Definition of a 3D modeling method to create and test customized knee implants

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INTRODUCTION

Pain and immobility issues insist on a 10-34% of patients after **Total Knee Arthroplasty**

Among the prevalent causes, there is **implant malalignment**

To increase the rate of patient's satisfaction:
- Individualized or **kinematic alignment**
- **Custom-made implants**

Finite Element Analysis FEA to analyze contact pressures in the implants and investigate the causes of implant failures

AIM

Definition of a 3D modeling method to create customized implant

Preparation and comparison of surgical virtual planning with
- **Off-the-shelf implant**
- **Custom-made implant**

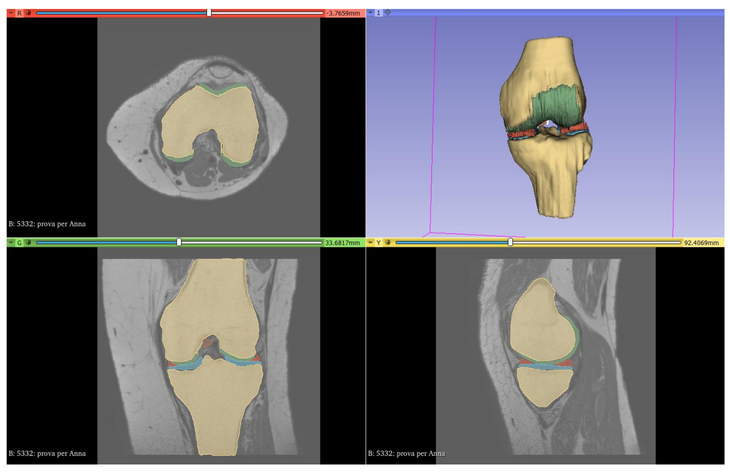
Study the performance of the implants in terms of stress and pressure distribution to understand which of the two implants better **restore the normal 'healthy' condition**

METHODS

Starting from MR images, the **3D model of a knee** has been reconstructed through a segmentation process.
Virtual surgical planning has been performed, following a **kinematic allignment**.
In the first scenario, an **off-the-shelf implant** has been virtually implanted. In the second scenario, a **custom-made implant** has been created.
FEA simulations have been performed in both the cases.

3D MODELING OF THE KNEE

- High resolution **MR images**
- Manual and semiautomatic **segmentation**
- **Patient-specific anatomy**

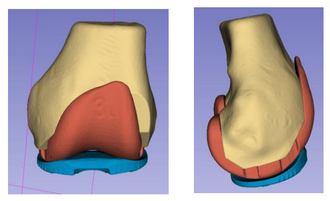


3DSlicer

VIRTUAL SURGICAL PLANNING

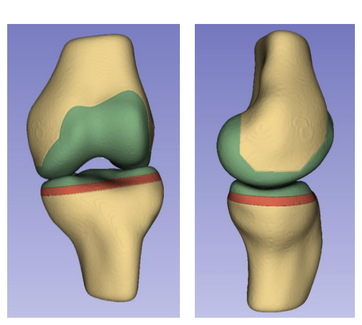
Off-the-shelf implant

Implant size choice → Implant alignment → Cut planes creation



Customized implant

Femur and femoral cartilage union; Tibia, tibial cartialge and menisci union → Smoothing process → Cut planes import



FINITE ELEMENT ANALYSIS

- **Tetrahedrons elements mesh**
  - avg. element quality 0,89
- **Load distribution**
  - 1150 N vertically on the top surface of the femur
  - Fixed support on the bottom surface of the tibial component
- **Contact conditions**
  - Bounded contact between femur and femoral component
  - Bounded contact between tibial insert and tibial component
  - Frictionless contact between femoral component and tibial insert

Materials

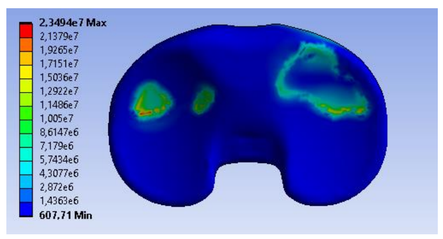
Femur	Femoral and tibial component	Tibial insert
Bone	Co-Cr-Mo alloy	UHMWPE

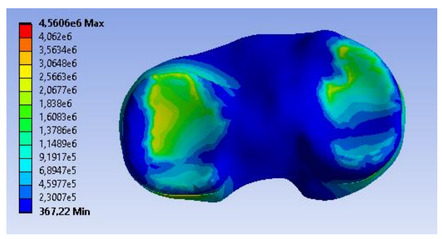
RESULTS

COMPRESSIVE STRESS [MPa]

Tibial part

Healthy condition	Off-the-shelf implant	Customized implant
2,35	7,18	2,07

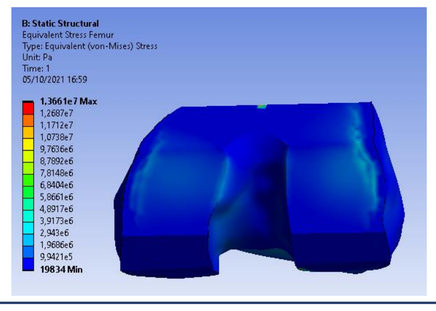


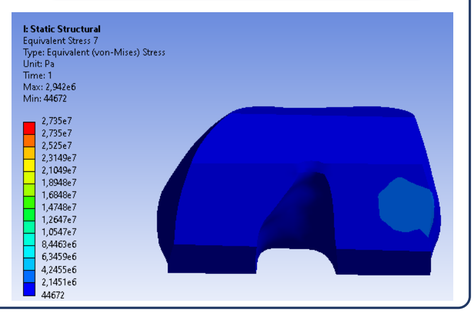


Femur

Off-the-shelf implant
The stress is concentrated along the boundary of the contact surface between the femur and the femoral component, where the bone is not covered

Customized implant
The stress is uniformily distributed, due to the complete coverage of the bone by the femoral component

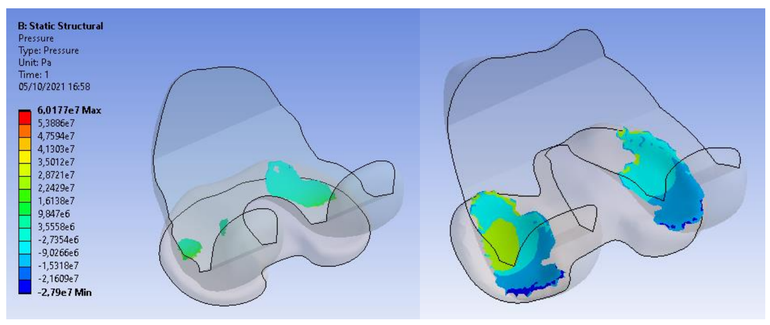




CONTACT PRESSURE [MPa]

Femoral-tibial compnents

Healthy condition	Off-the-shelf implant	Customized implant
3,97	3,56	2,07



DISCUSSION

- The implant aims at **restoring the healthy condition** in terms of stress and contact pressure distribution
- The customized implant allows a more **uniform distribution of the compressive stress** on the tibial implant compared to the off-the-shelf implant. Both the maximum and the average values of the stress are reduced, reproducing the healthy condition
- The contact surface increases in the customized implant. This cause a **reduction of the pressure peak**, that is more uniformly distributed on the tibial plateau

CONCLUSIONS

- The study presents a 3D modeling method to create a customized knee prostehsis
- The customized implant is compared with the off-the-shelf implant and the healthy condition by means of FEA
- The customized implant allows a more uniform distribution of the compressive stress and the pressure
- Future development will face the definition a more complex virtual model for simulate the dynamic behaviour during gait