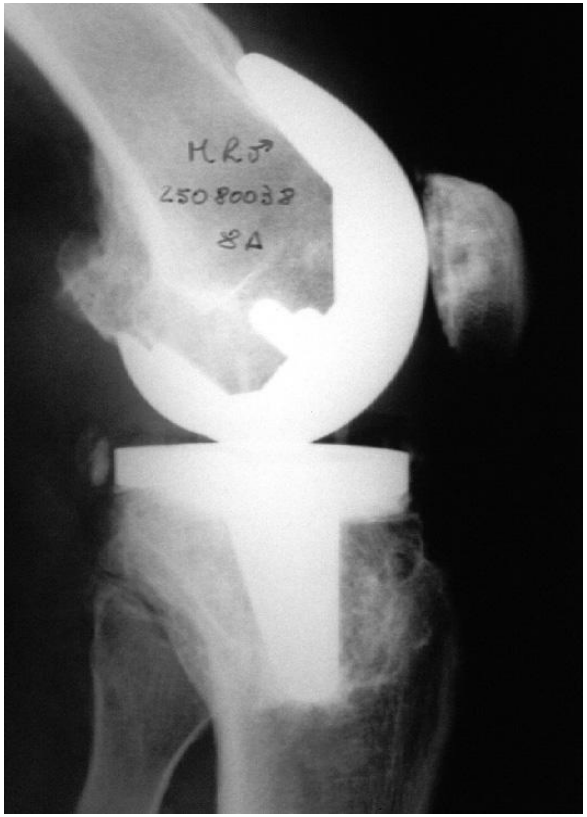
Why biomechanical studies of TKR?

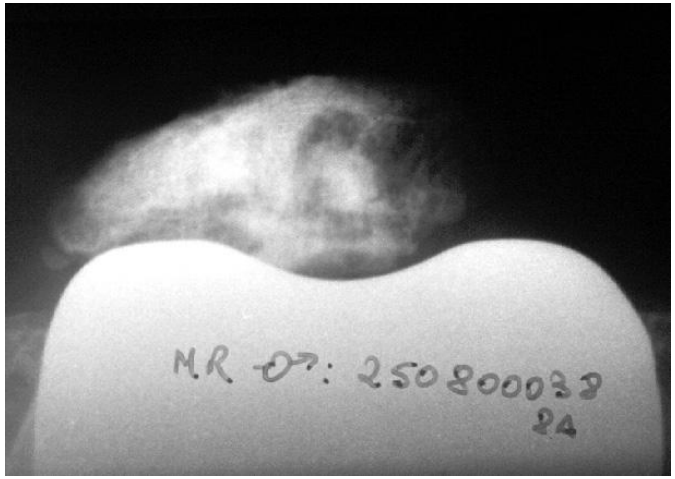
Correlate stresses and strains with clinical evidences

The knowledge of the mechanical behaviour of TKR can support decisions on material selection, designs, fixation techniques to optimize mechanical performance of the knee prosthesis and provide higher life quality for the patient and postpone life service of the implant

Infection

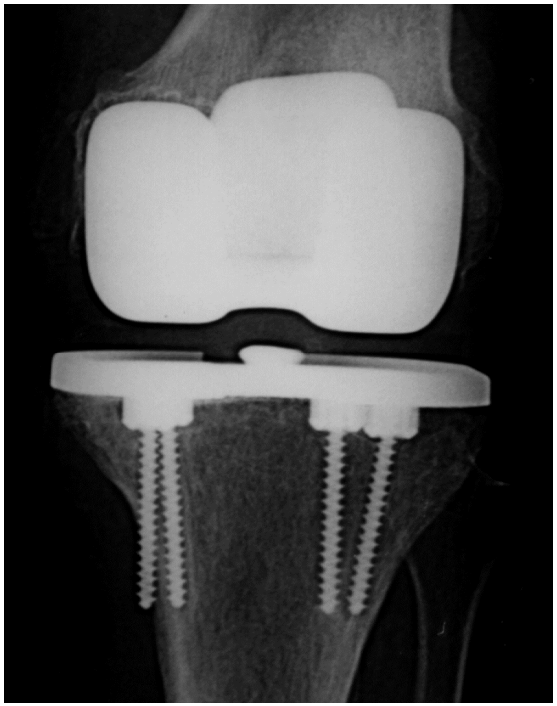
Loosening

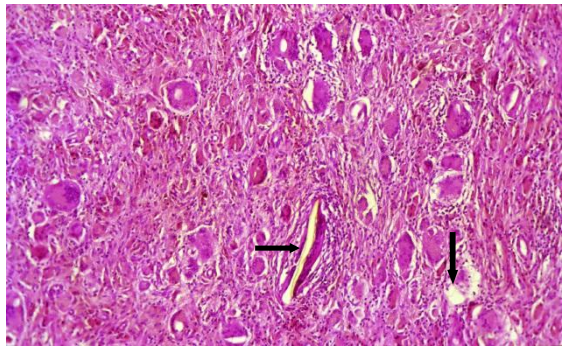


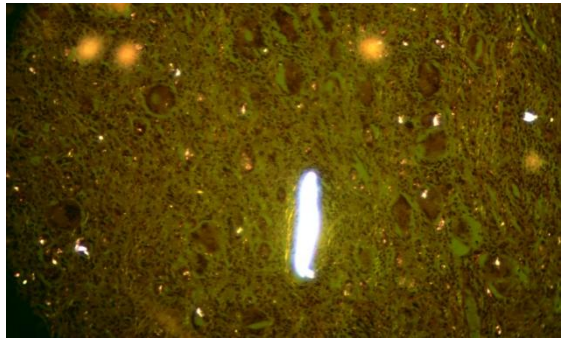


Loosening

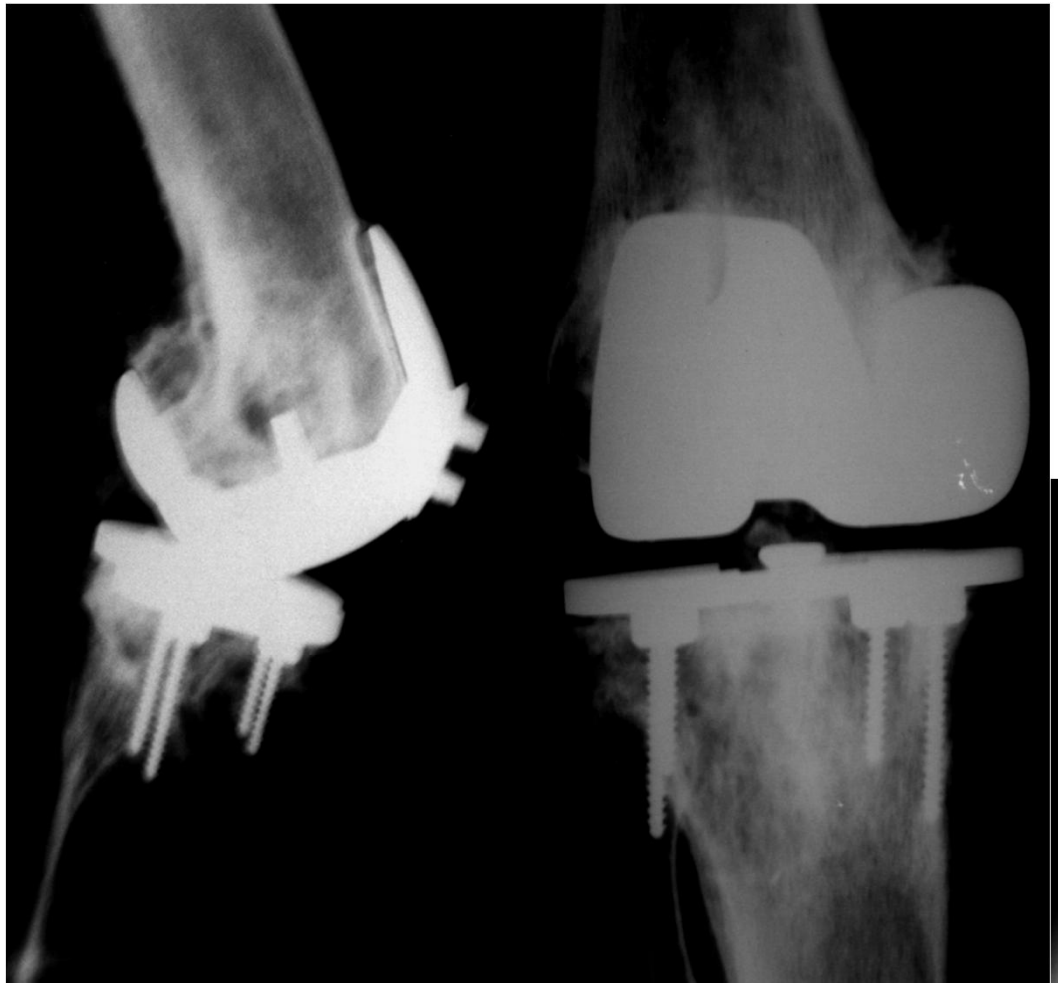
Osteolysis / debris

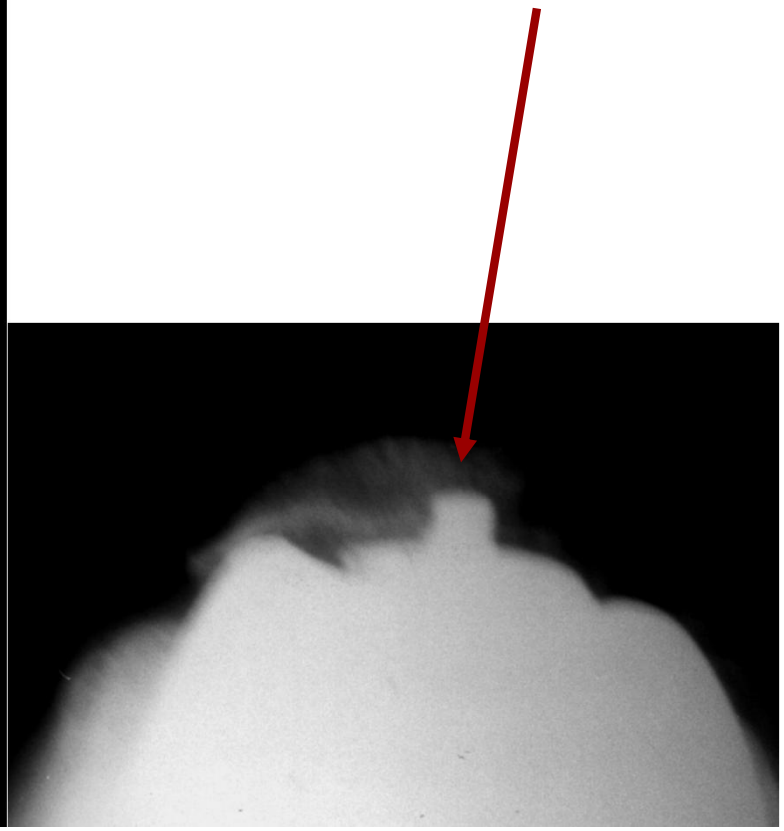




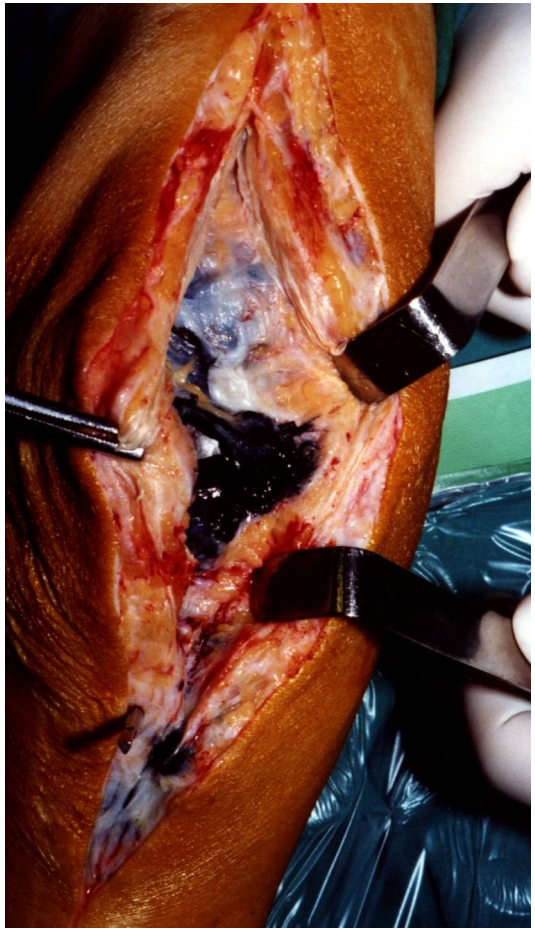


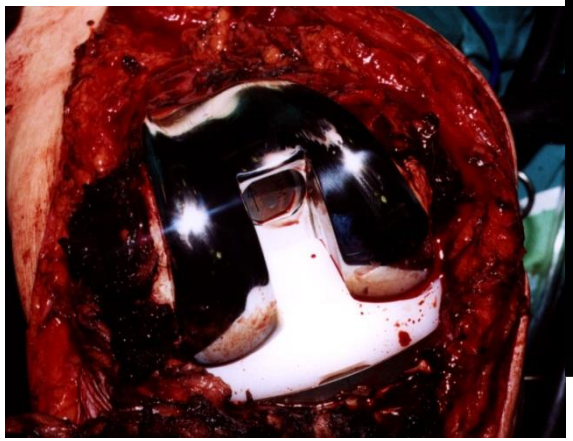
Metal-back





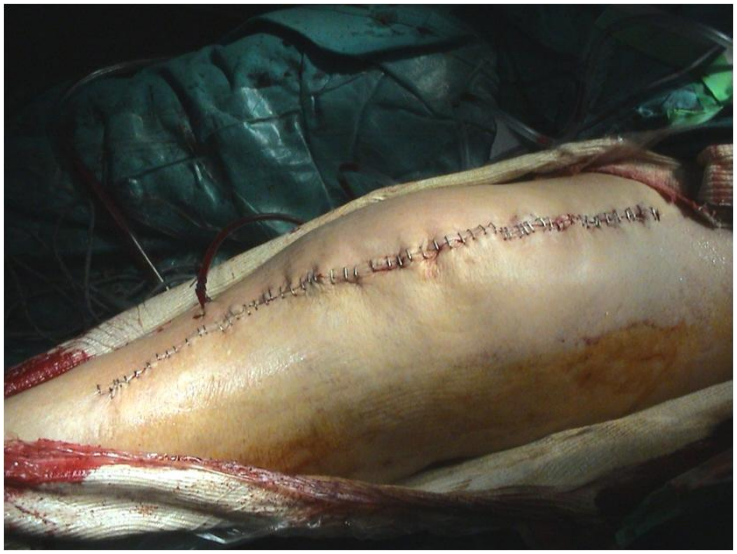
Metal-back

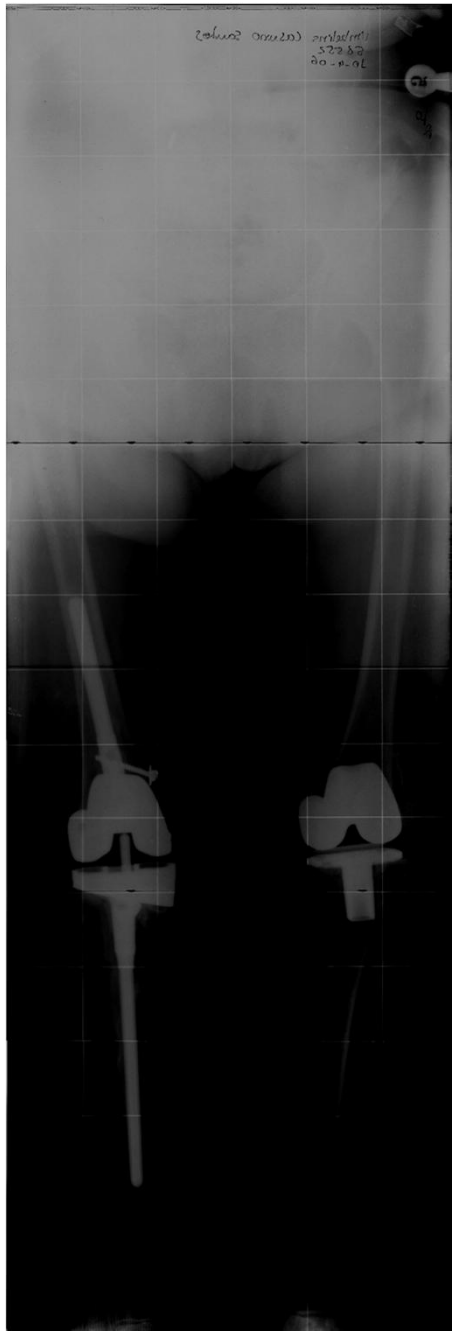




Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

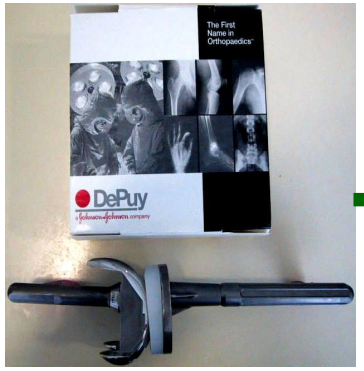
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)





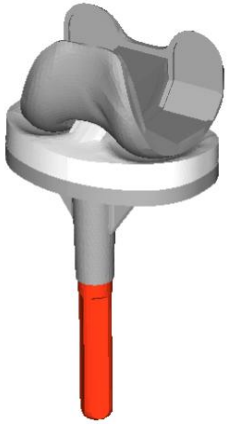
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

NUMERICAL SIMULATION_The process

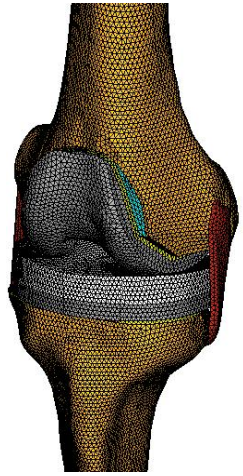


Selection of model
P.F.C Sigma Modular Knee System
(Depuy/ Johnson & Johnson-Warsaw/Indiana)

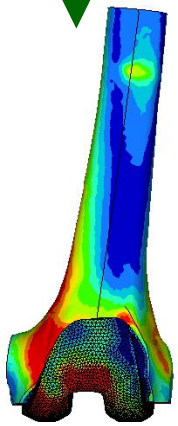
3D geometry acquisition
Roland LPX 250



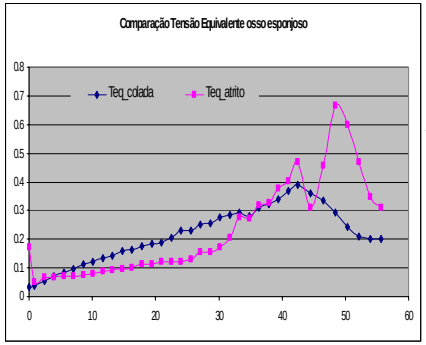
Geometric modelling
Catia V5
(Dassault Systèms).



Finite Element mesh generation
HyperWorks
(Altair Engineering Inc.)



Structural calculations (MEF)



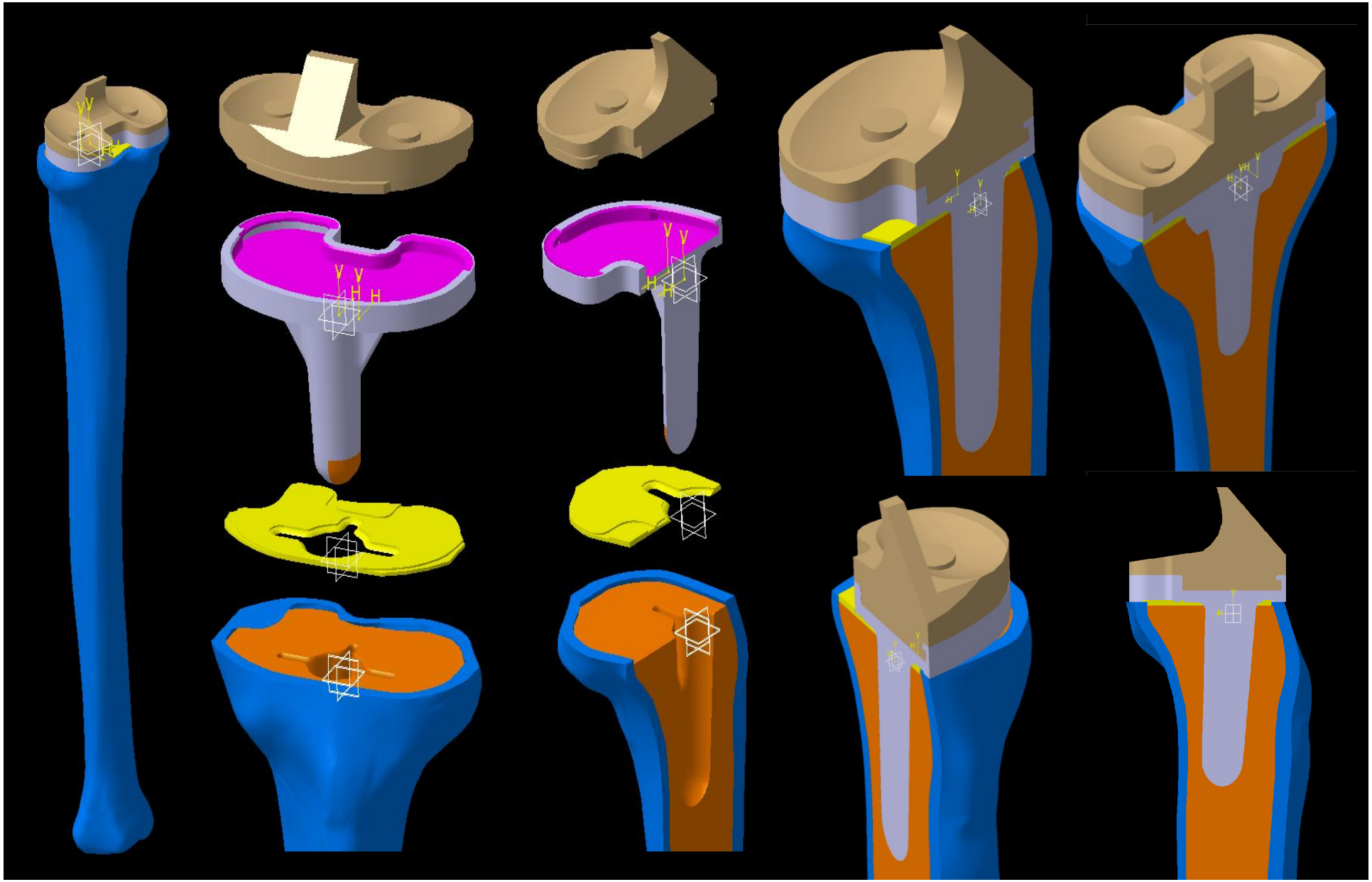
Comparison of results

Numerical-clinical correlation

Alternative proposals: optimization of geometry and materials

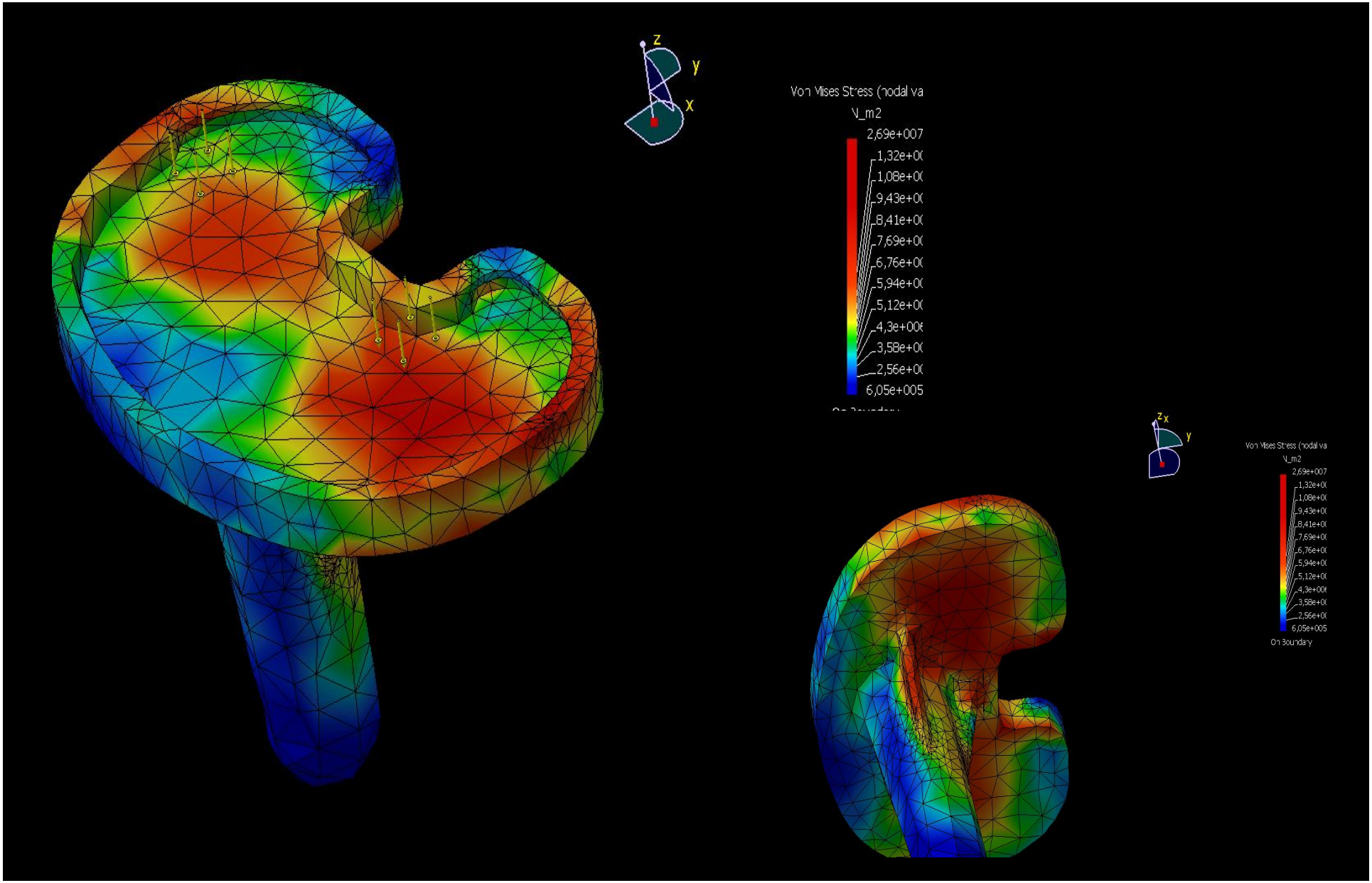
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

KNEE PROSTHESIS_Numerical simulation_CAD models



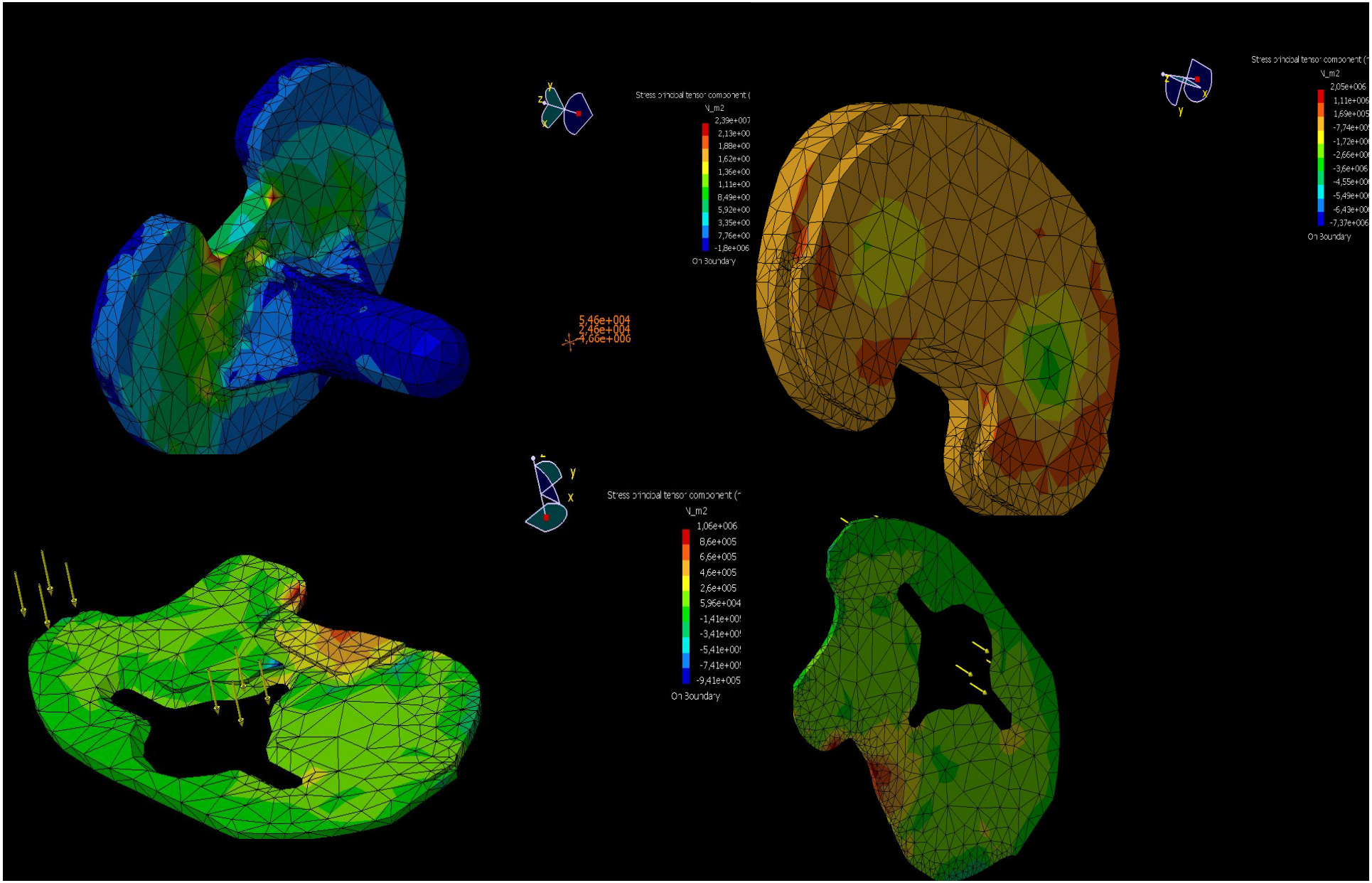
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

KNEE PROSTHESIS_von Mises stress on the tibial component



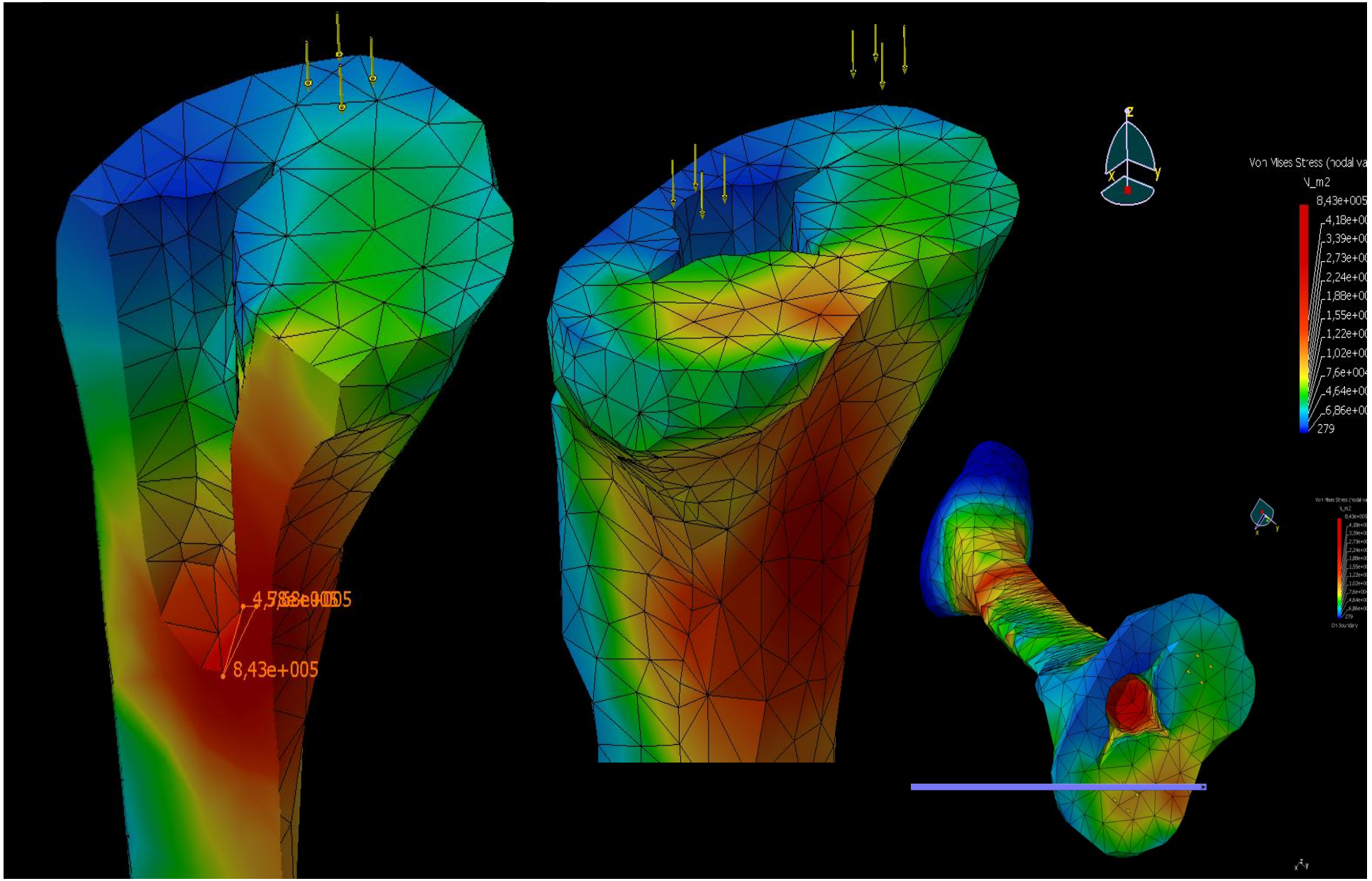
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

KNEE PROSTHESIS_Stresses (polyethelene and cement mantle)



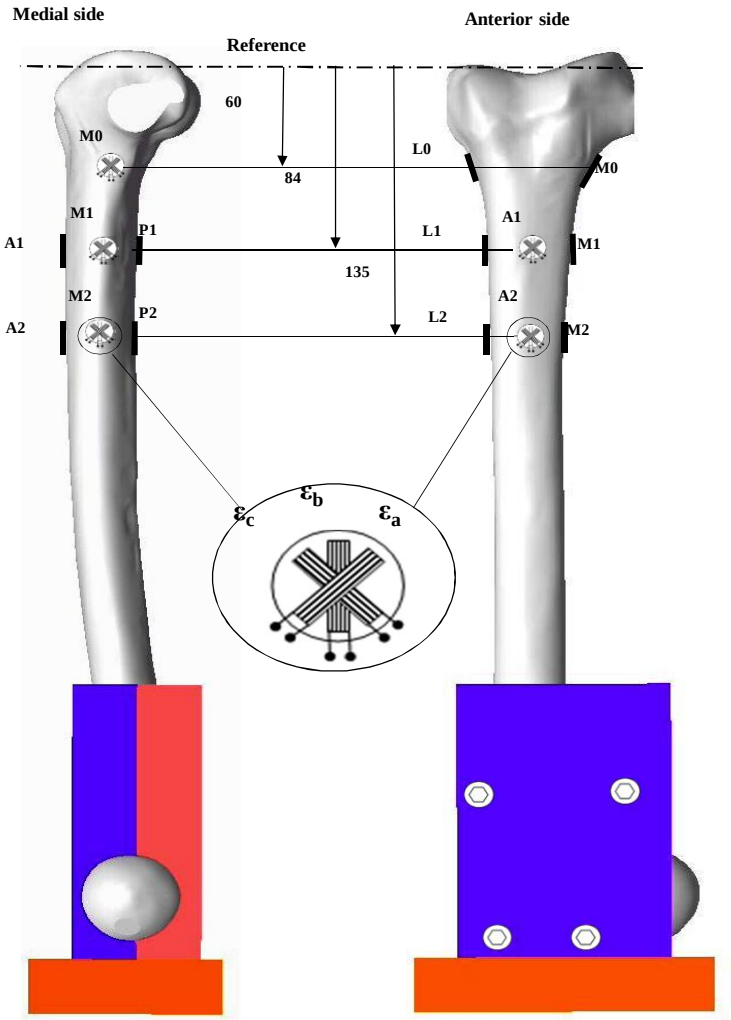
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

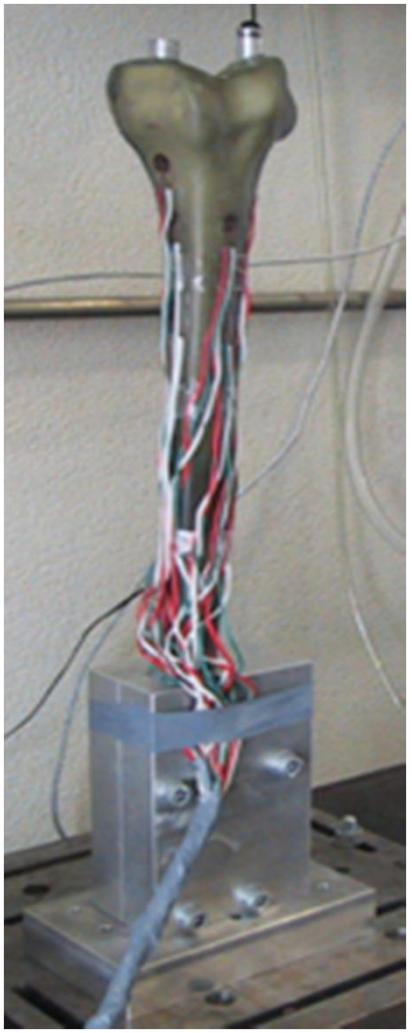
KNEE PROSTHESIS_Cancellous bone von Mises stress



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

NUMERICAL – EXPERIMENTAL VALIDATION: FEMORAL COMPONENT





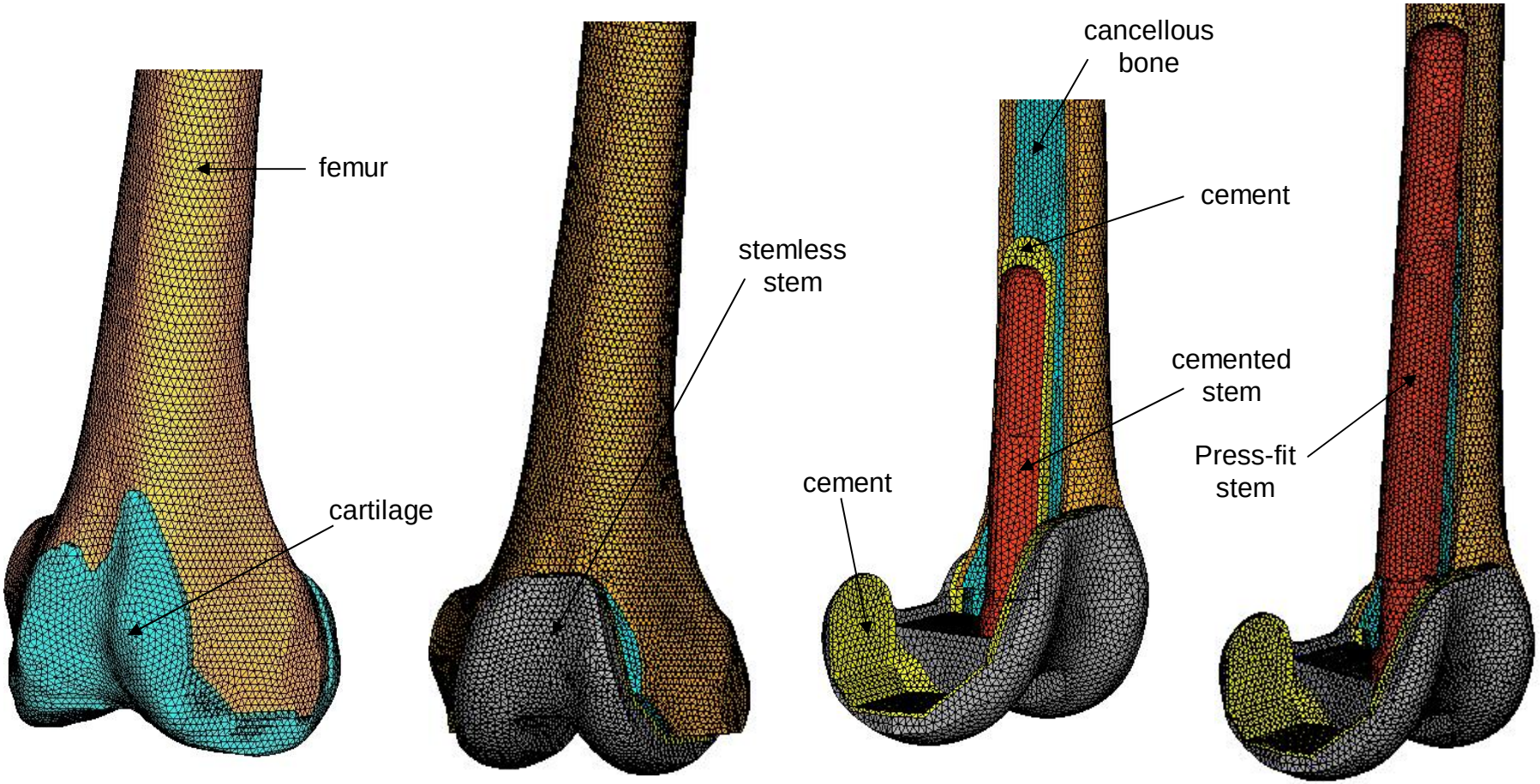
Triaxial strain gauges (rosettes): measure strains (strain-stress shielding)

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

NUMERICAL – EXPERIMENTAL VALIDATION: IN VITRO SURGERY

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

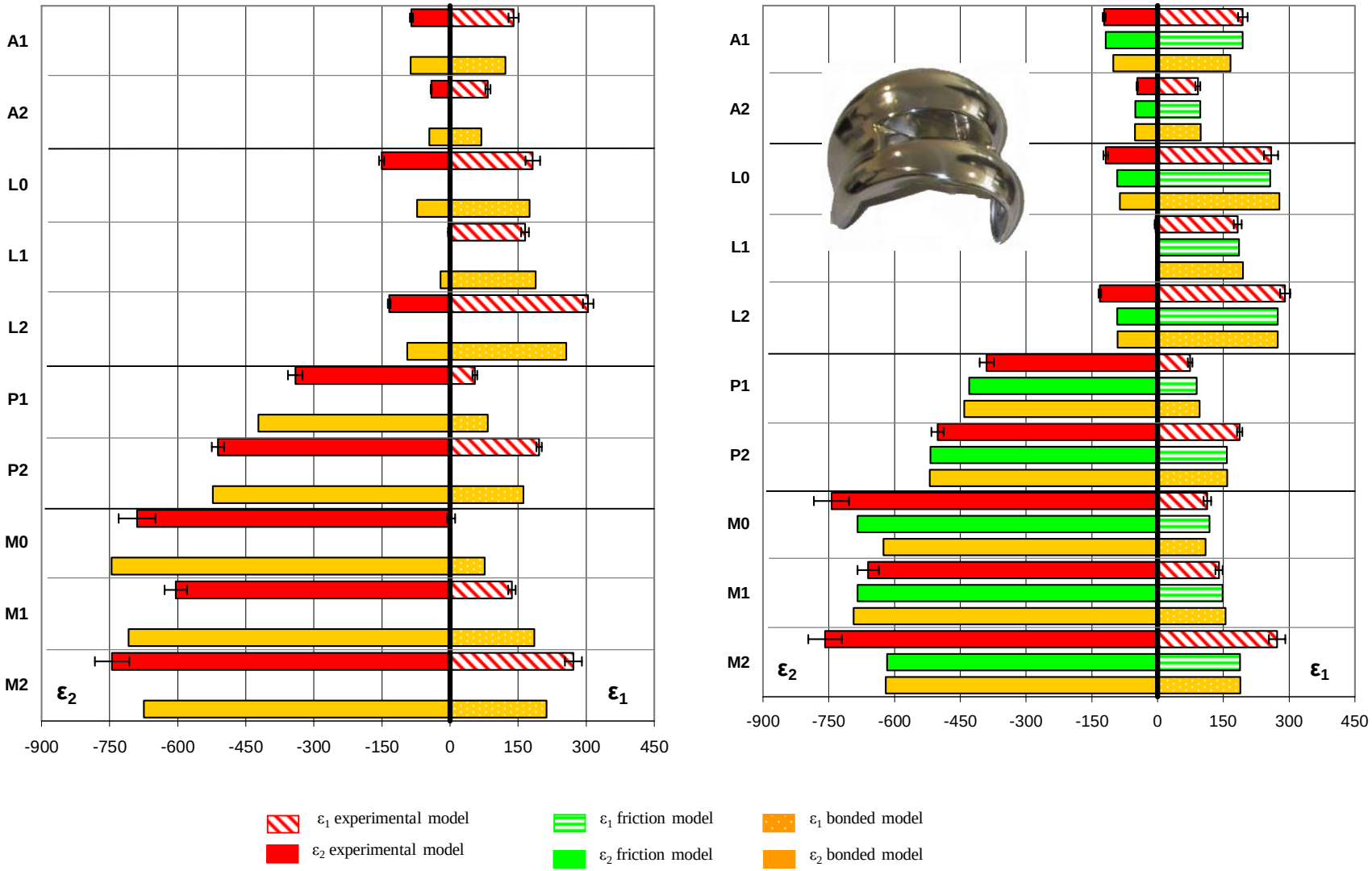
NUMERICAL – EXPERIMENTAL VALIDATION: FEMORAL COMPONENT



Intact model | Femoral component | Cimented stem | Non-cimented stem

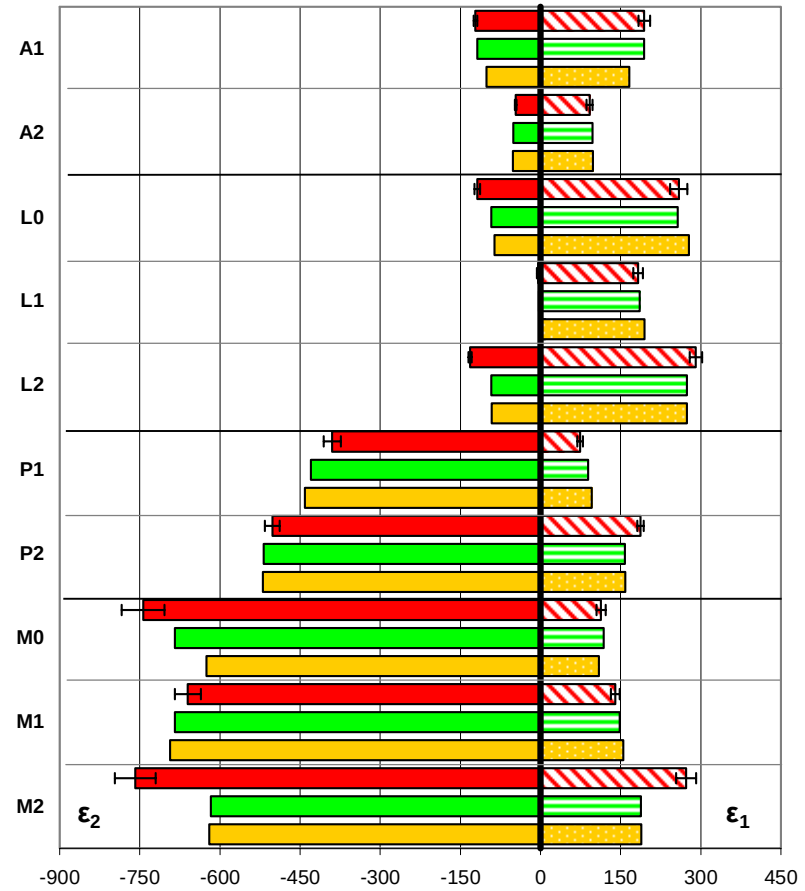
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

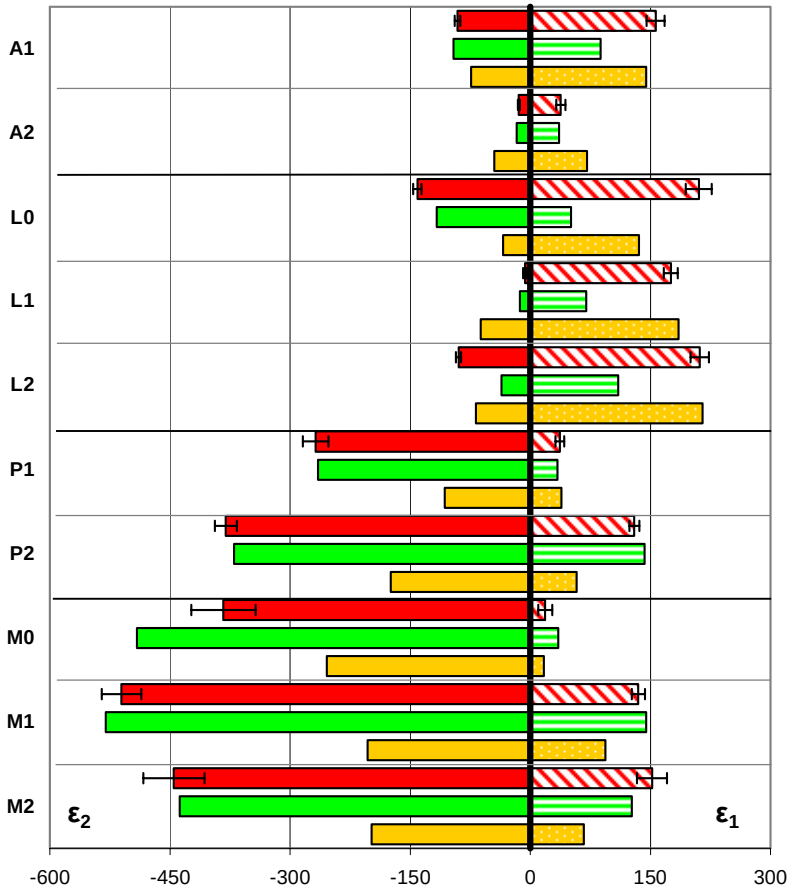
NUMERICAL – EXPERIMENTAL VALIDATION: FEMORAL COMPONENT



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

NUMERICAL – EXPERIMENTAL VALIDATION: FEMORAL COMPONENT

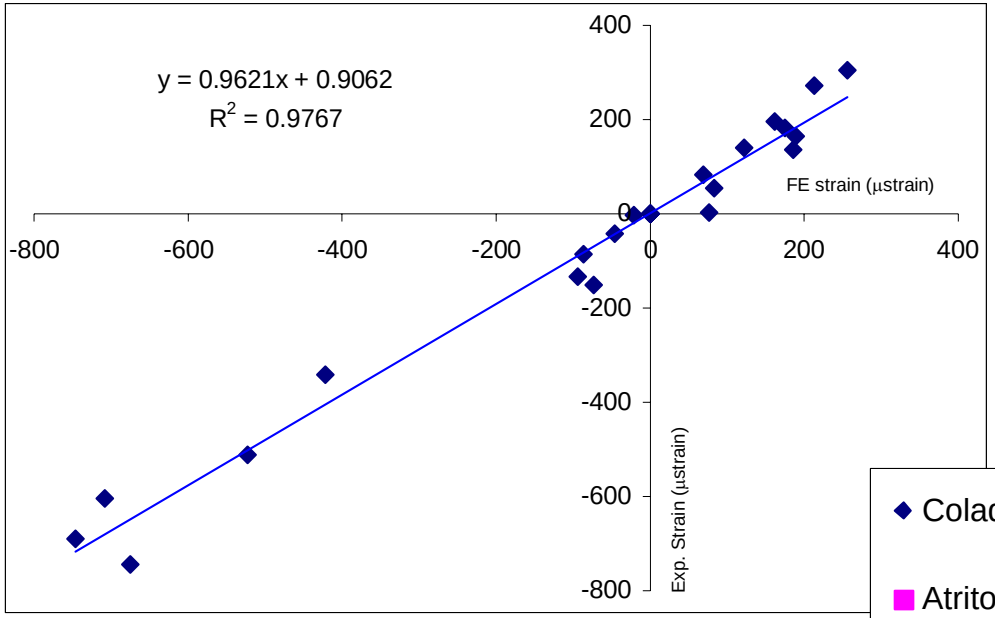




ε_1 experimental model
ε_2 experimental model
ε_1 friction model
ε_2 friction model
ε_1 bonded model
ε_2 bonded model

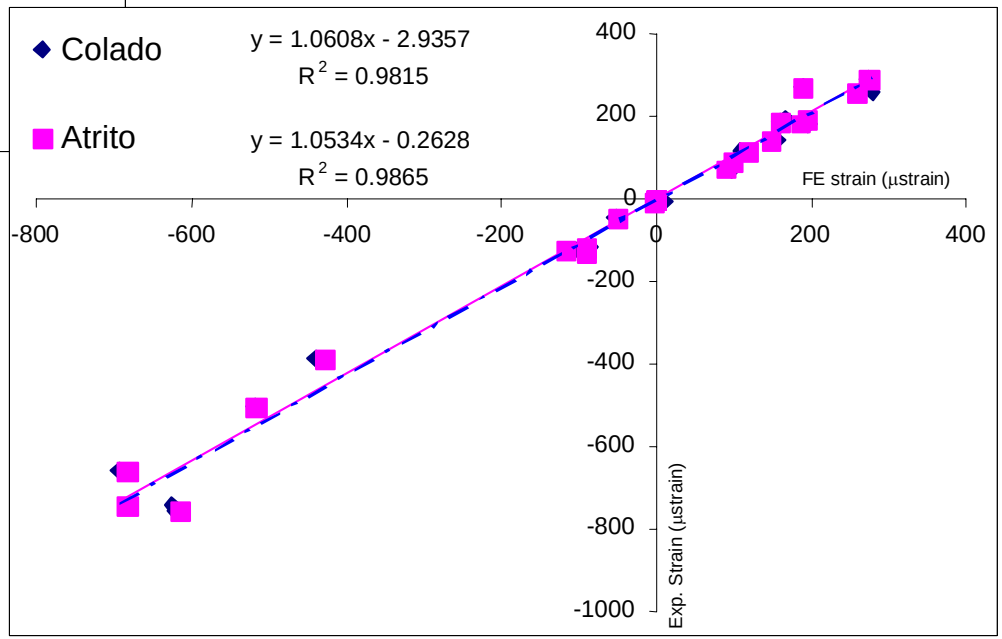
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

NUMERICAL – EXPERIMENTAL VALIDATION: FEMORAL COMPONENT



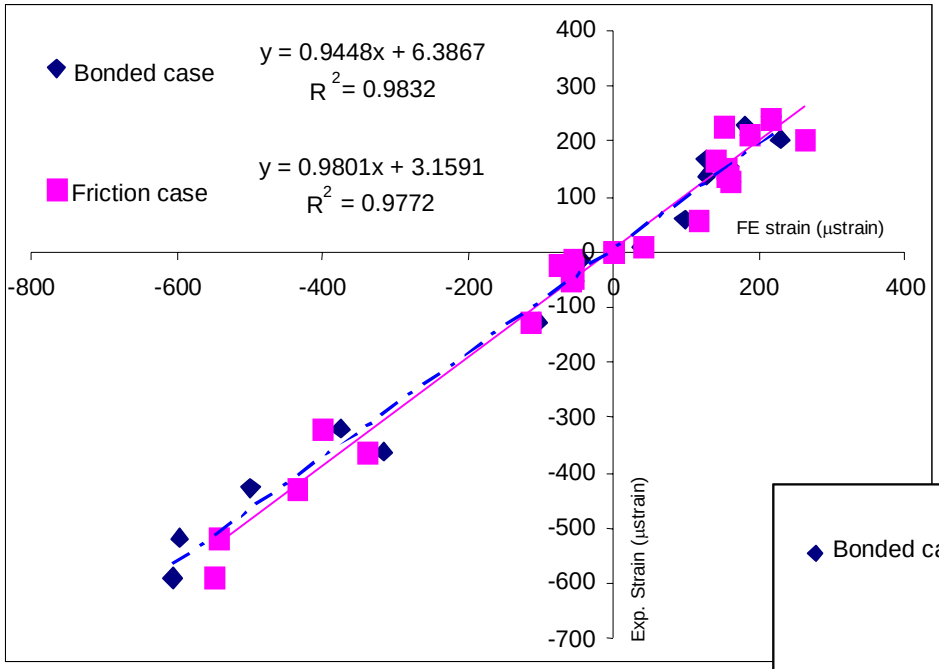
INTACT FEMUR

STANDARD IMPLANT



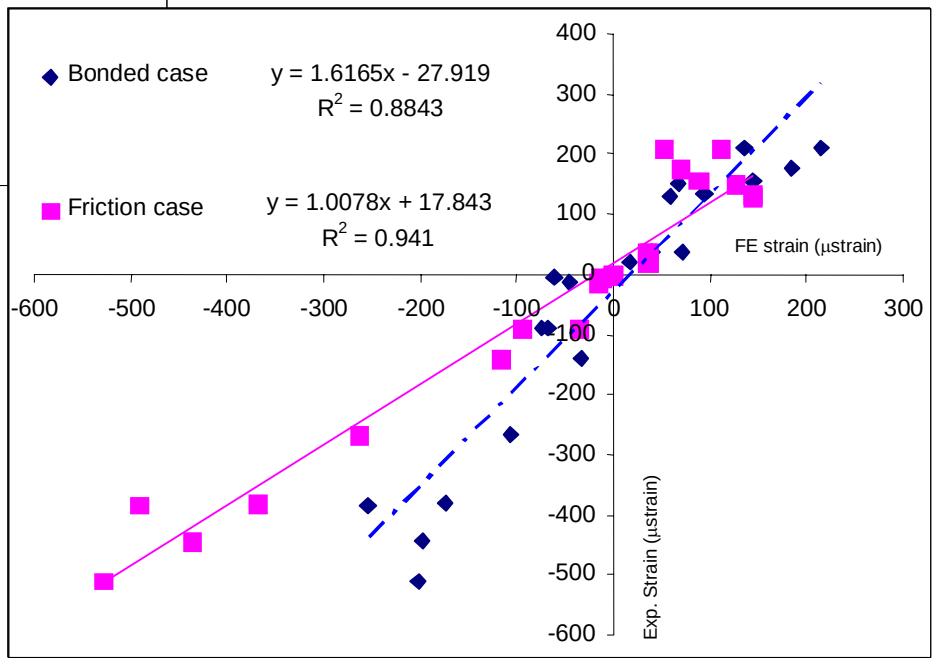
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

NUMERICAL – EXPERIMENTAL VALIDATION: FEMORAL COMPONENT



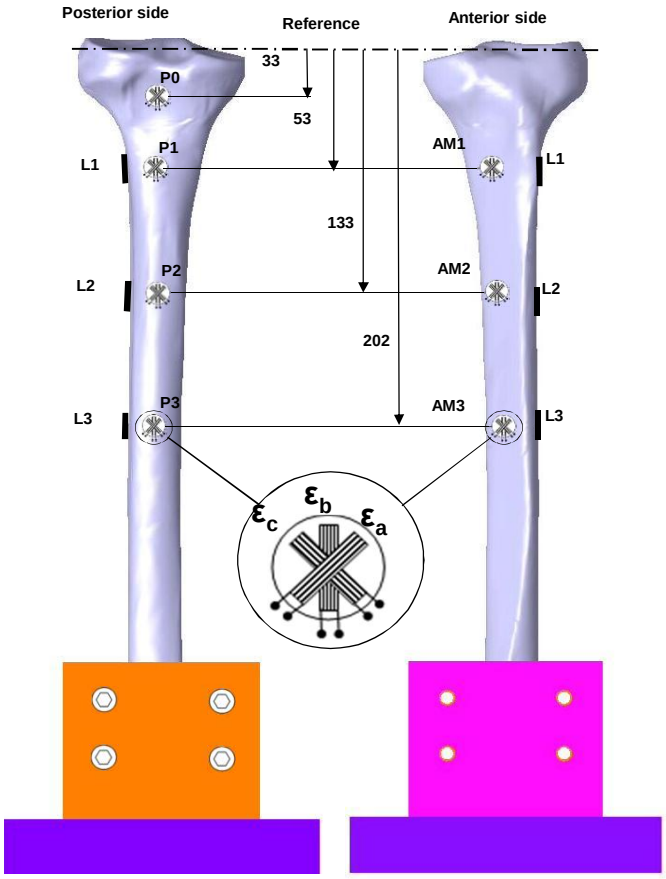
CEMENTED STEM

PRESS-FIT STEM



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

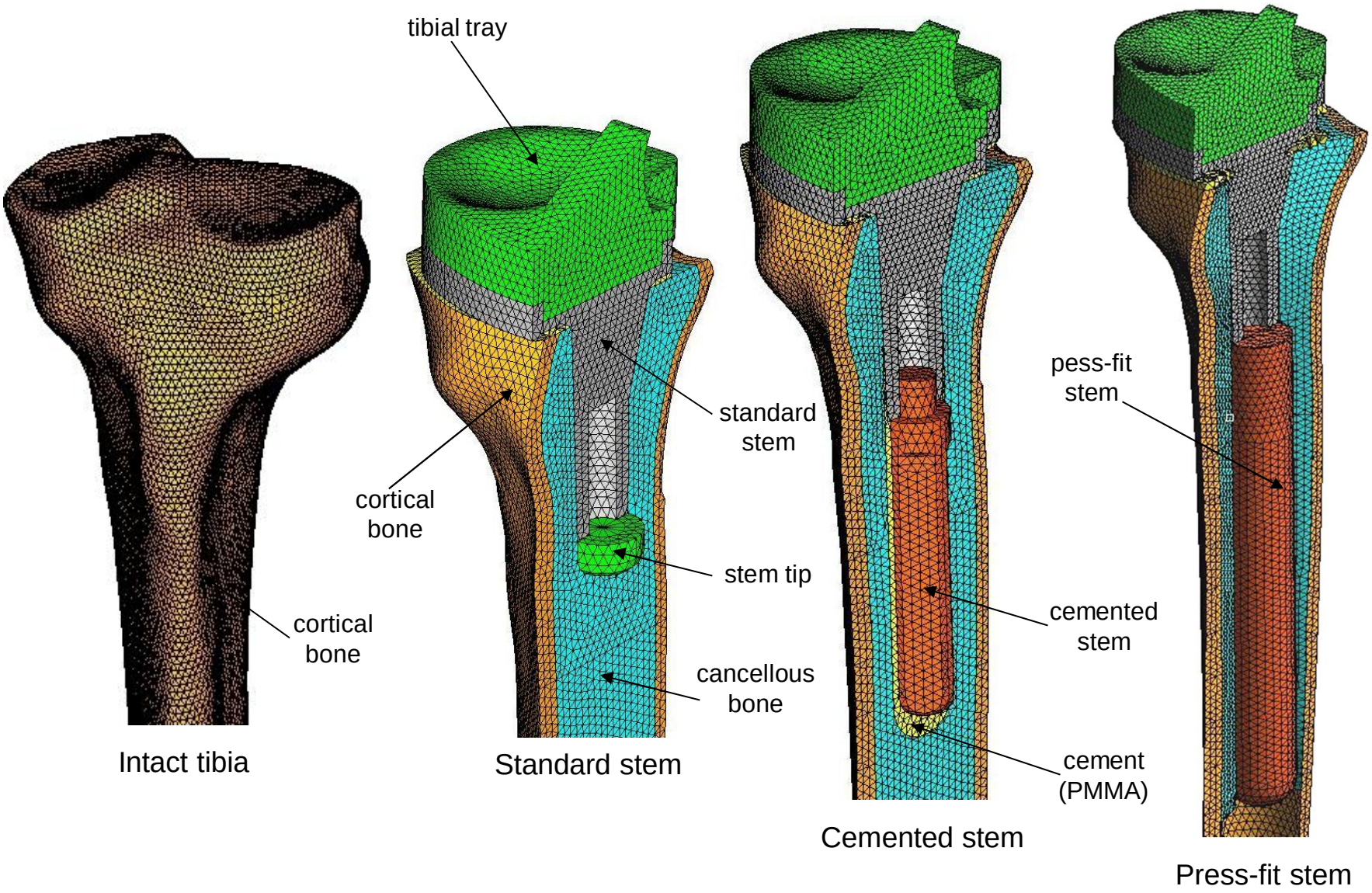
NUMERICAL – EXPERIMENTAL VALIDATION: TIBIAL COMPONENT



Triaxial strain gauges (rosettes): measure strains (strain-stress shielding)

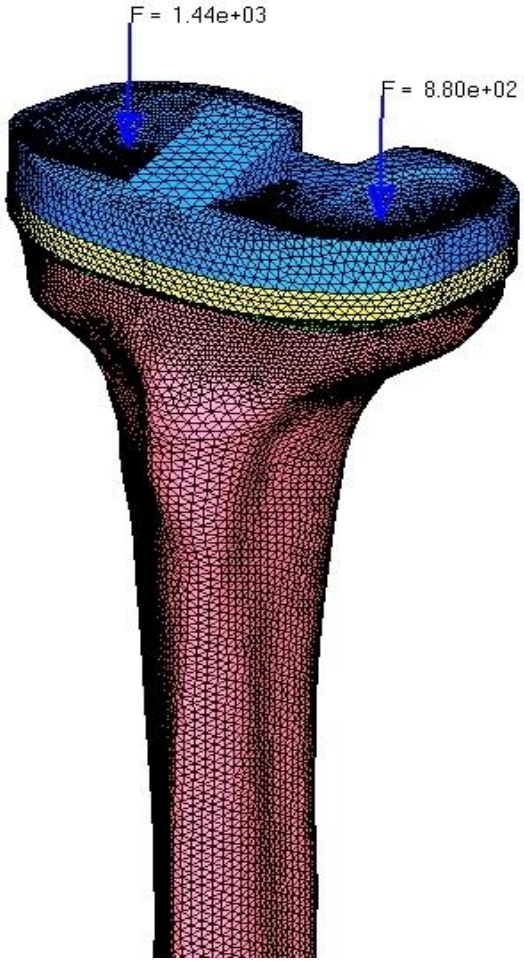
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

NUMERICAL – EXPERIMENTAL VALIDATION: TIBIAL COMPONENT

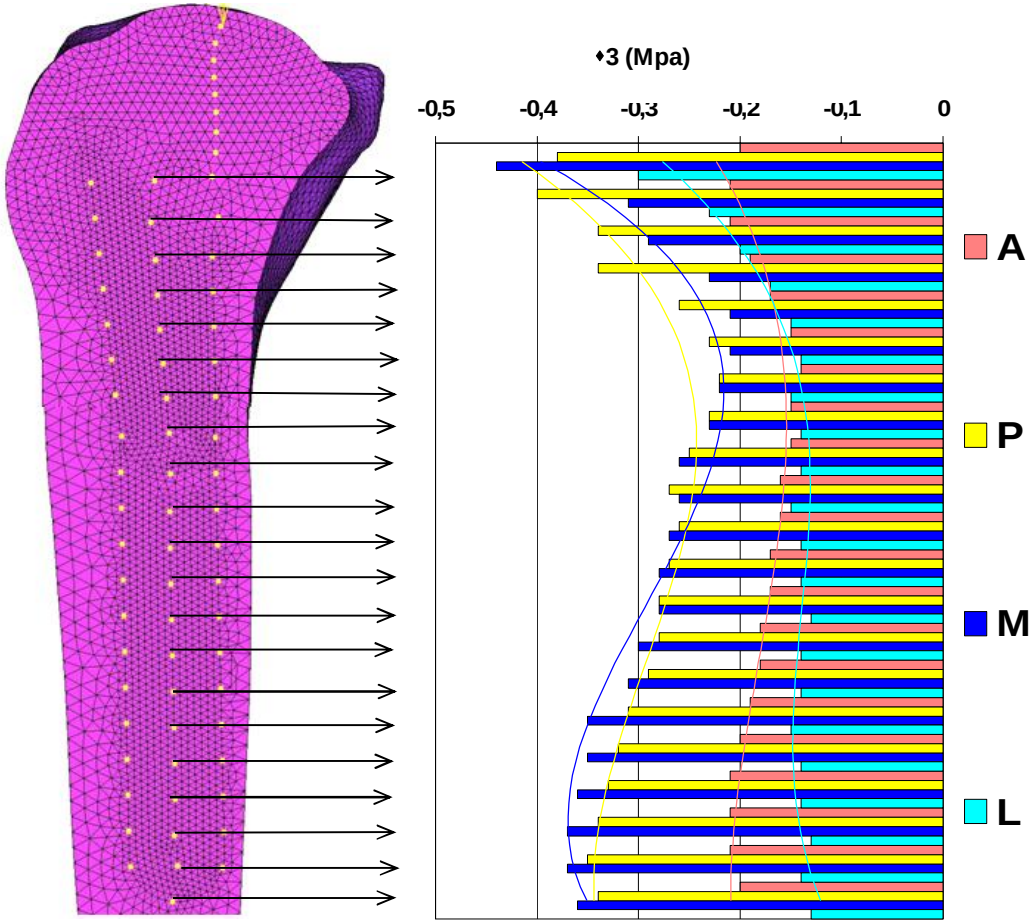


Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

PHYSIOLOGICAL TIBIAL STRESSES



Finite Element Model

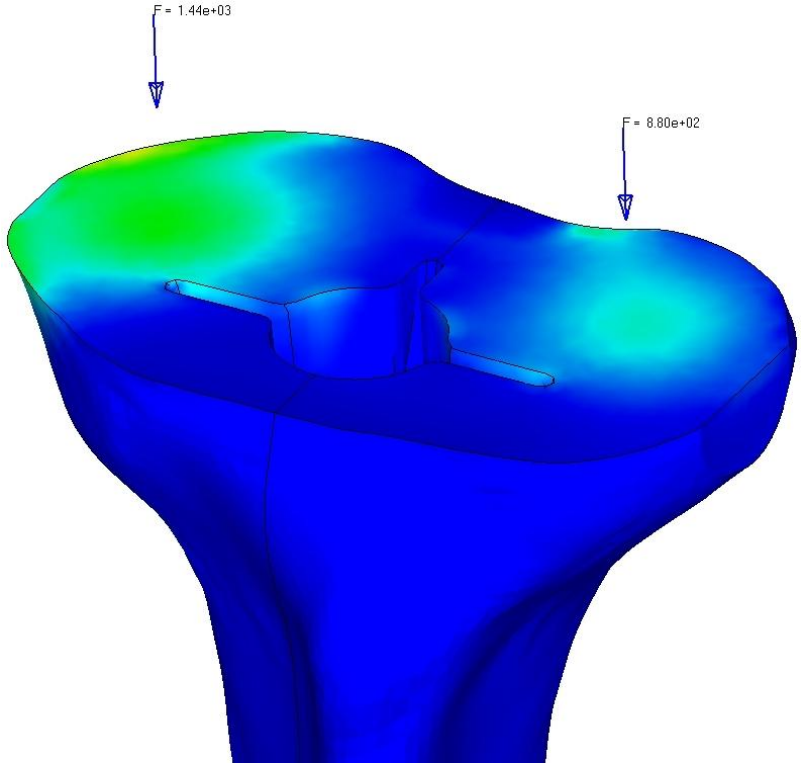


Minimal Principal Stresses

A-anterior, P-posterior, M-medial, L-lateral

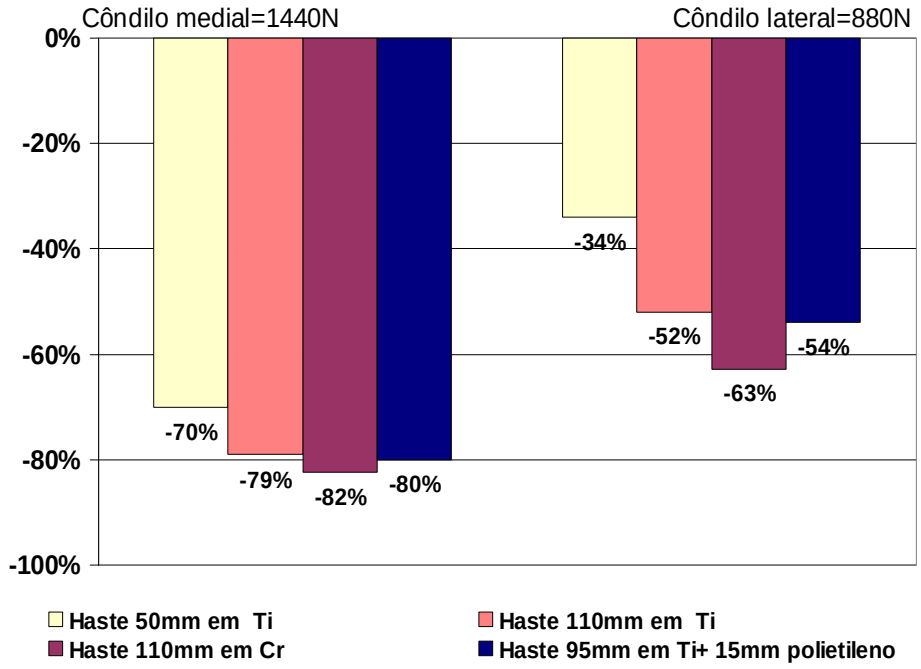
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

STRESS-SHIELDING EFFECT – material & geometry role



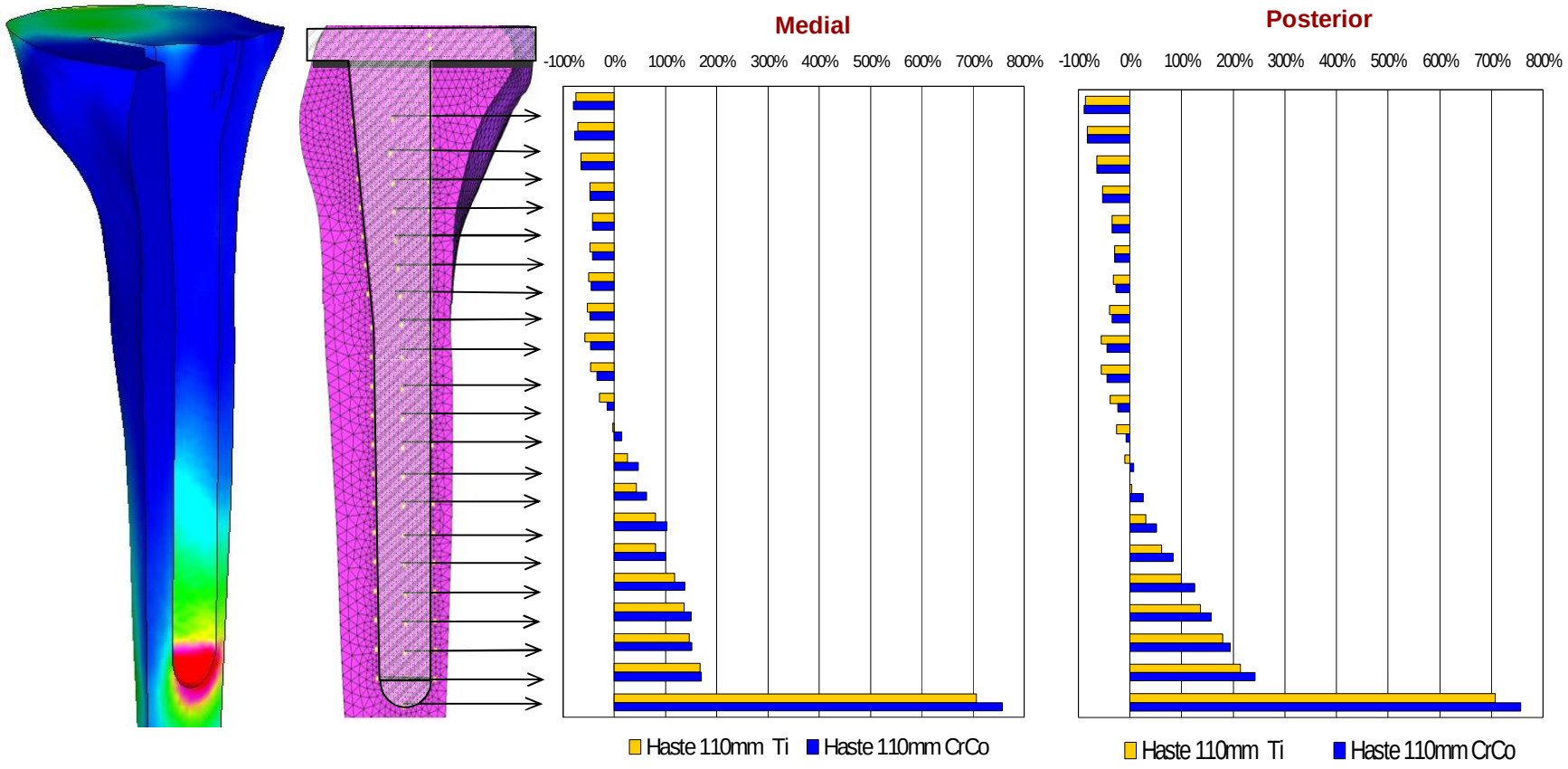
Bone-cement interface stresses

Stress-shielding



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

INFLUENCE OF MATERIAL AND LENGTH – TIBIAL STEM

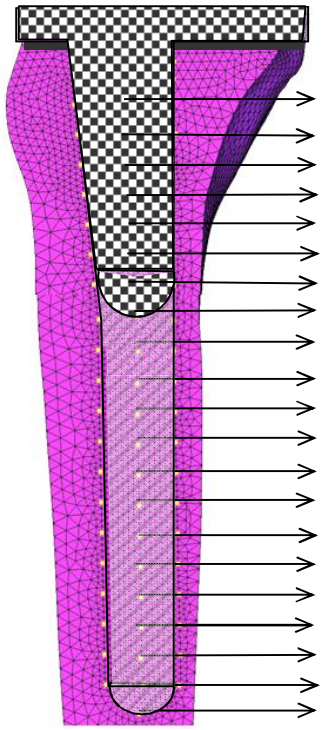


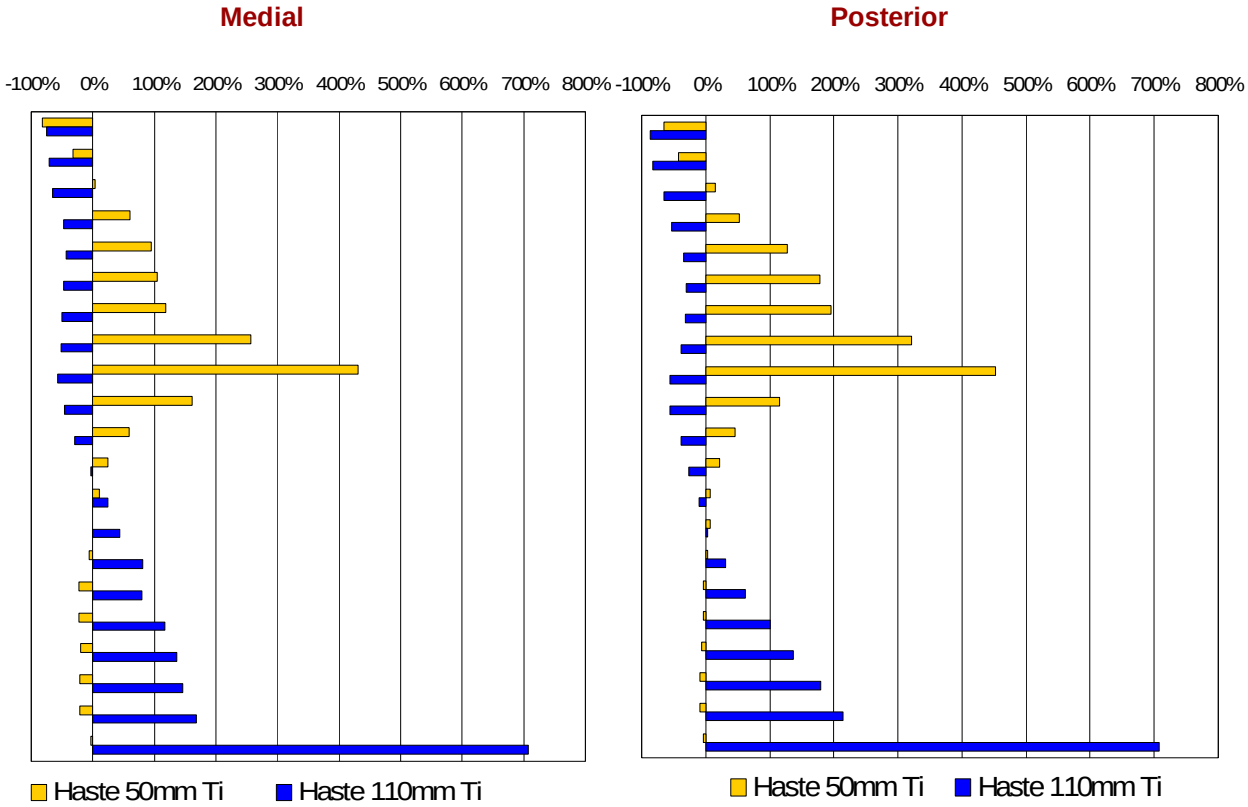
Minimal principal stress deviation (intact tibia): Ti and CrCo stem of 110mm

Bone-stem interface stresses

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

INFLUENCE OF MATERIAL AND LENGTH – TIBIAL STEM

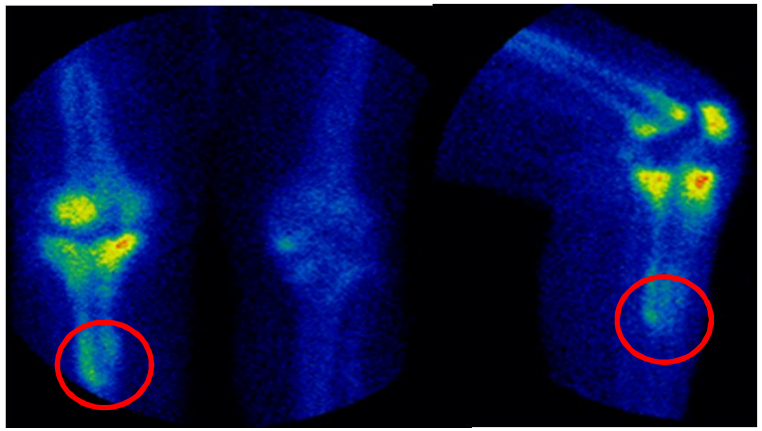


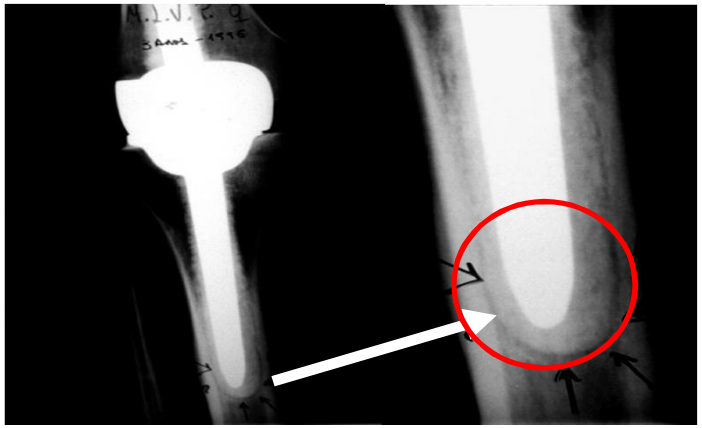


Minimal principal stress deviation (intact tibia): Ti stem of 50 and 110mm

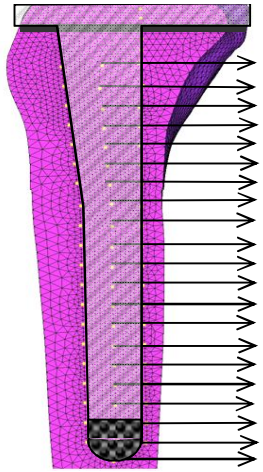
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

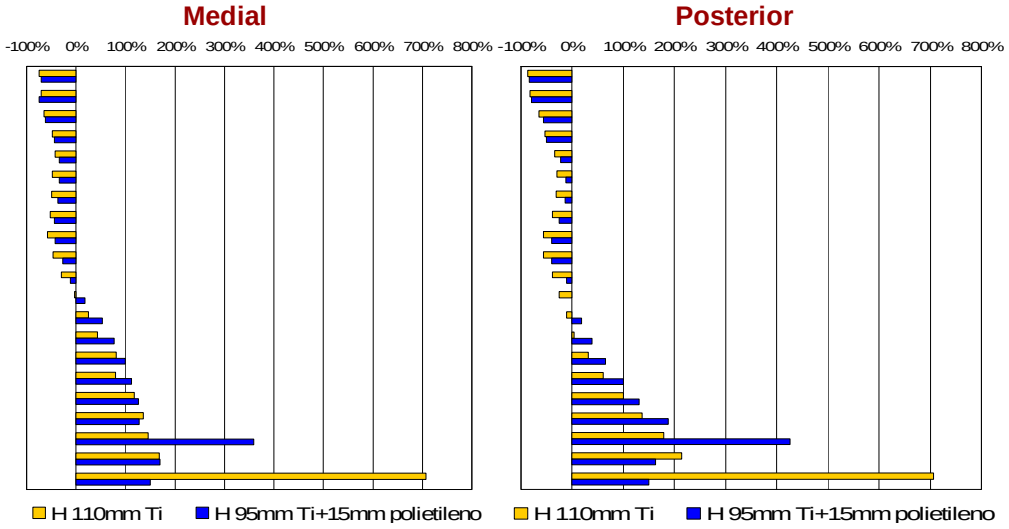
INFLUENCE OF MATERIAL AND LENGTH – polymeric tip





Antero–Posterior Radiograph

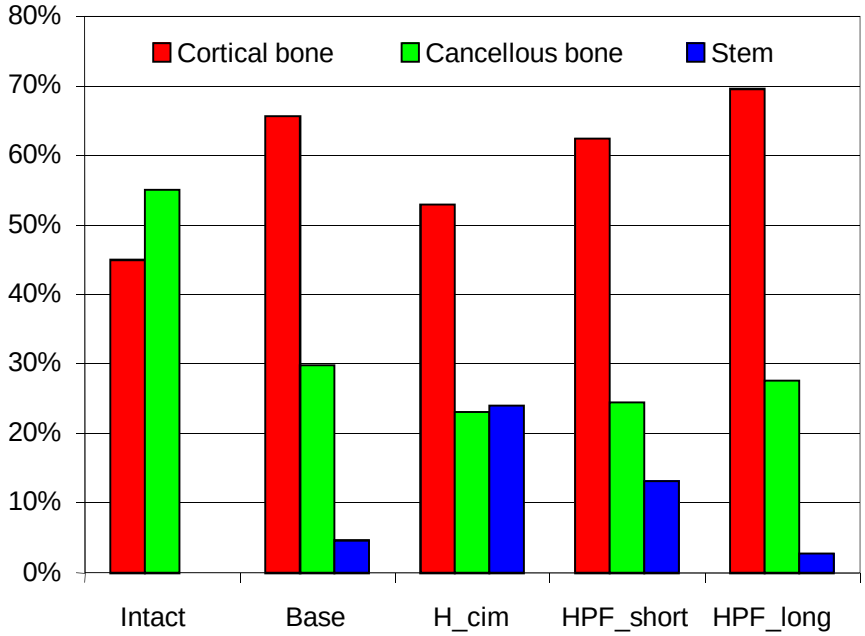




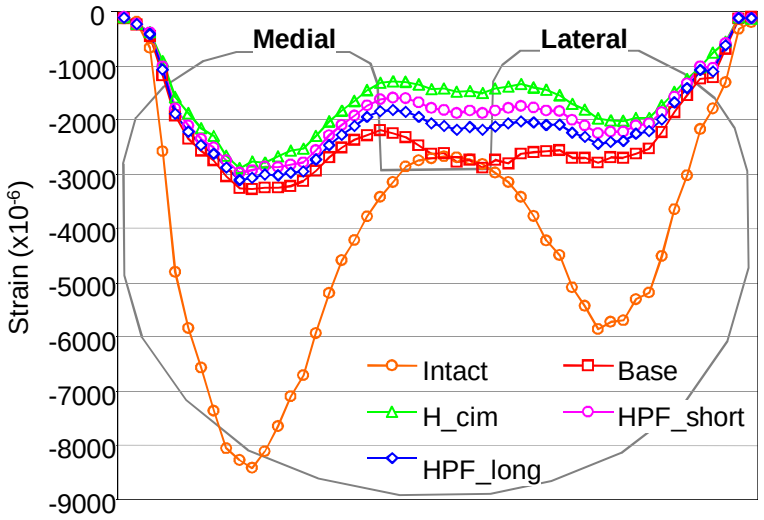
Minimal principal strain for stems of 110mm Ti and 95mm Ti, with a polyethelene tip of 15mm

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

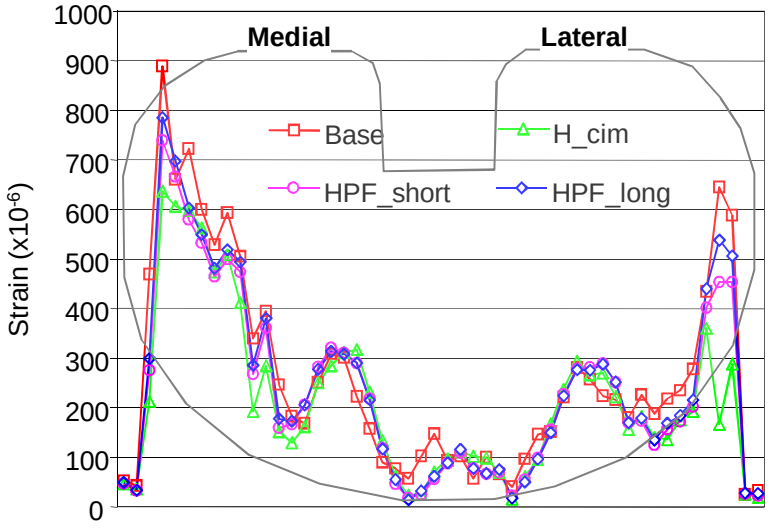
INFLUENCE OF PROSTHESIS DESIGN



Axial load distribution at the cement-bone interface



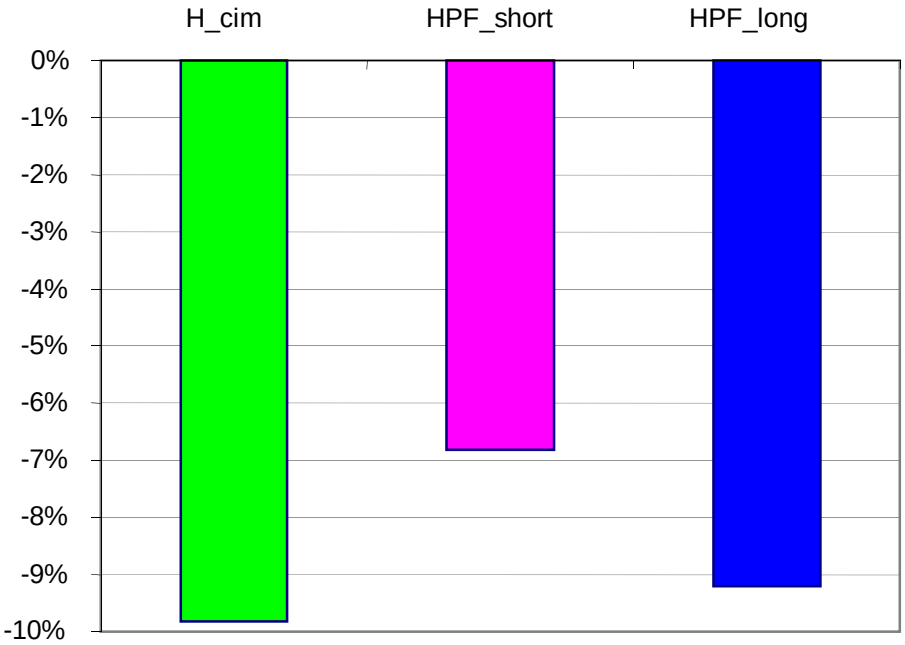
Cancellous bone minimal principal strains



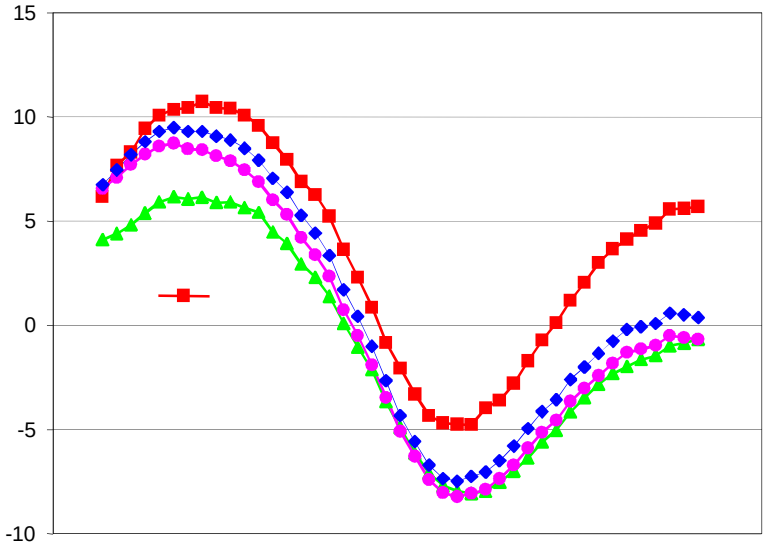
Cancellous bone shear strains

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

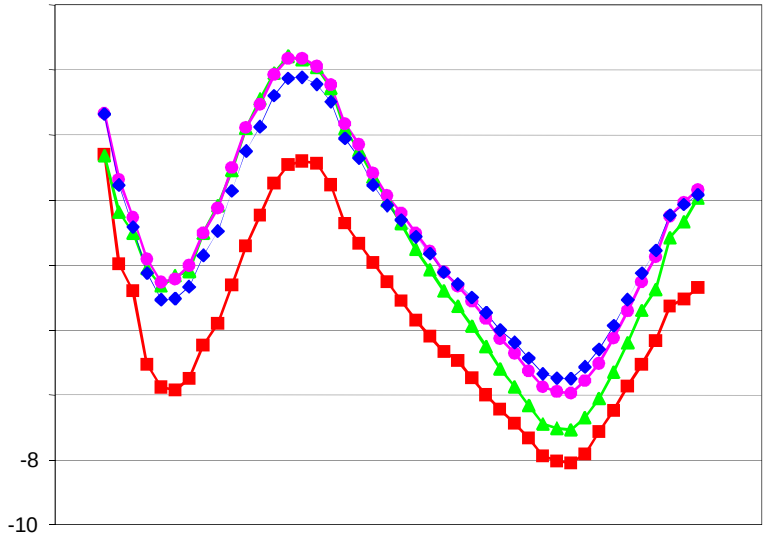
INFLUENCE OF PROSTHESIS DESIGN



Reduction of micromovement of the tibial tray-cortical bone relative to the non-stemmed implant



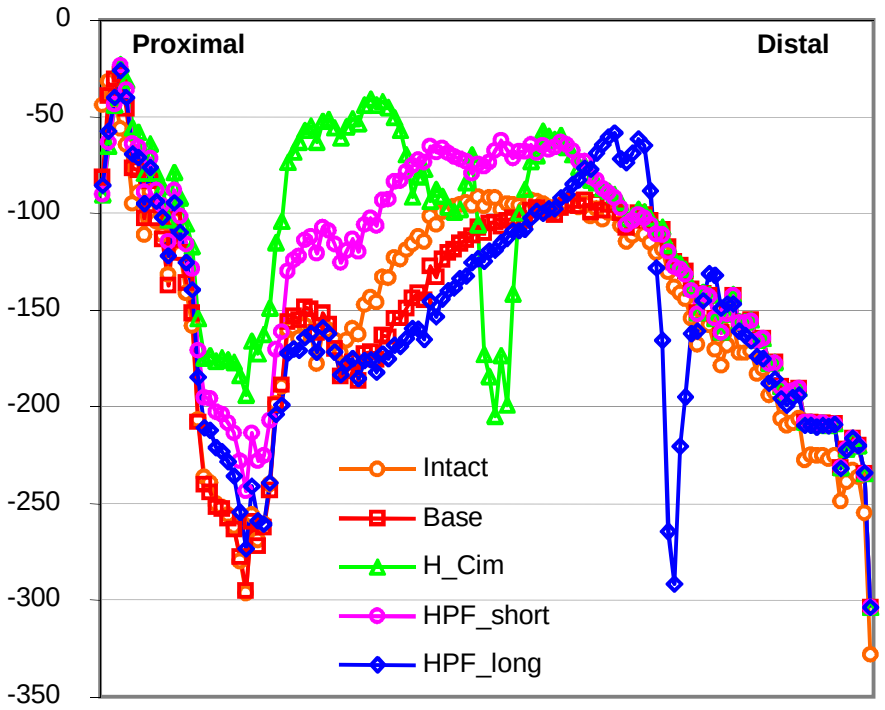
Micromovement at cement-bone interface

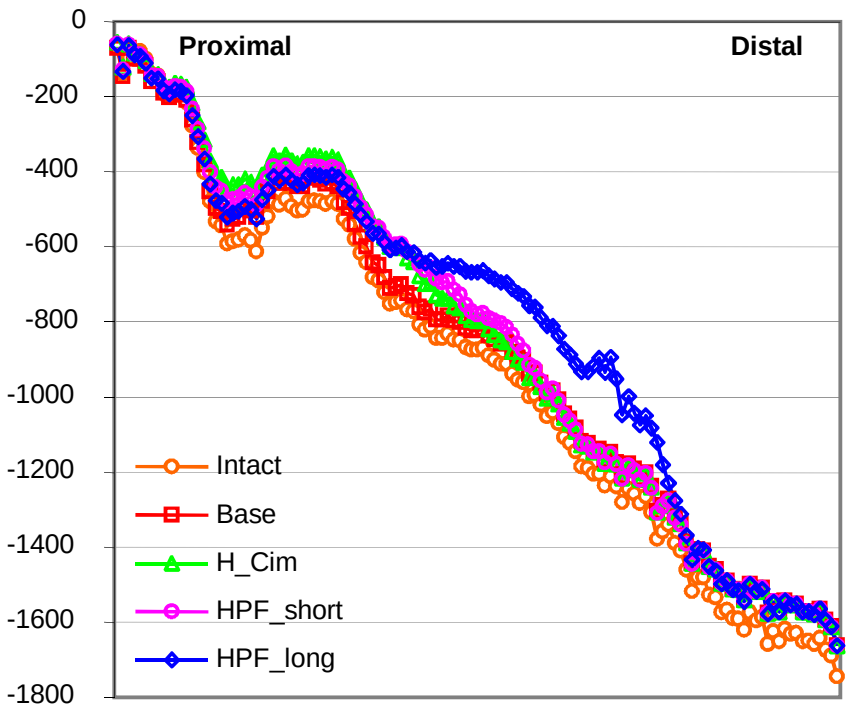


Micromovement at cement-bone interface

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

INFLUENCE OF PROSTHESIS DESIGN





Cortical bone principal minimal strains (medial and lateral side)

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

SOME CONCLUSIONS

It was possible to observe that load transferred at the bone-implant interface ranges from 3% to 24%, depending on the type of stem

The cemented stem transfers higher degree of load, 24% of axial load to distal bone

The non-cemented long stem transfers only 3% of the axial load to distal bone

Stems have a more pronounced effect on load transferred to cortical bone than to cancellous bone, 19% difference of load transfer in cortical bone can be found between the stemless implant and the cemented stem

Cemented stems can be beneficial for clinical cases were cortical bone is affected by bone tissue quality

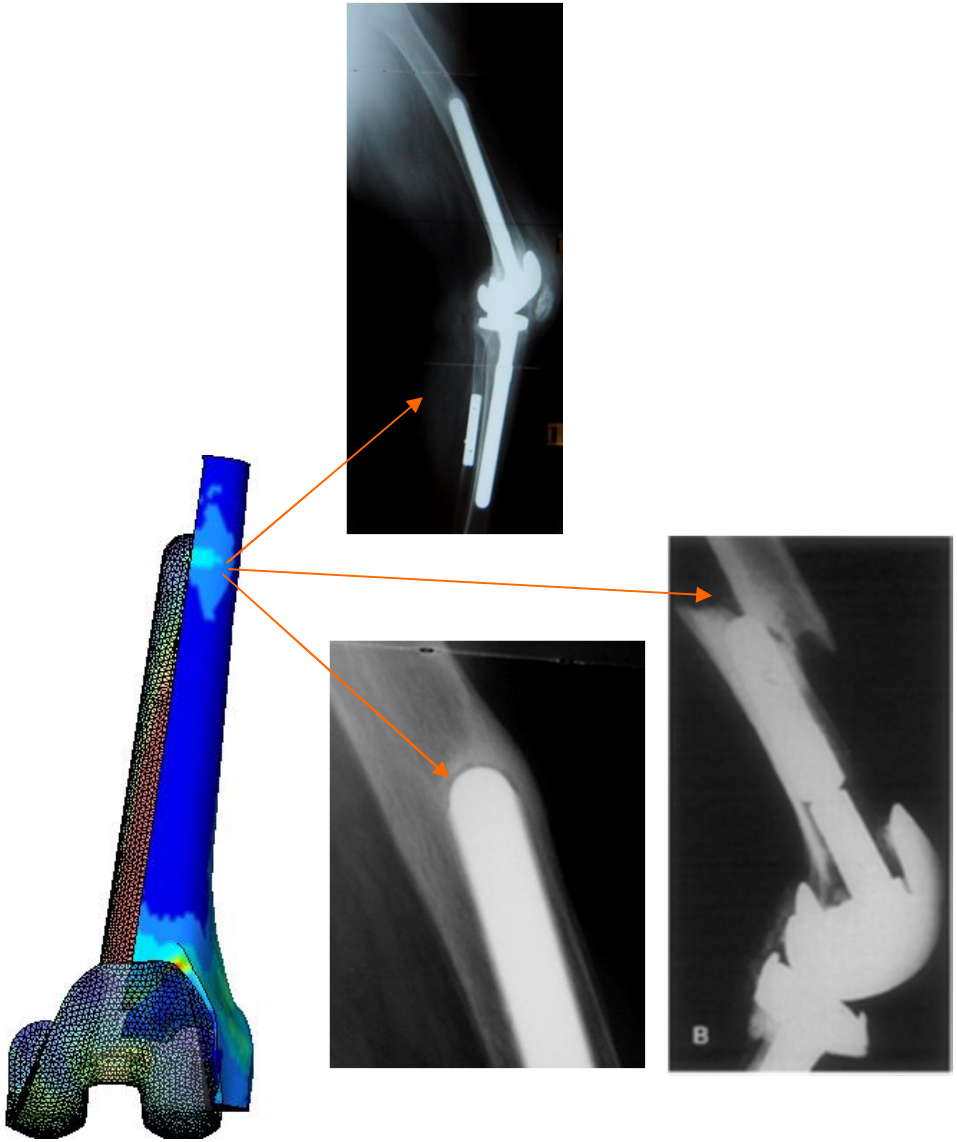
Considering the average of the micromotions in all aspects, the long press-fit stem presented similar performance to the cemented one

Long stem produces high bone strains at the tip and do not depend on load transfer but on the resistance to moments generated at condilar the surfaces

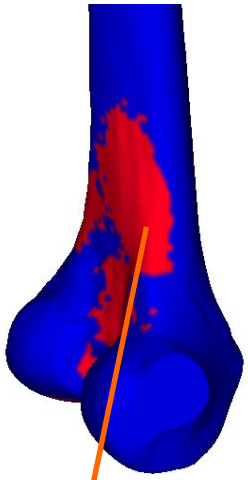
All commercial designs, cemented and non-cemented, produce high bone strains at the tip of the stems. Load transfer to the proximal and distal regions of the tibia is effectively achieved when cemented stems are used, but this type of the fixation presents a clinical inconvenient in surgical revision. Revisions of TKA are extremely difficult

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

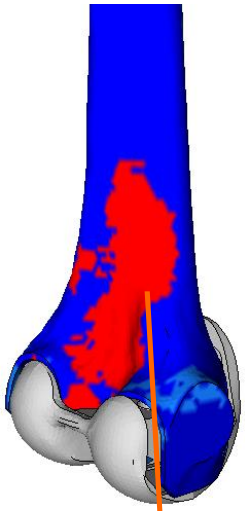
Fracture estimation based on stress fields

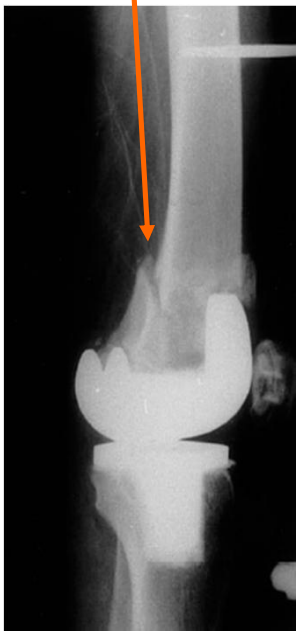


Intact femur

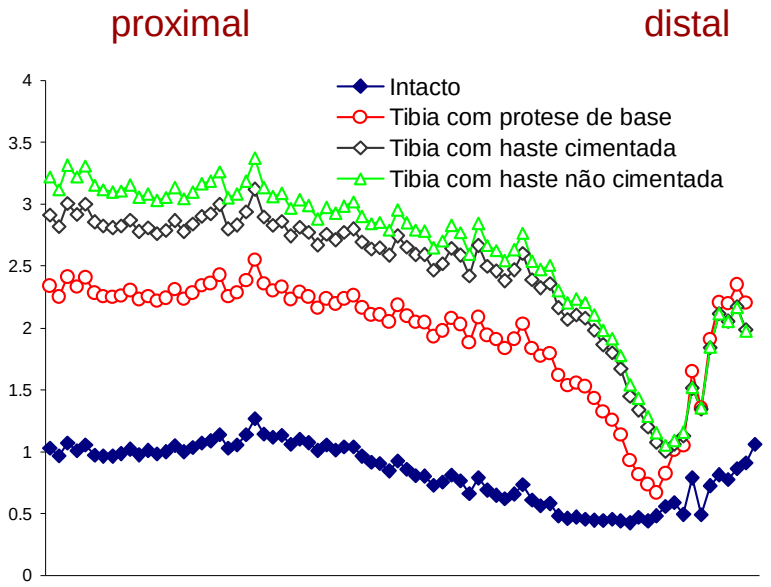


Standard prosthesis

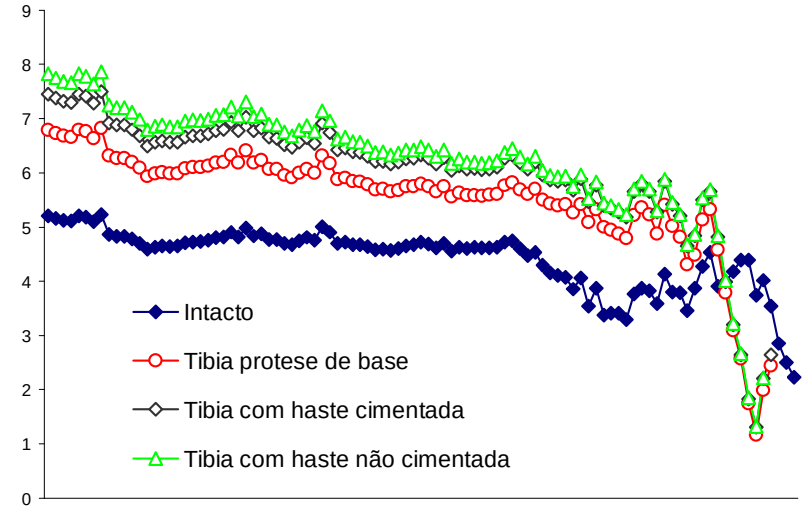




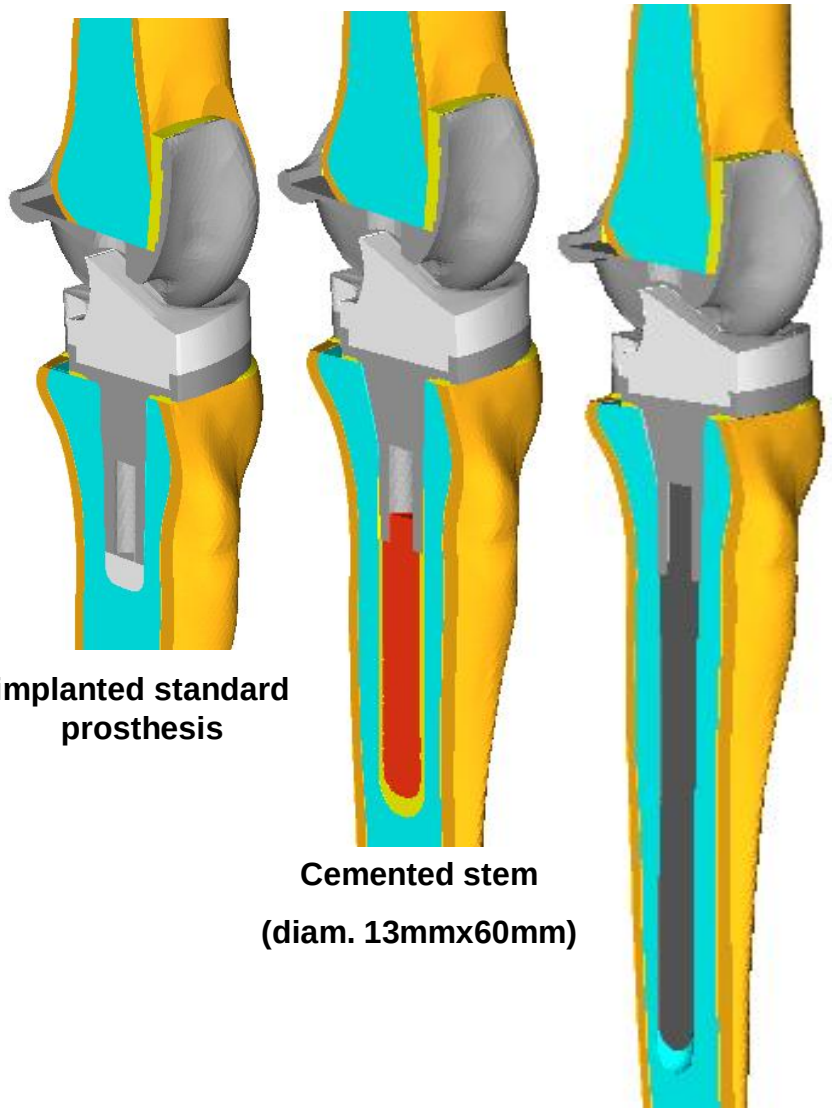
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)



Interface von Mises stress



Interface shear stress



implanted standard prosthesis

Cemented stem

(diam. 13mmx60mm)

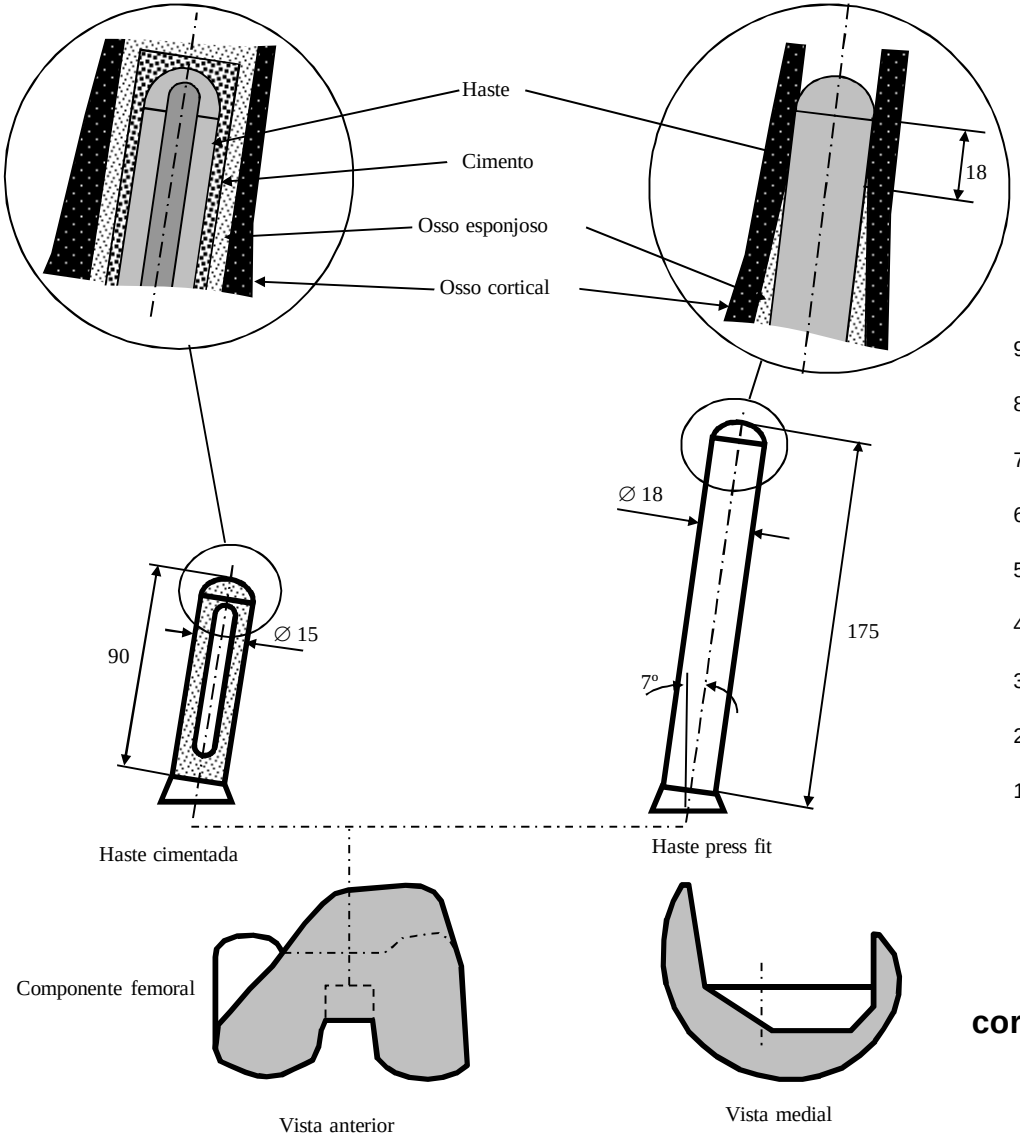
Non-cemented stem

(diam. 14x115mm)

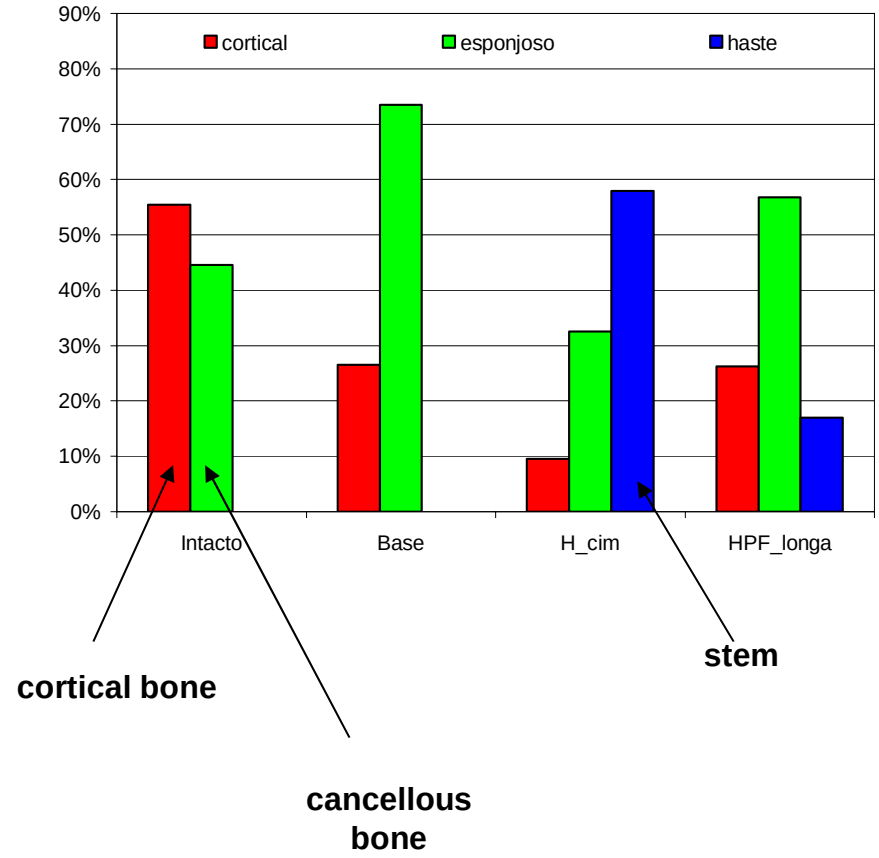
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

Cemented stem

Press-fit stem



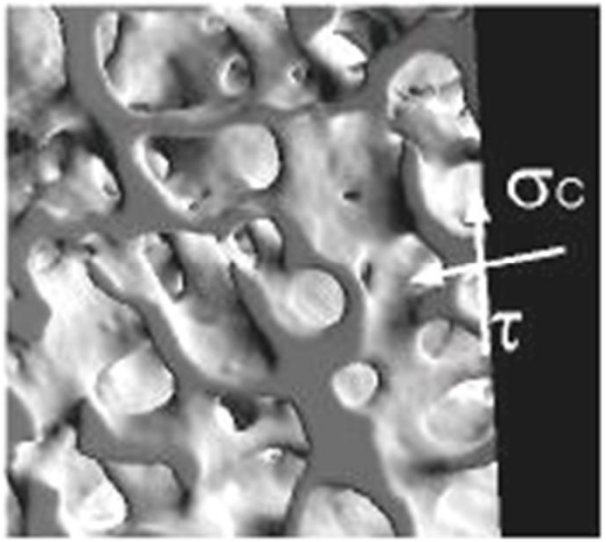
LOAD SHARE



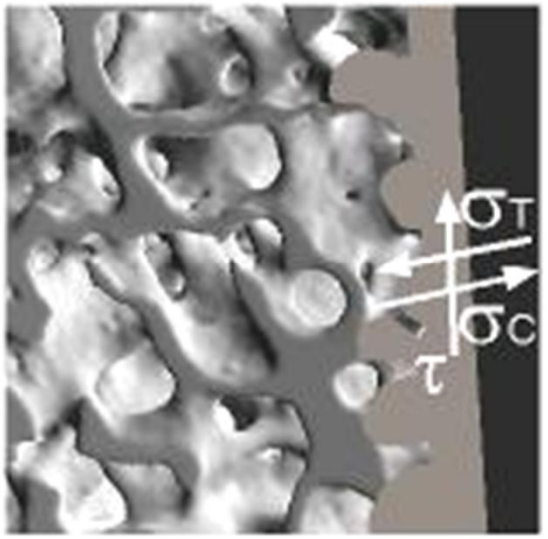
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

LOAD SHARE – contact problem

PRESS-FIT

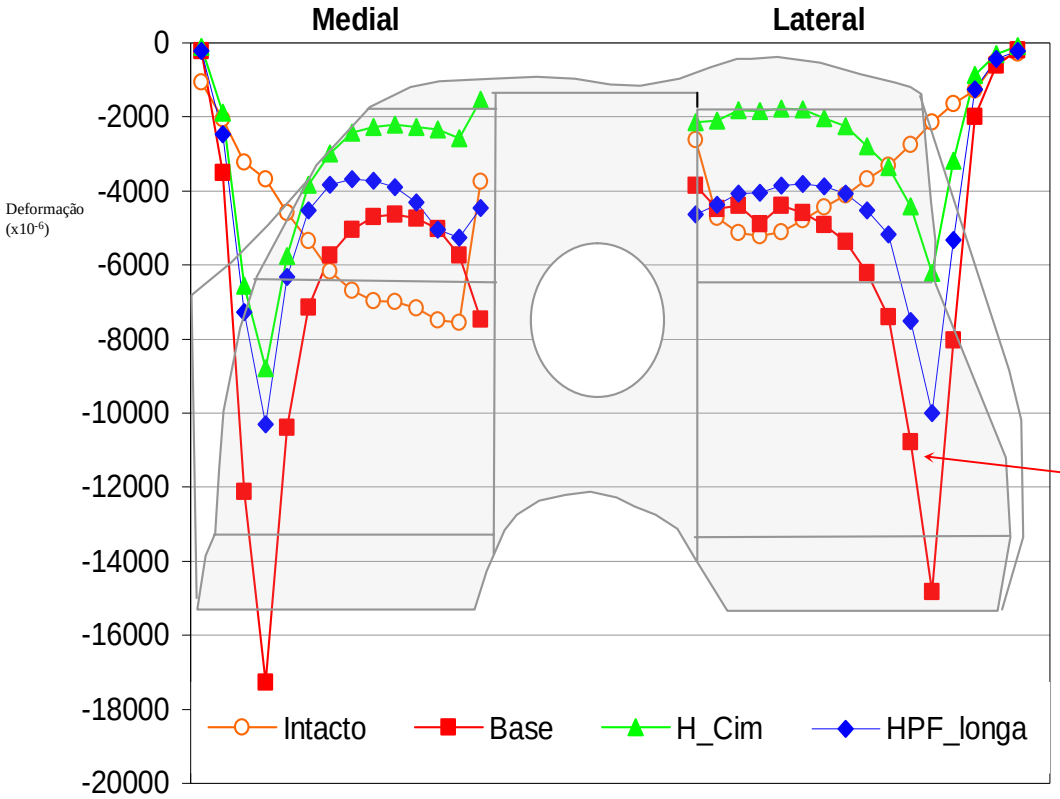


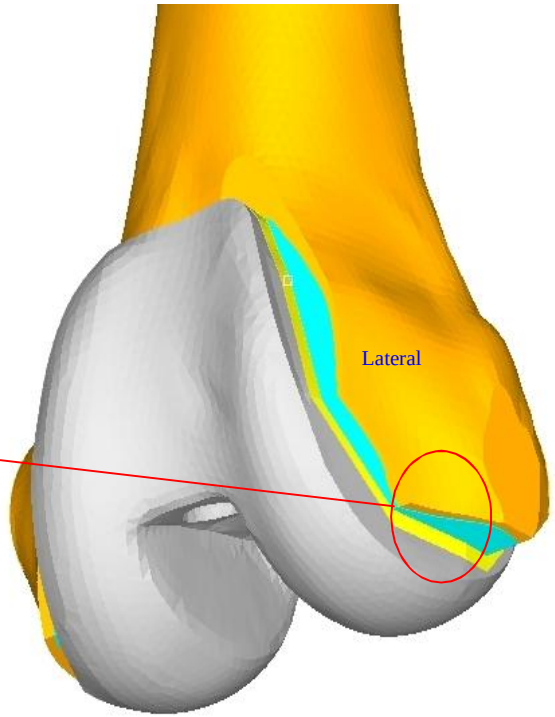
CEMENTED



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

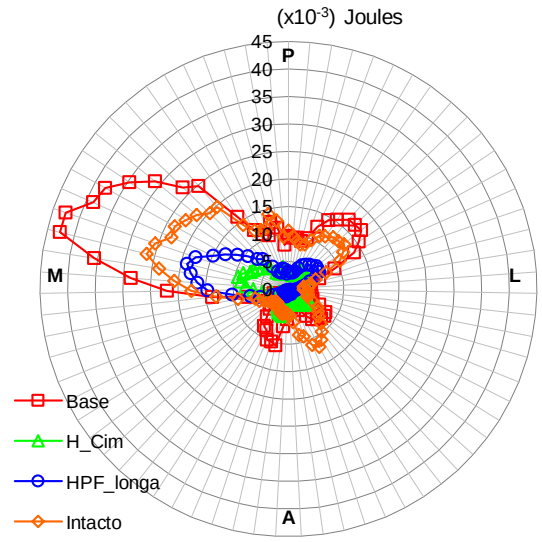
MINIMAL PRINICIPAL BONE-CEMENT INTERFACE STRAIN: MEDIAL-LATERAL DIRECTION



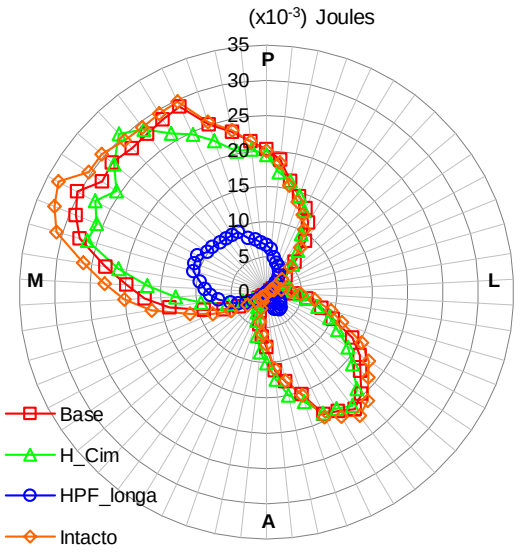


Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

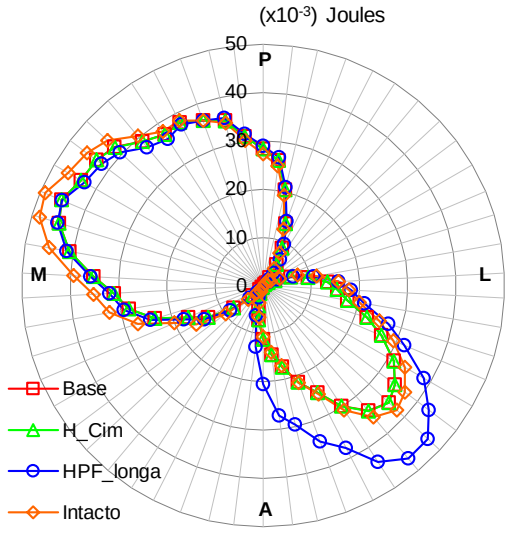
CORTICAL STRAIN ENERGY - FEMUR



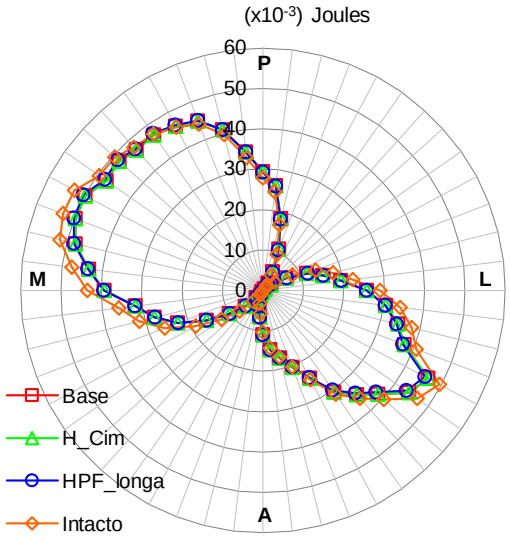
DISTAL REGION AFTER FEMORAL COMPONENT



POSITION OF THE CEMENTED STEM (90mm)



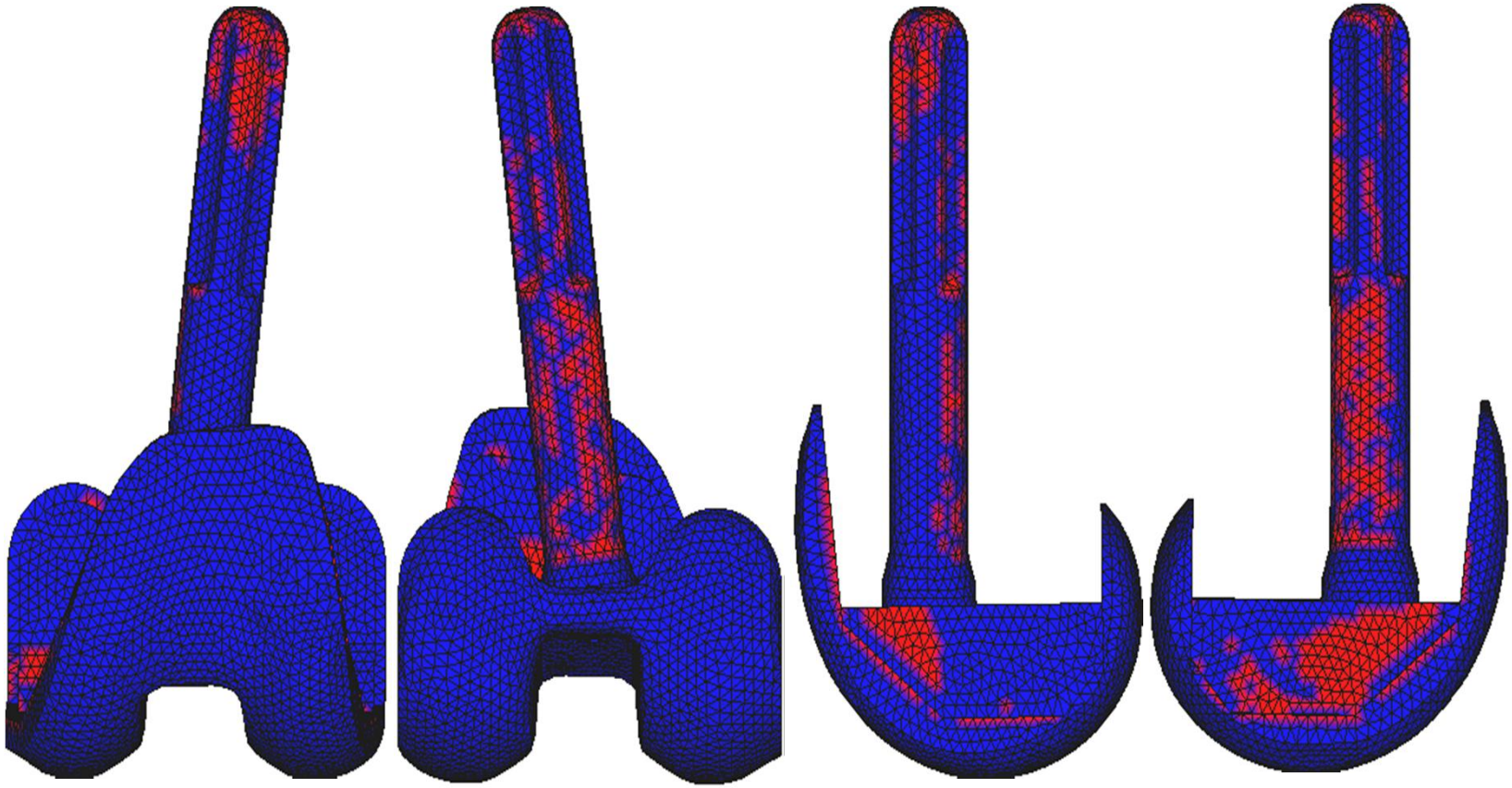
POSITION FROM THE PRESS-FIT STEM (175mm)



200mm FROM THE BONE-CEMENT INTERFACE (PROXIMAL REGION)

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

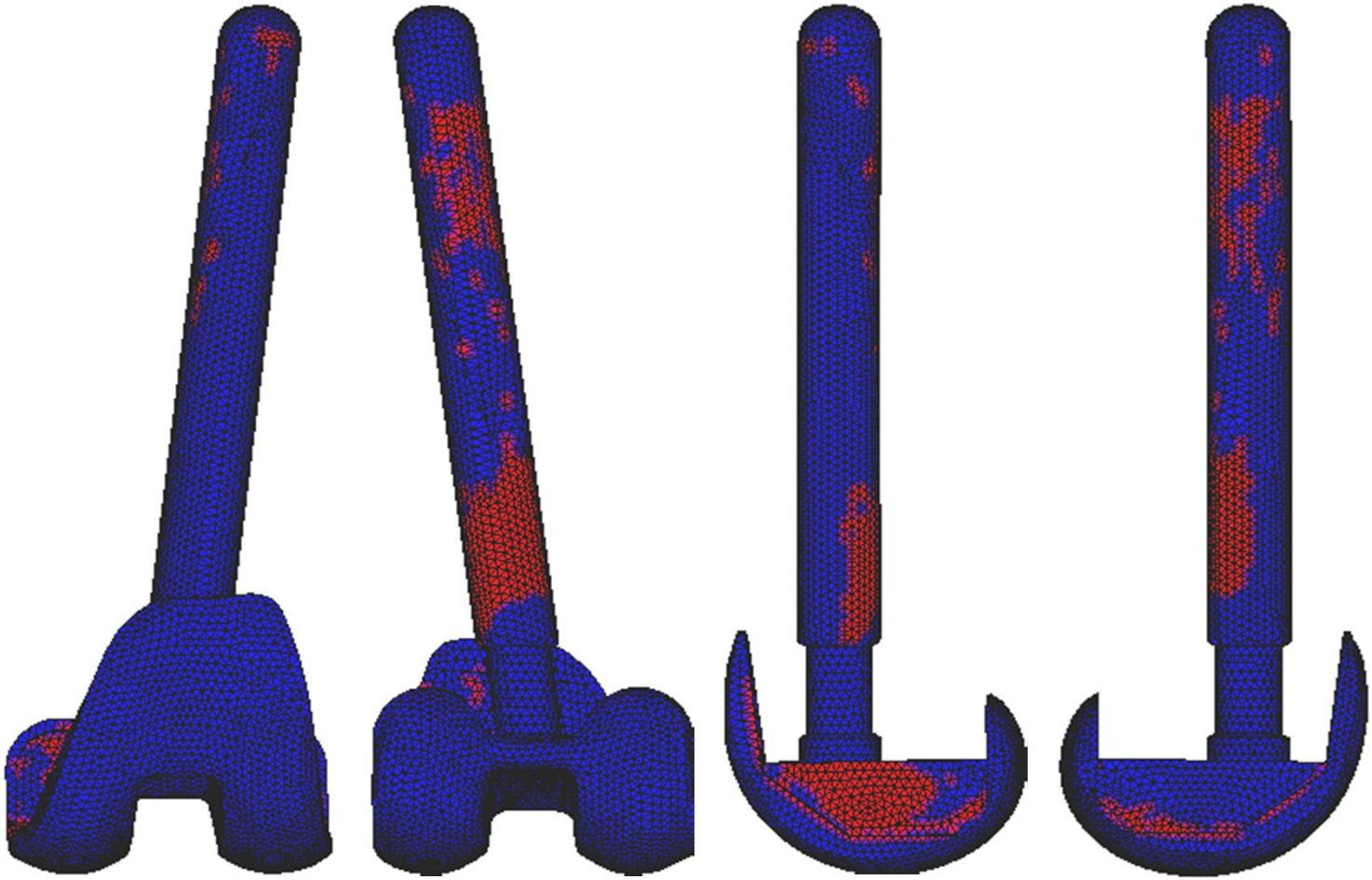
CONTACT REGIONS BETWEEN STEM AND CEMENT (CEMENTED STEM)



Anterior Posterior Lateral Medial

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

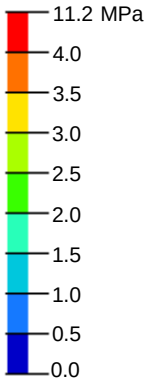
CONTACT REGIONS BETWEEN STEM AND CEMENT (PRESS-FIT STEM)

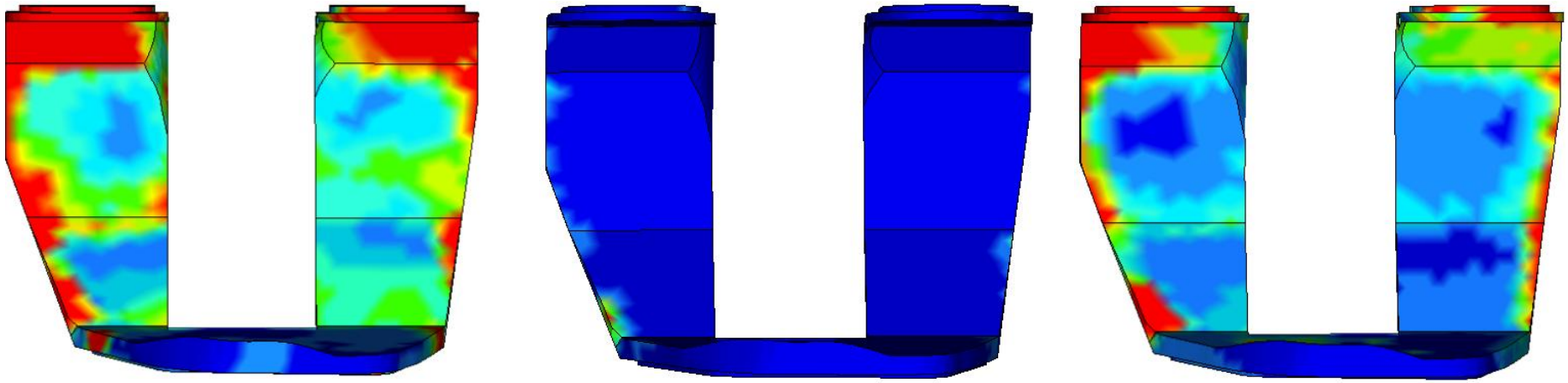


Anterior Posterior Lateral Medial

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

CEMENT VON MISES STRESSES





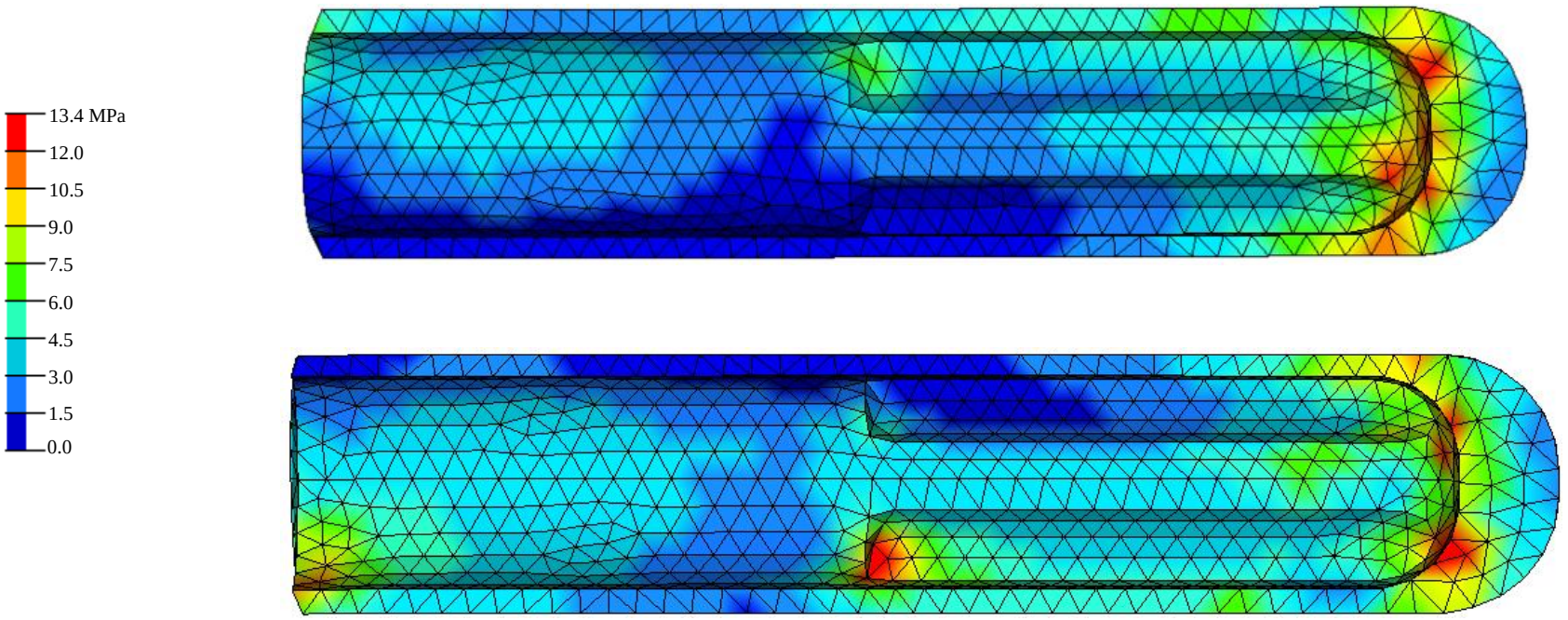
No stem (Standard)

Cemented Stem (H_CEM)

Press-Fit Stem (H_LONG)

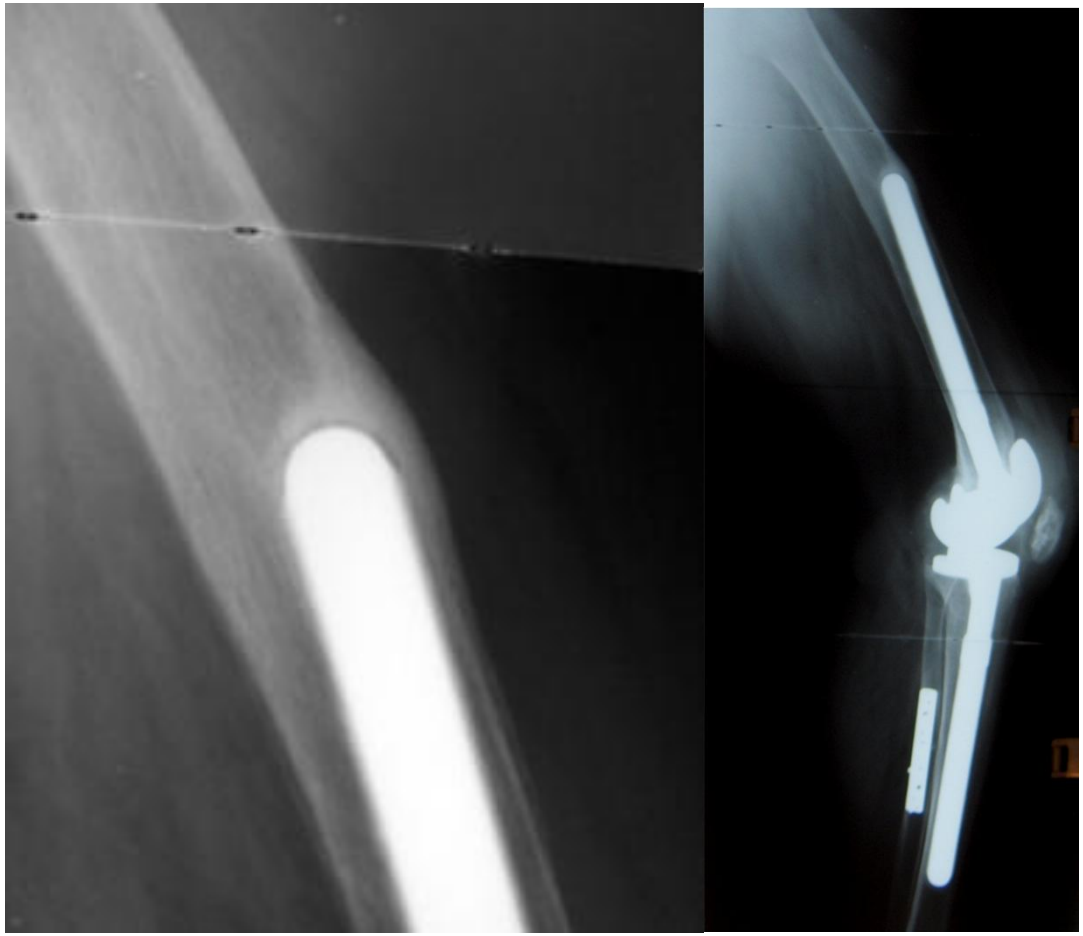
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

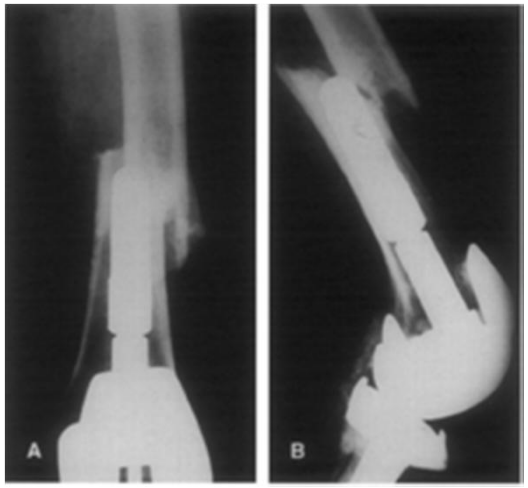
VON MISES STRESSES AROUND THE STEM



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

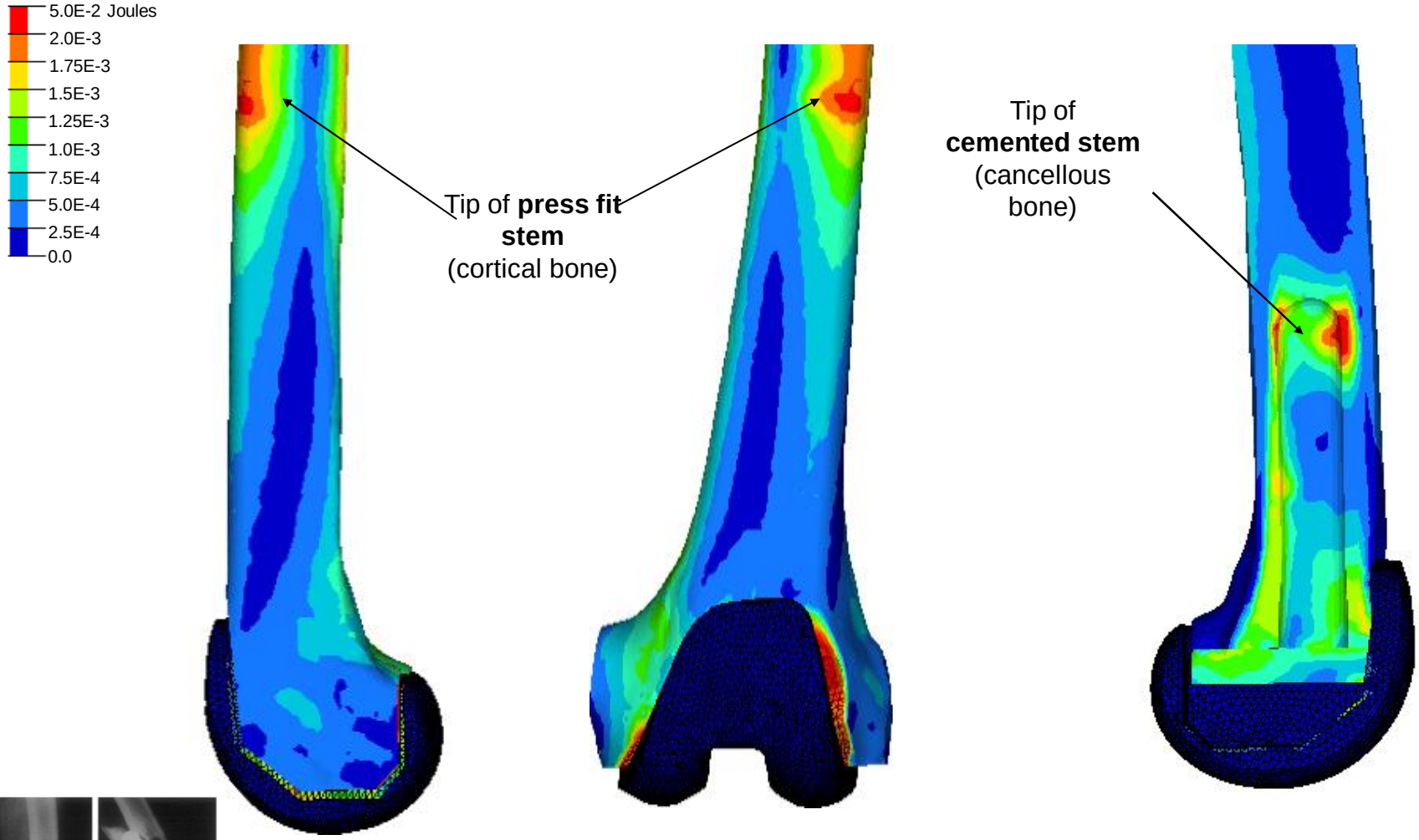
RADIOGRAPHS (HIPERTROFY AND FRACTURE): can numerical simulations predict these?





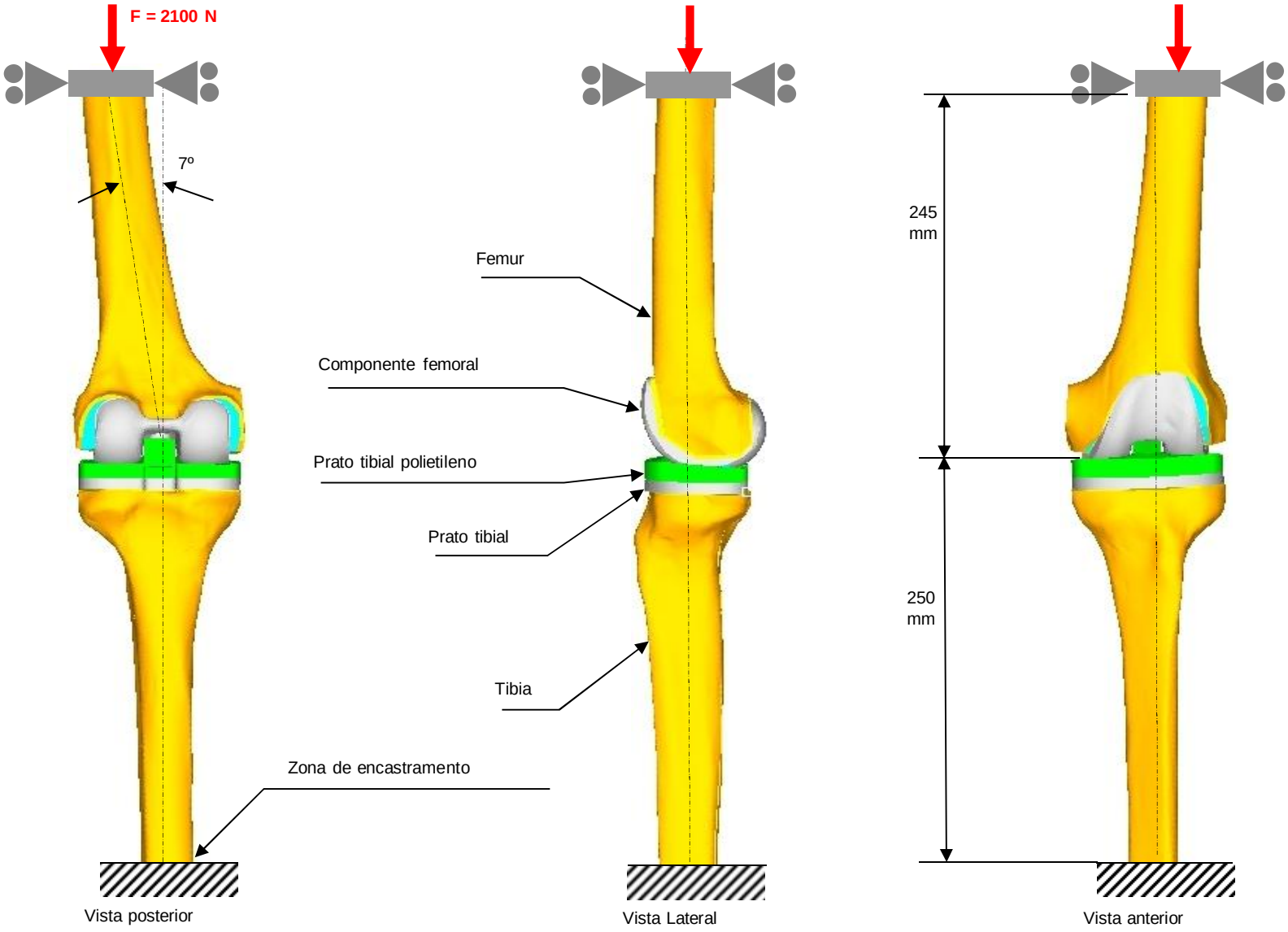
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

PRESS-FIT CORTICAL STRAIN ENERGY



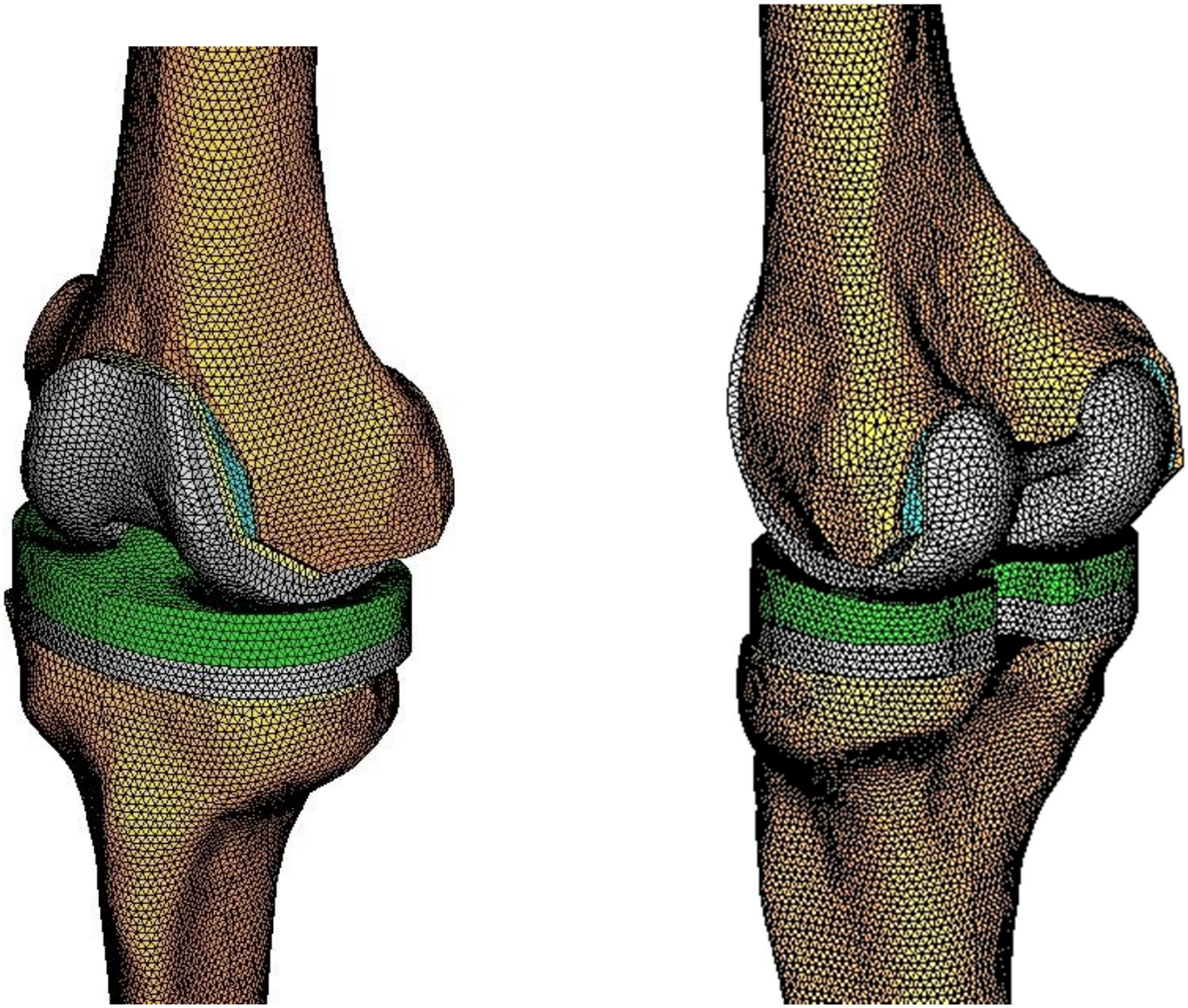
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

TOTAL KNEE PROSTHESIS – FEMORAL + TIBIAL



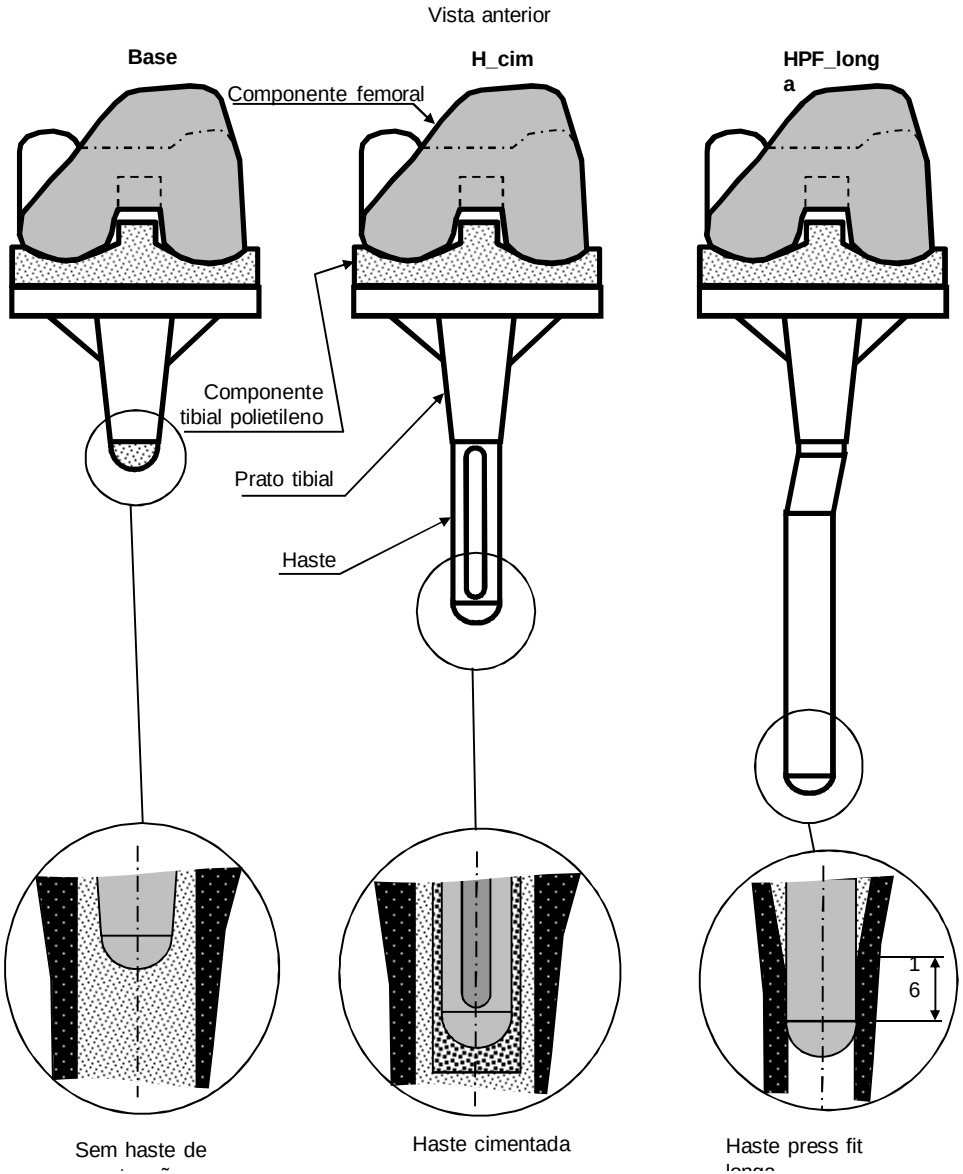
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

FINITE ELEMENT MESHES



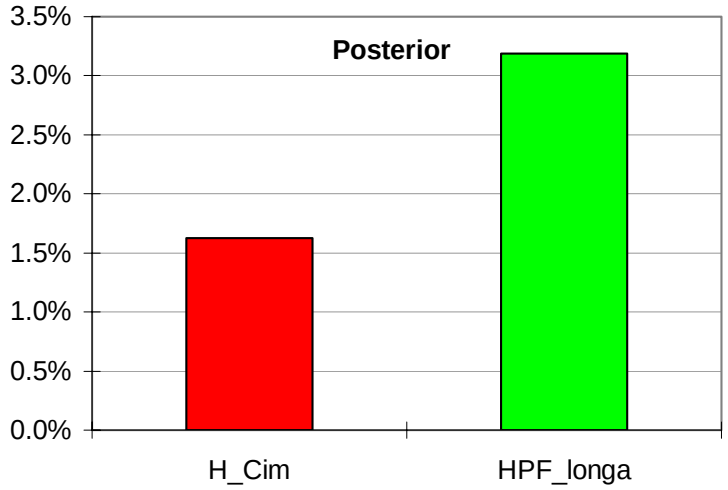
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

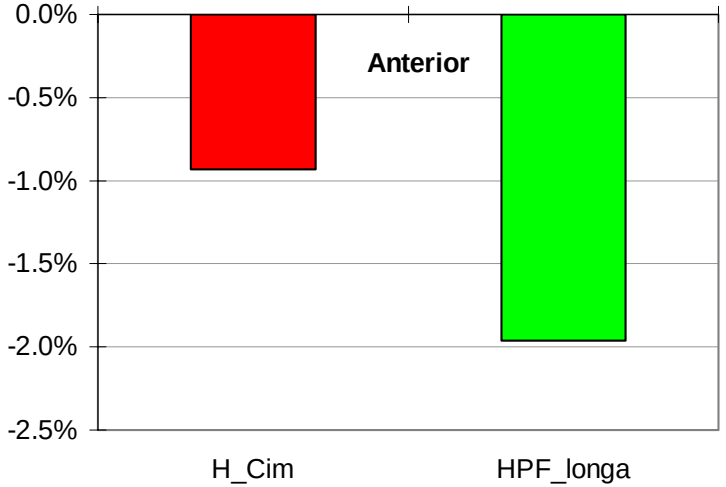
TOTAL KNEE PROSTHESIS

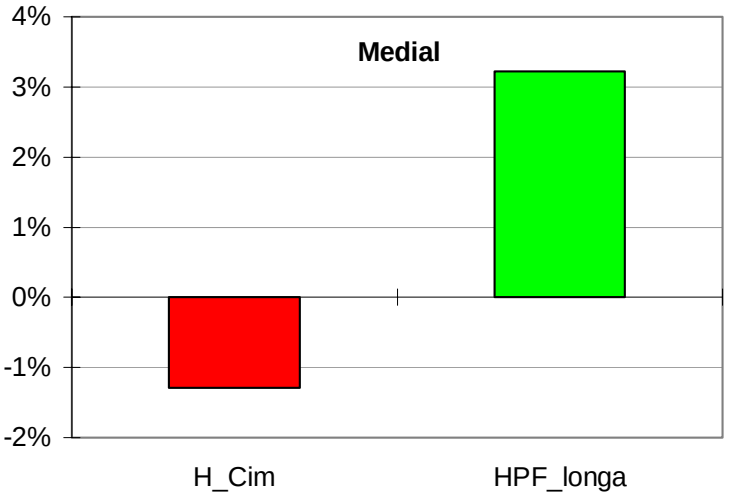


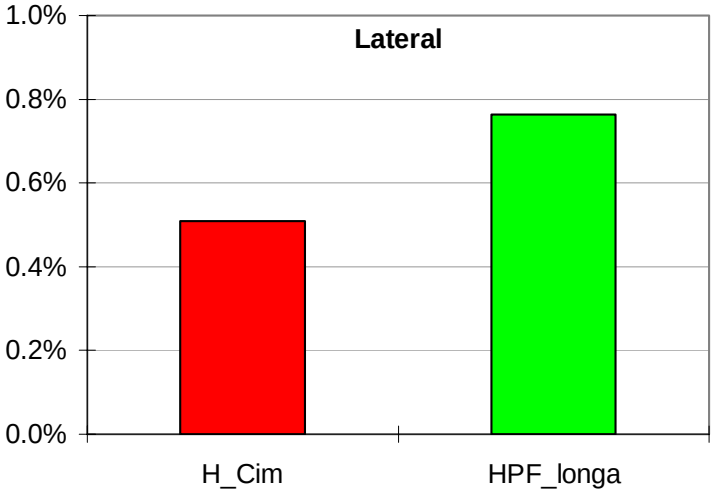
Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

MICROMOVEMENTS BETWEEN BONE AND FEMORAL COMPONENT



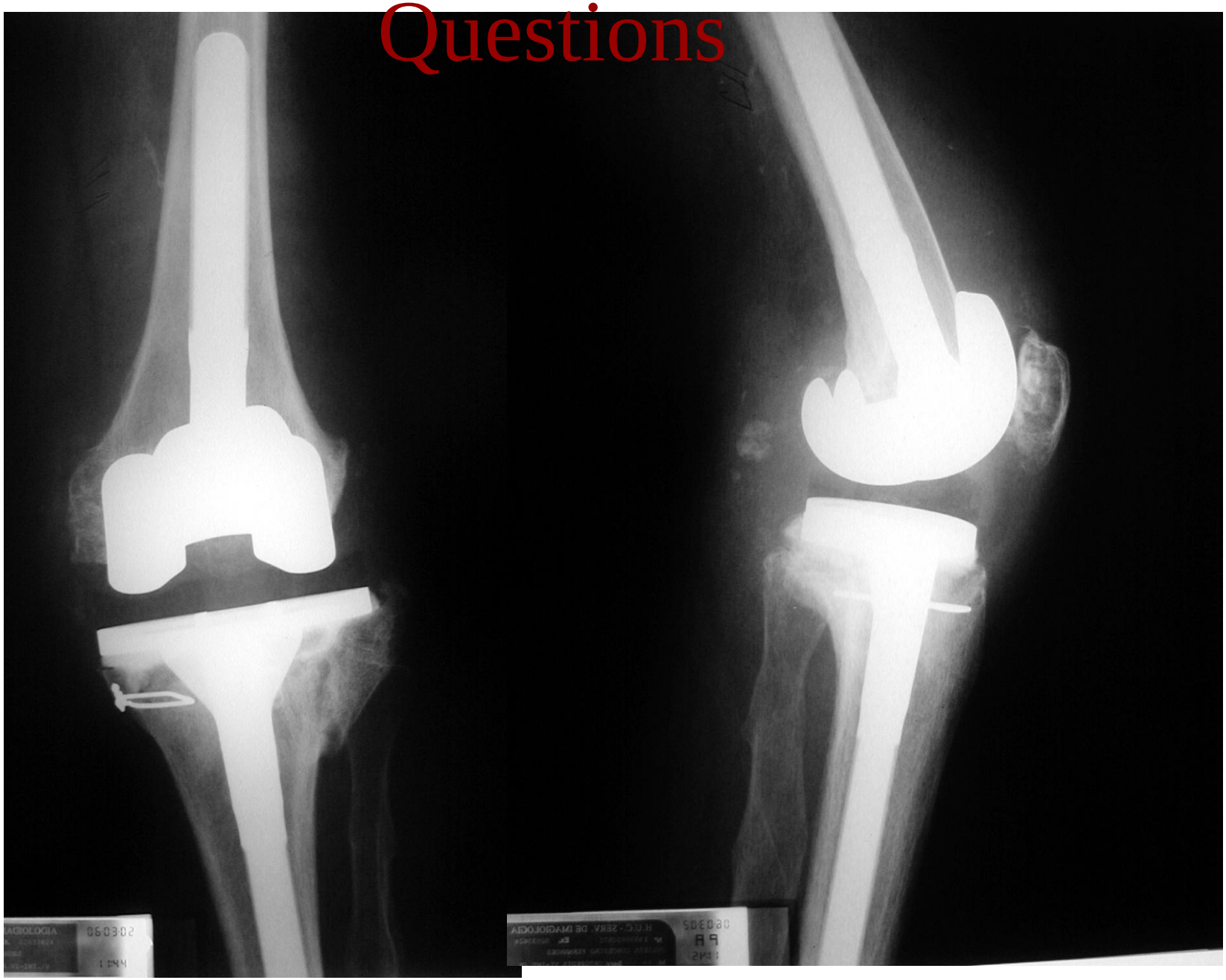






Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

Questions



Biomechanical Investigations on the Total Knee Arthroplasty (TKA)

Or ?

Biomechanical Investigations on the Total Knee Arthroplasty (TKA)