Knee exo-prosthesis development for osteoarthritis treatment

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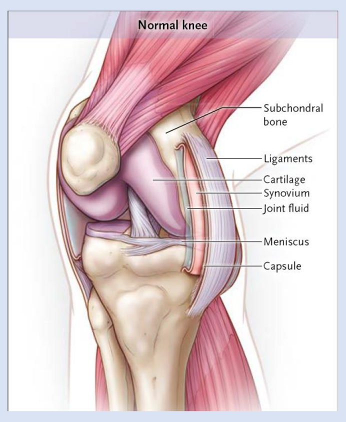
Introduction

Anatomy



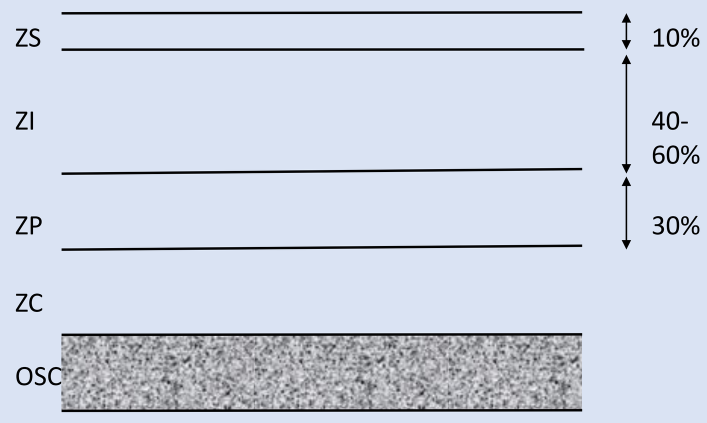
Knee is a very important joint for locomotion.

This joint must accomplish two opposite tasks in every day life : **mobility** and **stability**.

It undergoes very important loads (until 10 x BW) for two reasons :
- The knee is a **weight-bearing articulation**
- **Lever arm** between the knee and the center of mass of the body is wide

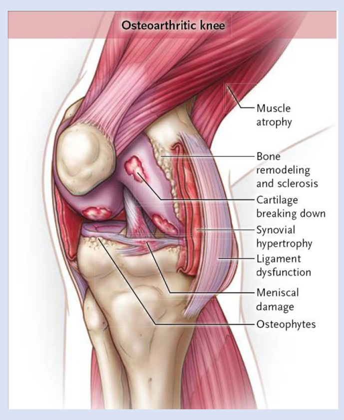
The knee is a complex structure made of :
- Bones : femur, tibia and patella
- Cartilages :
  - Hyalin articular : femoral and tibial
  - Fibrocartilages : mensicus (medila and lateral)
- Fibrous tissues :
  - A joint capsule that enclosure synovial fluid into the joint
  - Anterior and posterior cruciate ligaments
  - Medial and lateral collateral ligament

Histology of the hyalin articular cartilage



Cartilage is a **mechanical-sensitive tissue** and can be seen as a :
- Multiphasic tissue :
  - Solid phase = ECM (collagens + proteoglycans + cells)
  - Liquid phase = interstitial fluid (water + solutes)
  - Ionic phase = Charged solutes and molecules within each previous phase
- Multi layer tissue :
  - 3 intrinsic layers (superficial, middle and deep zones)
  - 1 transition layer (calcified zone) to the subchondral bone

Osteoarthristis : a polyfactorial pathology



WHO definition : « Osteoarthritis (OA) is the result of **mechanical** and **biological** phenomena that destabilize the balance between the synthesis and the degradation of cartilage and subchondral bone […]».

Public health : OA is the first osteoarticular pathology in France (17% pop. affected by OA) [1] and in the world.

Risks factors ≈ Symptoms → vicious circle
Ex : Inflammatory syndroms, trauma, meniscals damages, joint laxity, etc [2]

Actual common therapies

Therapy	+	-
Painkillers & anti-inflammatories	Easy prescription	symptomatic treatment only
Corticoid infiltration	Immediate effectivness	Short-term effectivity only
High Tibial Osteotomy	Unloading cartilage	Invasivity and overload of the other compartment
Uni-compartmental prosthesis	No more cartilage disease	Higher invasivity, irreversibility and limited lifespan

Problem

Problem : *there is no therapy that stops efficiently OA progression during the middle stages of the pathology*

Research hypothesis :

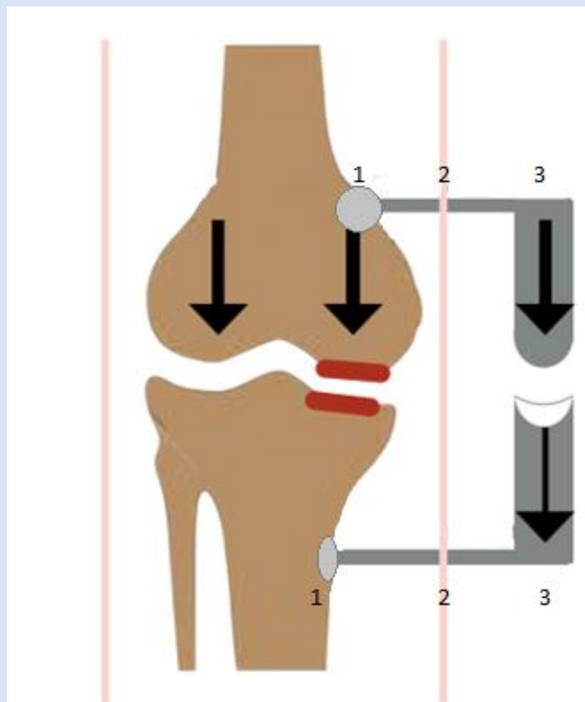
« Cartilage unloading is good for knee osteoarthritis treatment »

Technological solution :

« Knee exo-prosthesis, a medial unloading implantable device » (concept patented by RLC SYSTEMS & RESEARCH)

Knee Exo-Prosthesis :

- Medial load shunt
- Temporary semi-implanted device (internal/external)
- Easy coupling with biochemicals approaches
- Highly reversible and low invasivity
- « Knee kinematics »-friendly



Genou avec exo-prothèse

Methods

Modelisation of the knee

- Finite Element modeling
- Patient specific geometries = hard tissus segmented from CT-scan
- Articular cartilages, meniscus and major ligaments
- Body-weight loading
- Comparison with and without KEP

KEP Design

- Shape and design
- Two functions : kinematics and unloading
- Computer-Assisted Design
- Mechanical tests (failure, fatigue, induced-unloading on cadaveric specimen)
- Biological tests (small animal test)

Tribology and wear of the cartilage

- Understanding the complexity of the tissue
- Multi-physics modelisation
- Study method for OA progression
- Which kind of mechanical stress is the more deleterious for articular cartilage ?

Biological issues for KEP development

At the scale of the joint :
Biocompatibility of the device for the patient (biomaterials, wear, immunity, etc)
→ The device must be tolerated and beneficial for the patient

At the scale of the tissue :
The cartilage isn't innervated nor vascularized
- Passive feeding of the chondrocytes (diffusion + convection by fluid pumping)
- The cartilage needs mechanical stresses
→ The device must unload just as much as needed, to maintain cellular nutrition

At the scale of the cells :
Metabolic adaptation of the chondrocytes to mechanical stress :
- Compression → Collagen synthesis = Proteoglycans synthesis
- Shear → Collagen synthesis > Proteoglycan synthesis (2:1) [3]
→ The device must not impact too much the natural kinematic of the knee

Mechanical issues for KEP development

Kinematic of the knee :
- Knee : Asymmetric bicondylar articulation → Complex kinematic
- Bio-inspired design from knee patient to mimics natural kinematic

Unloading cartilage :
- Overload can induce OA but no load at all induces chondrocyte death.
- An optimal unloading must be found to allow the cartilage to regenerate without shielding all the stress it experiments.

Patient-specific design :
- Anatomy varies from one patient to an another
- Surgical techniques can't be infinitely accurate → Needing of post-surgical adaptativity

References

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