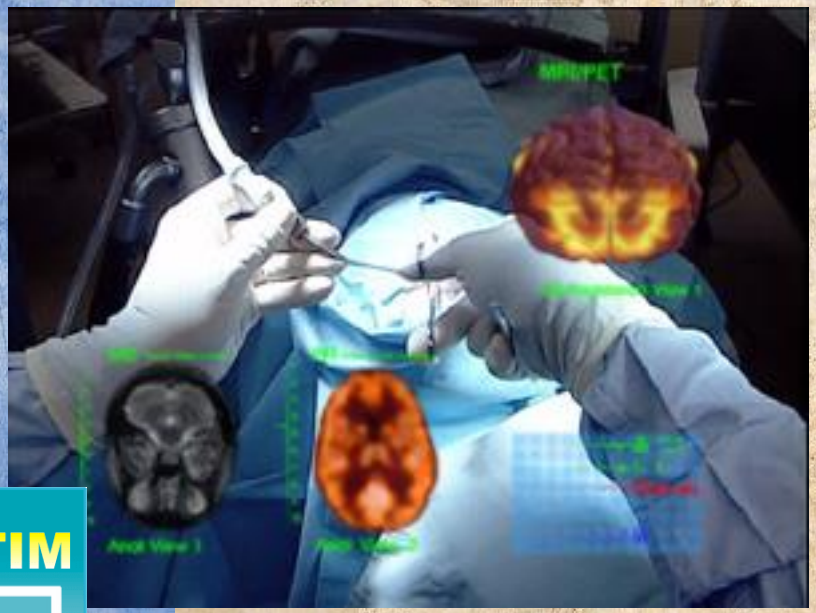
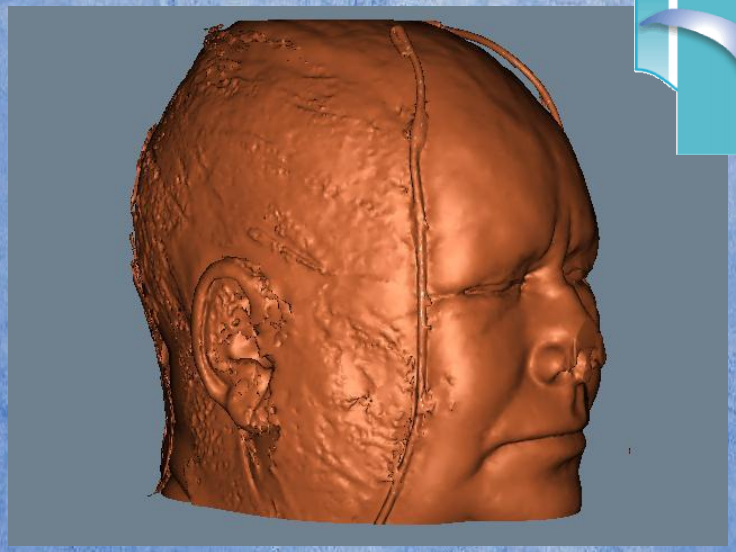
| Computer Assisted Orthopaedic Surgery |





L@TIM

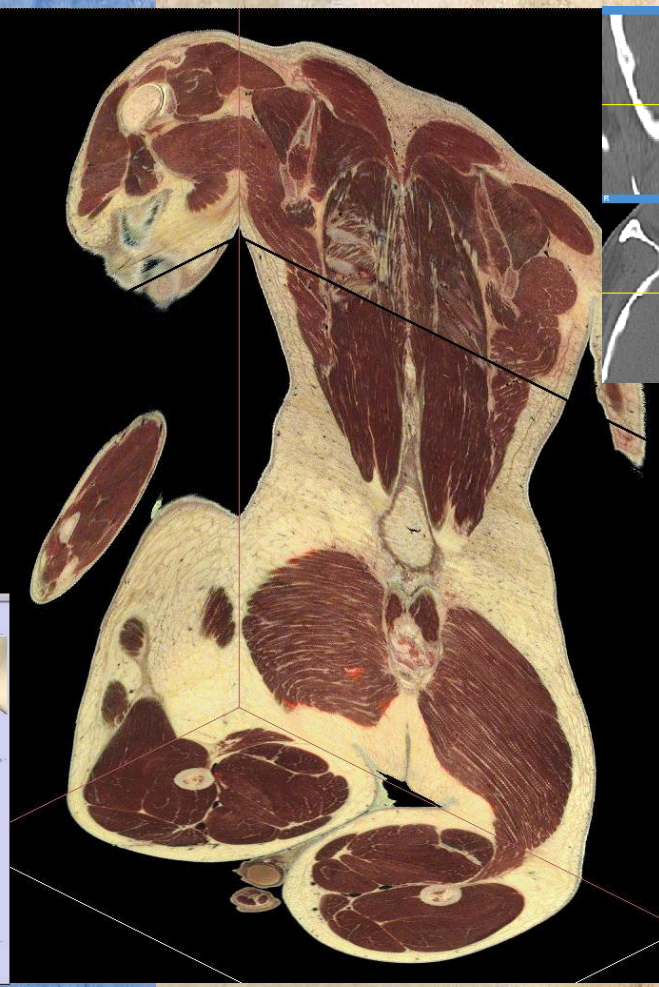
université de bretagne occidentale

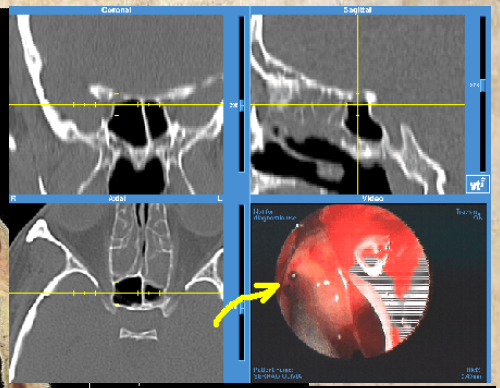
Eric STINDEL, M.D. Ph.D.

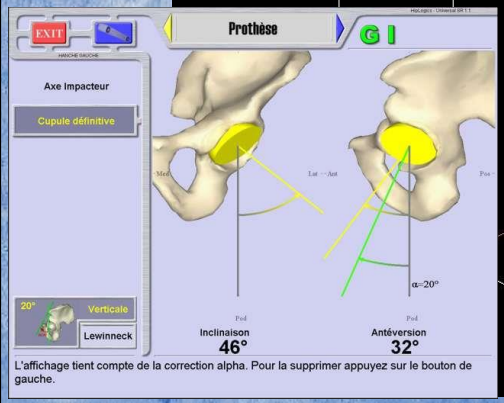
| Computer Assisted Orthopaedic Surgery |

Introduction

« Perform 3D actions in a 3D space on a 3D Object: a human being »







History

Neurosurgery

Frame based Stereotaxy : Clarke et Horsley - 1806

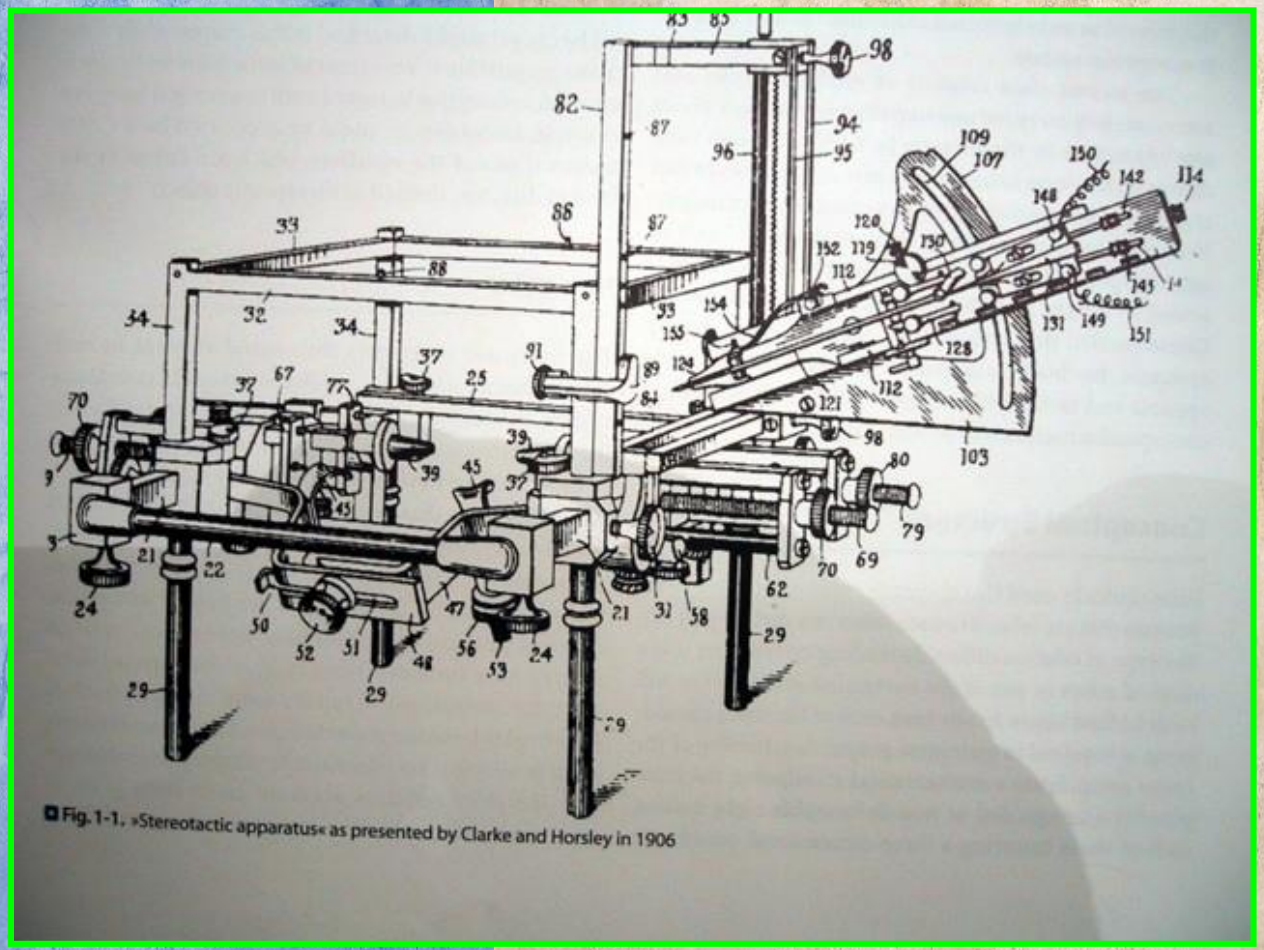


Fig. 1-1. »Stereotactic apparatus« as presented by Clarke and Horsley in 1906

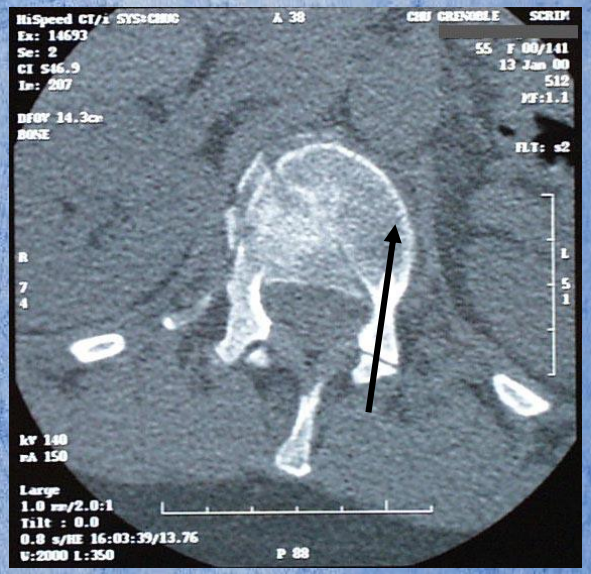
| Computer Assisted Orthopaedic Surgery |

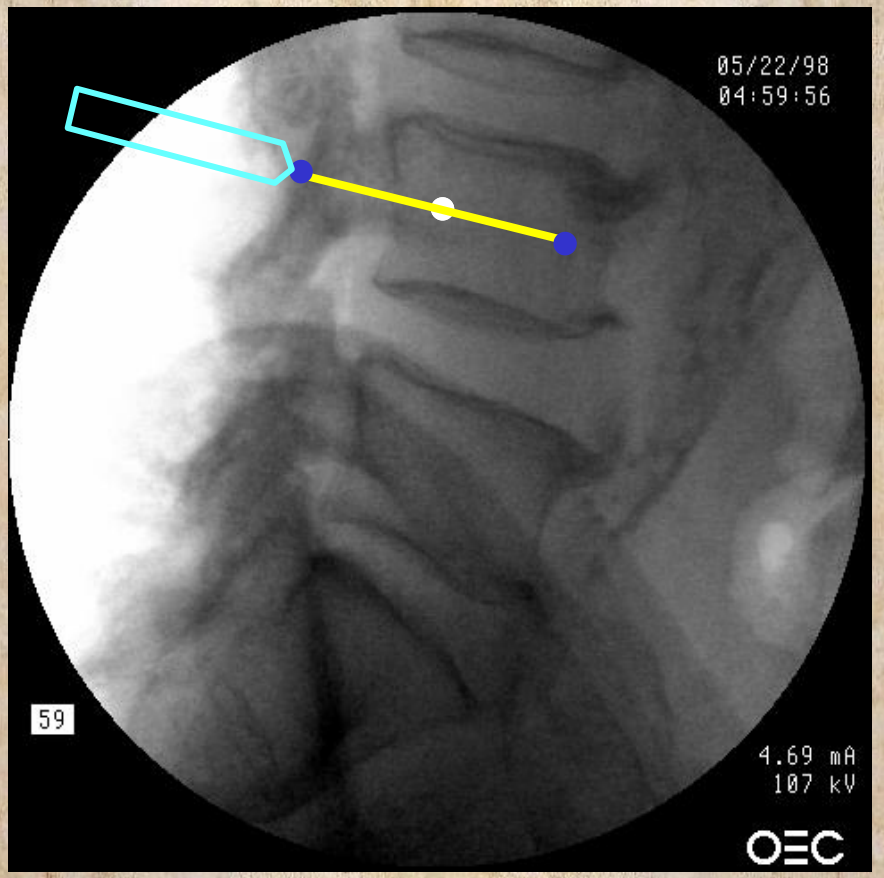
- Introduction
- History
- Basics
- TKA
- HTO
- ACL
- THA
- Conclusion

1990 1995 2000

Spine Surgery

Pedicular screwing





1990 1995 2000

Robots for Hip

First generation : ROBODOC and CASPAR

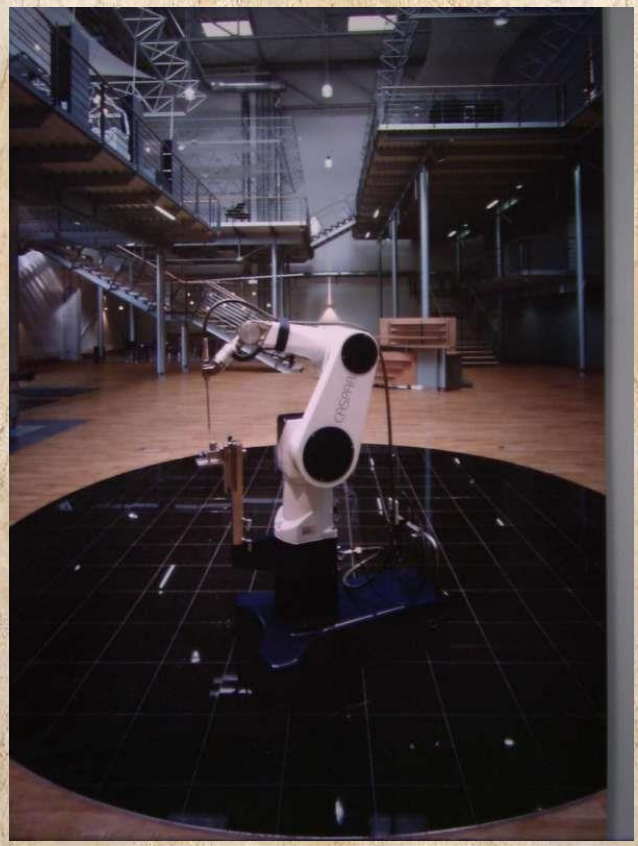
Femoral drilling

Out of business

Cost

Invasiveness

No added value



| Computer Assisted Orthopaedic Surgery |

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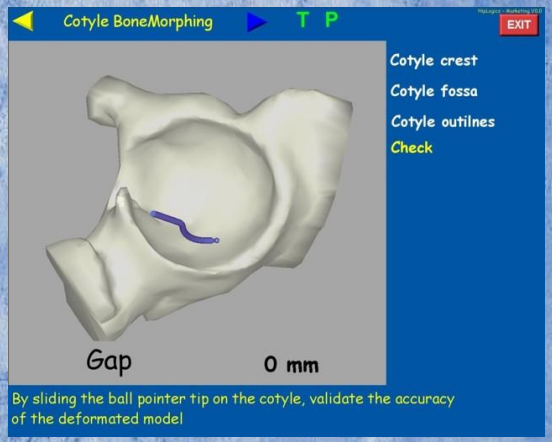
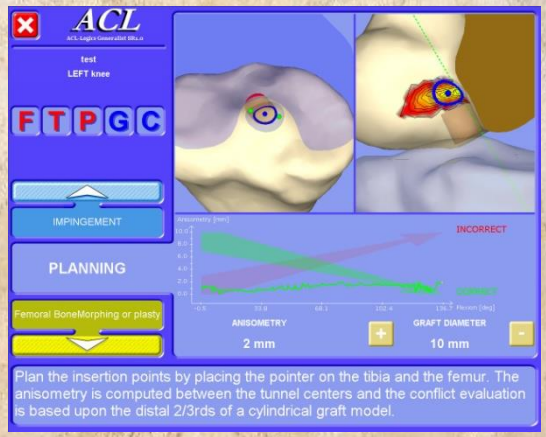
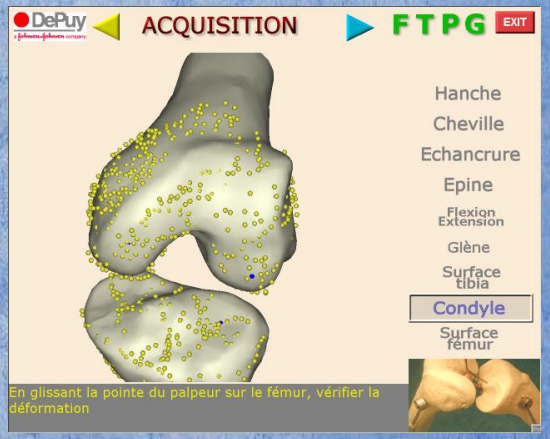
- THA
- Conclusion

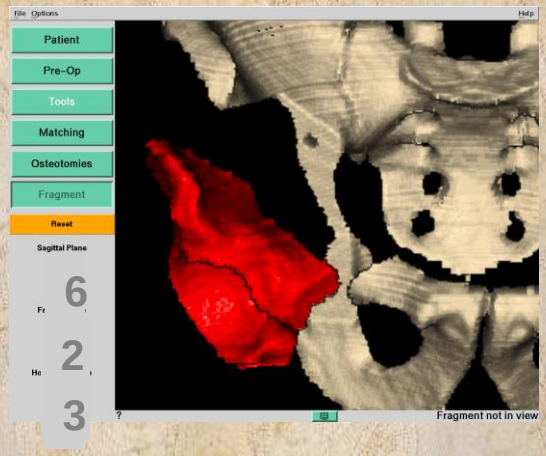
1990 1995 2000

Orthopaedic Surgery



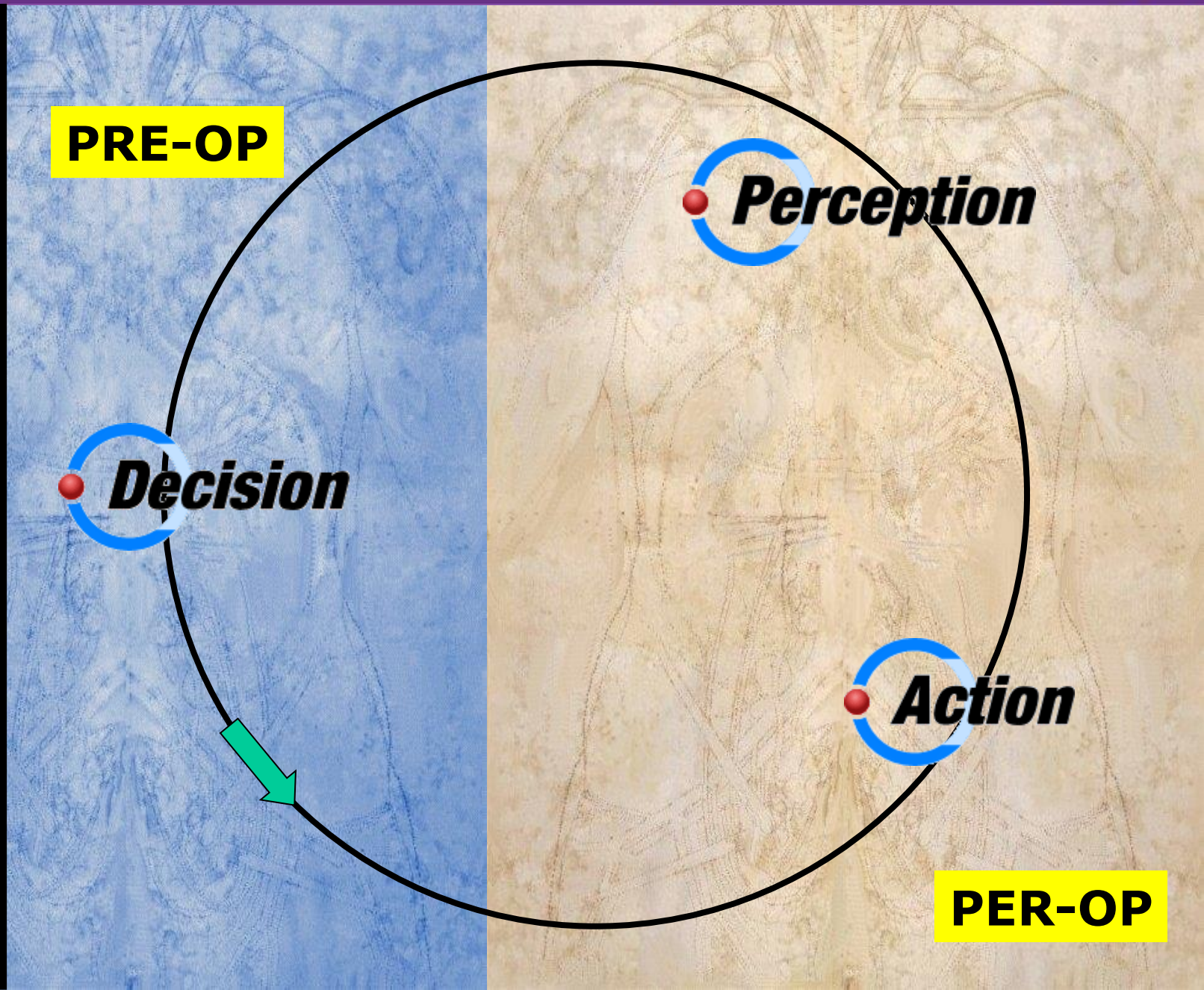






Basics

The Perception – Decision – Action loop



Action

PASSIVE SYSTEMS
Navigation systems

Guiding systems

3D localizers

Real-time feed back on the location of :

-Therapeutic objects

- Surgical instruments

Action

Guiding systems

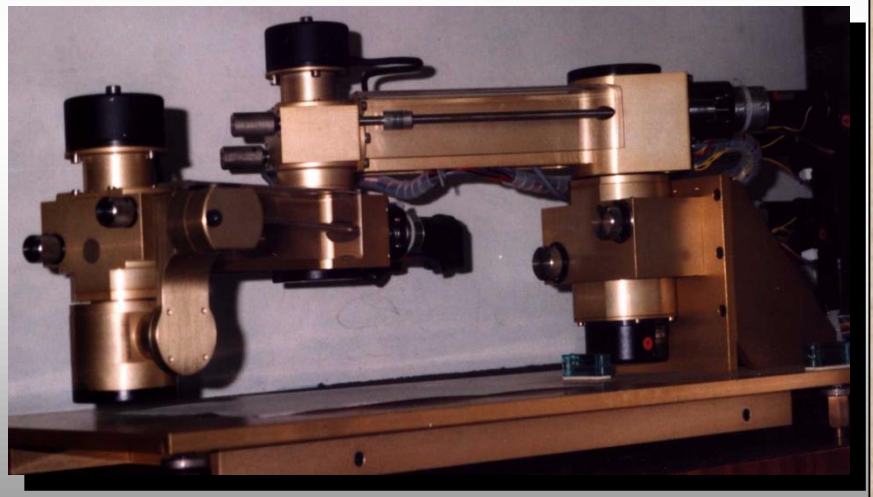
SEMI-ACTIVE SYSTEMS
The surgeon is guided in a restricted volume

Padyc

Synergistic robots

Collaborative robots

Impeachment robots



http://www-timc.imag.fr/

Action

ACTIVE SYSTEMS
Active robots which performs
Part of the surgical procedure

Guiding systems

Active robots

Perform parts of the procedure

Based on per-op planning

Action

| Computer Assisted Orthopaedic Surgery |

Introduction

History

Basics

TKA

HTO

ACL

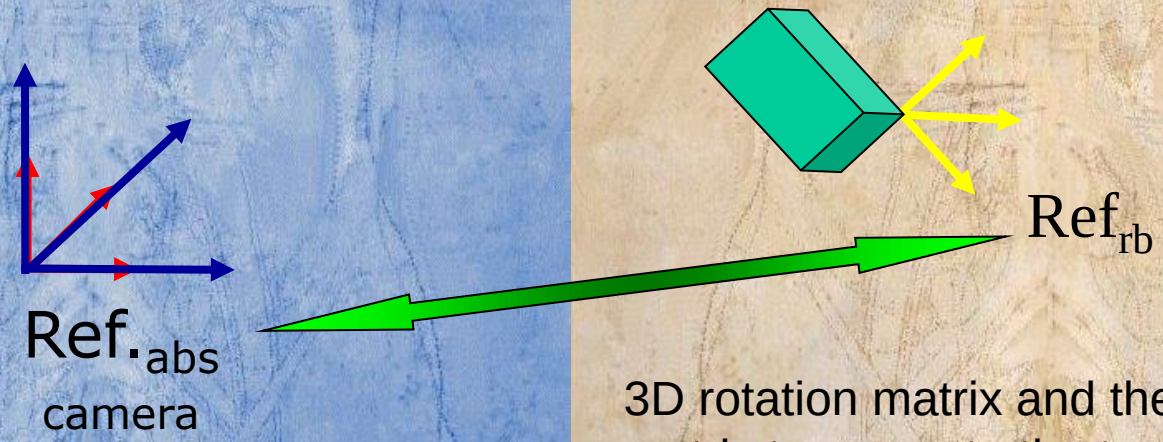
THA

Conclusion

3D Localizers

Localization : non deformable Objects

- Bones or surgical tools
  - Location
  - Orientation



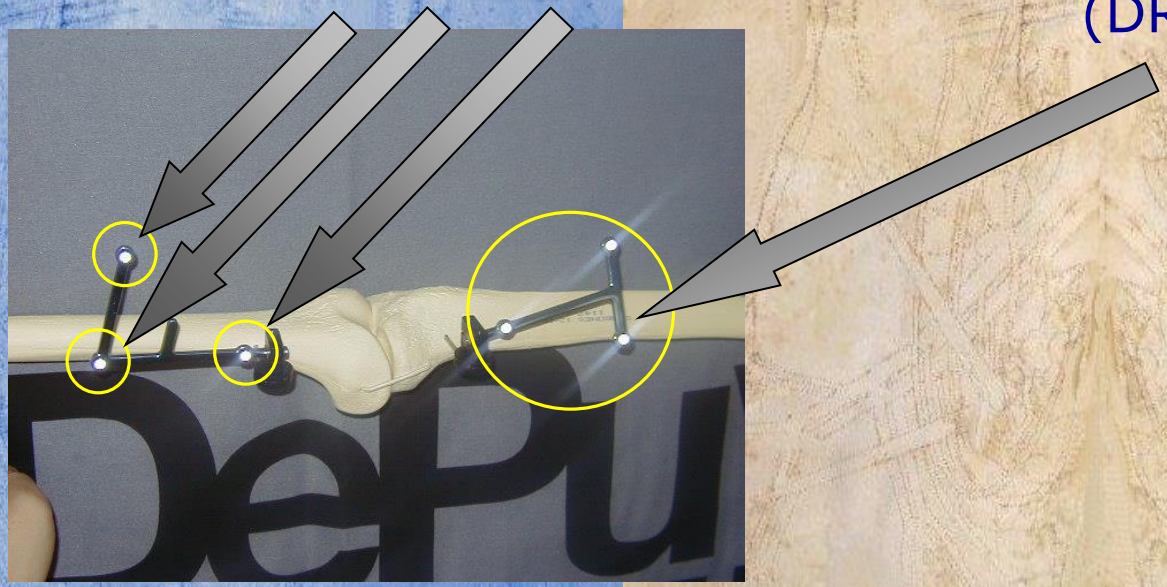
3D rotation matrix and the translation matrix to compute the transformation from Ref_{abs} to Ref_{rb}

3D Localizers

Non deformable Objects

- Bony structures : therapeutic objects
- Surgical tools

- **Dynamic reference base** (DRB)

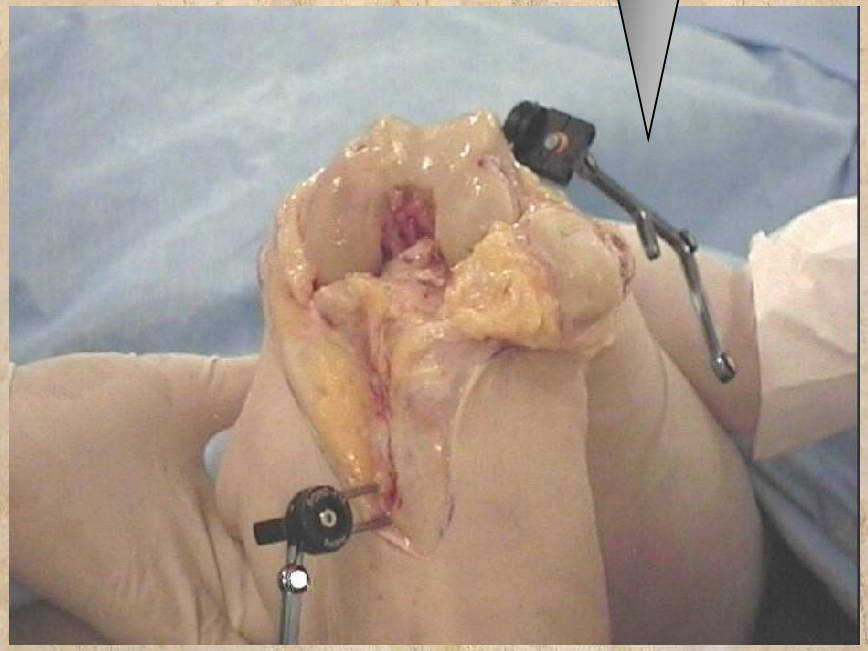


3D Localizers

Non deformable Objects

- DRB attached to :
  - Bony structures : therapeutic objects
  - Surgical tools

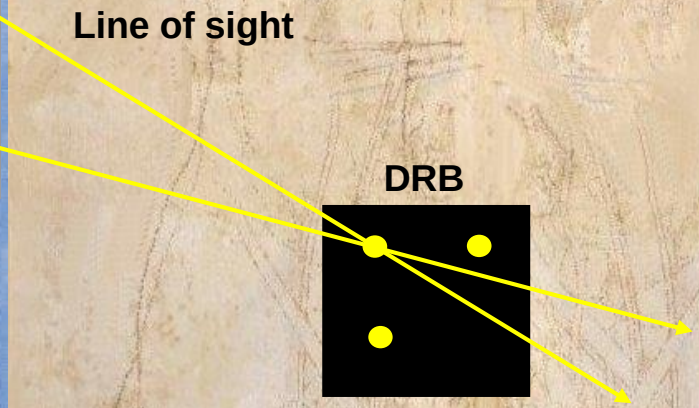
- **Dynamic reference base** (DRB)



3D Localizers

Localizer = 1 Source + 1 Sensor

- Optical localizer with two 2 Dimensional sensors



3D Localizers

Localizer = 1 Source + 1 Sensor

- Polaris :

POLARIS® - Technical Specifications

Accuracy	
0.35 mm 3D RMS(1)	
Workstation Interface	
Interface	RS-232/422
Max. Data Rate	115 kBaud
Position Sensor	
Weight	2 kg
Mounting	1/4" thread tripod mount
Dimensions	590 mm x 80 mm x 120 mm
enhanced Tool Interface Unit	
Weight	5 kg
Dimensions	320 mm x 130 mm x 300 mm
Power Requirements	
hybrid	100/120/220/240 V, 50/60 Hz, 2.5 A
passive	100-250 V, 50/60 Hz, 0.8 A

*Above weights and dimensions are approximate

3D Localizers

Optical systems

- Infra-red sensors

Basics

Emitted by the DRB

Reflected by the DRB

Wave length **880 nm**

In the OR one can find
70 000 Lux
400 et 500 nm

3D Localizers

Optical systems

- Active systems

Active emission of light
= source of energy

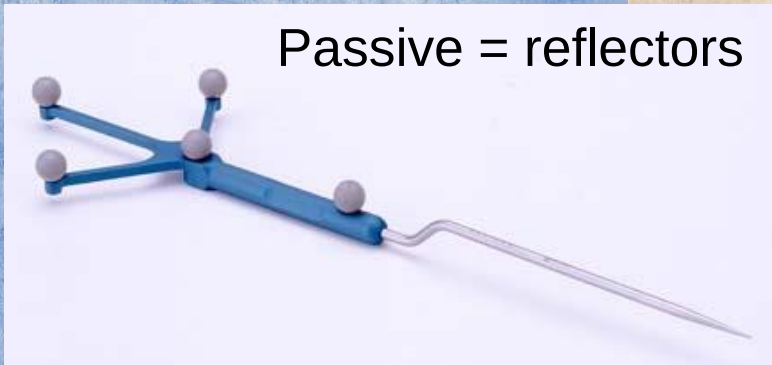
Drawbacks

- Cables on the operating field
- Batteries
- Weight
- Sterilization issues

3D Localizers

Optical systems

- Passive system



Drawbacks

Single use

Sensitive to surrounding light

Pros

Cheap

Light

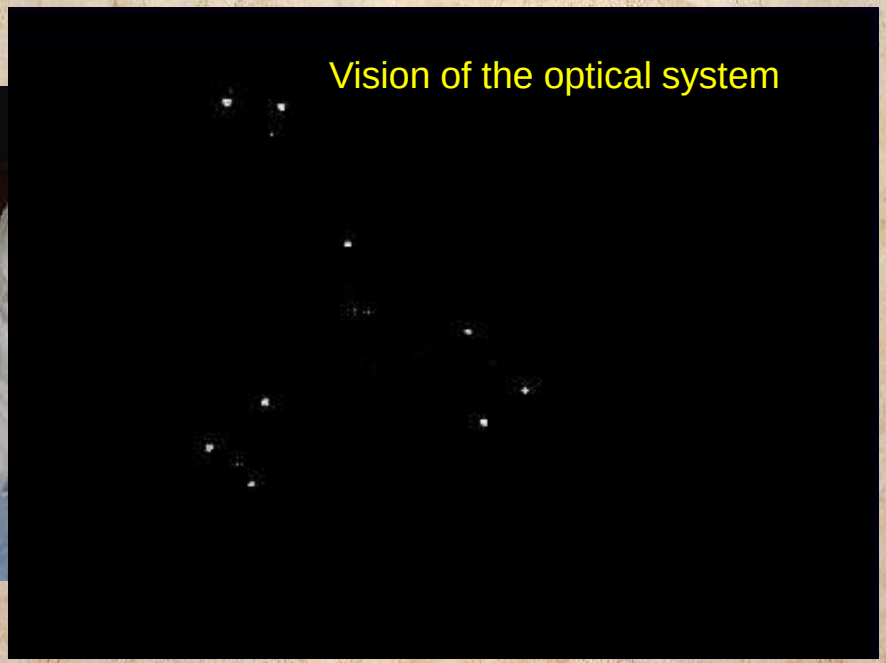
Can be set on any type of instrument

3D Localizers

Optical systems

- Vision of the camera

Surgical scene



Application : TKA

40 000 TKA / Year / France

8 000 Uni / Year / France

The challenges

- The challenges : two faces

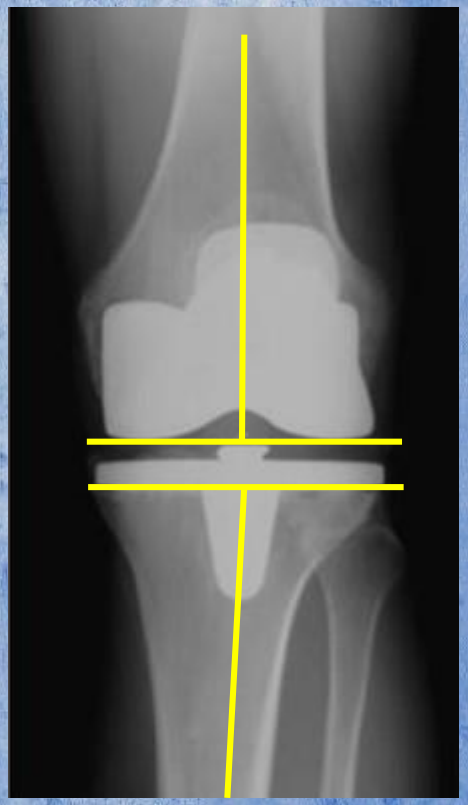
- Geometric challenge
  - Align the implants with respect to mechanical axes

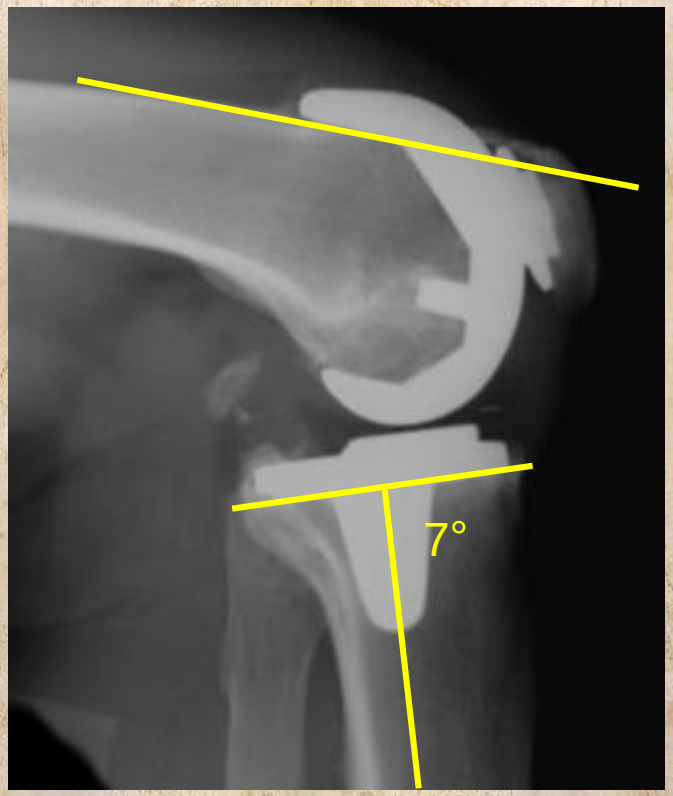
- Functional challenge
  - Perform a good ligament balance
  - Enough mobility
  - Enough stability

The challenges

- The challenges : two faces

•Mechanical axes :





The challenges

- The challenges : two faces

- Geometric challenge
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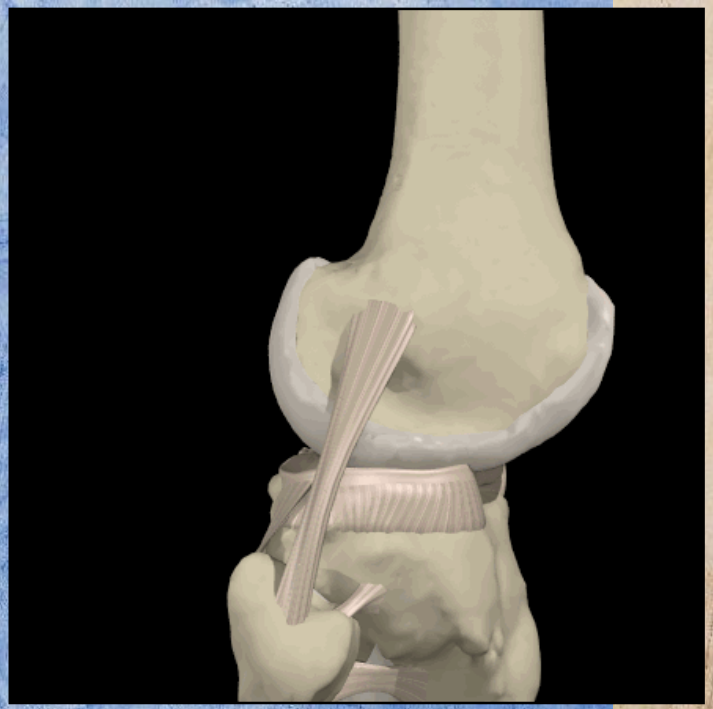
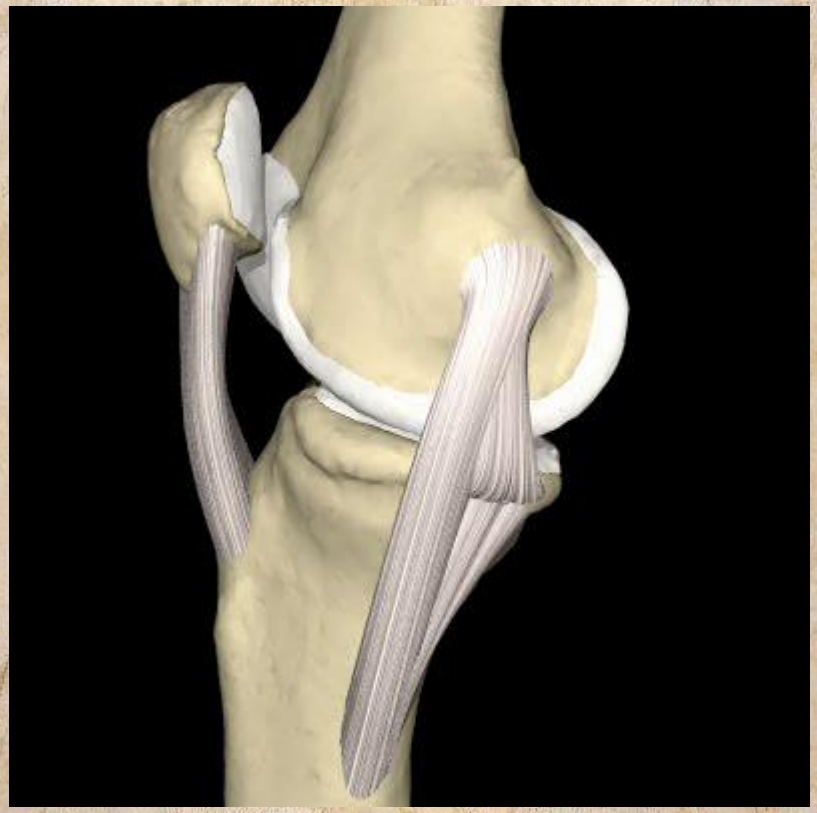
The challenges

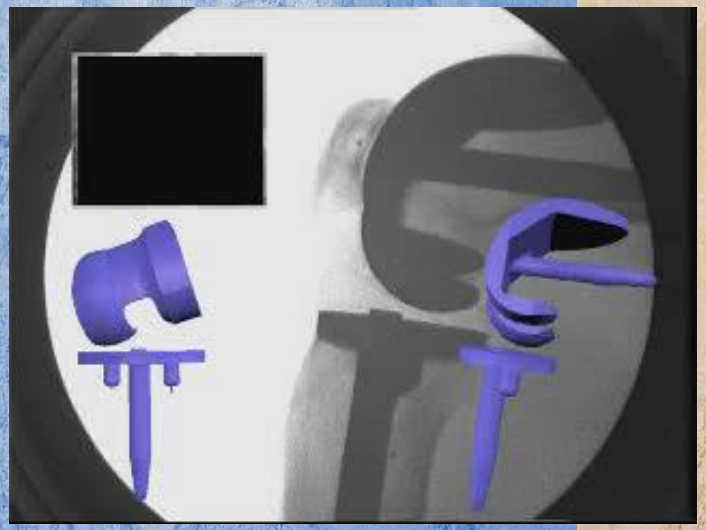
- Functional challenge
- Ligament balancing



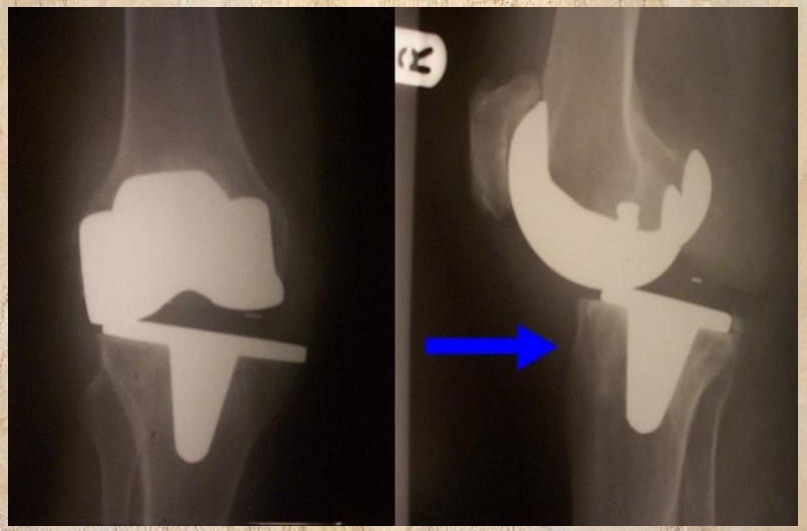


The challenges

- Functional challenge
- Ligament balancing



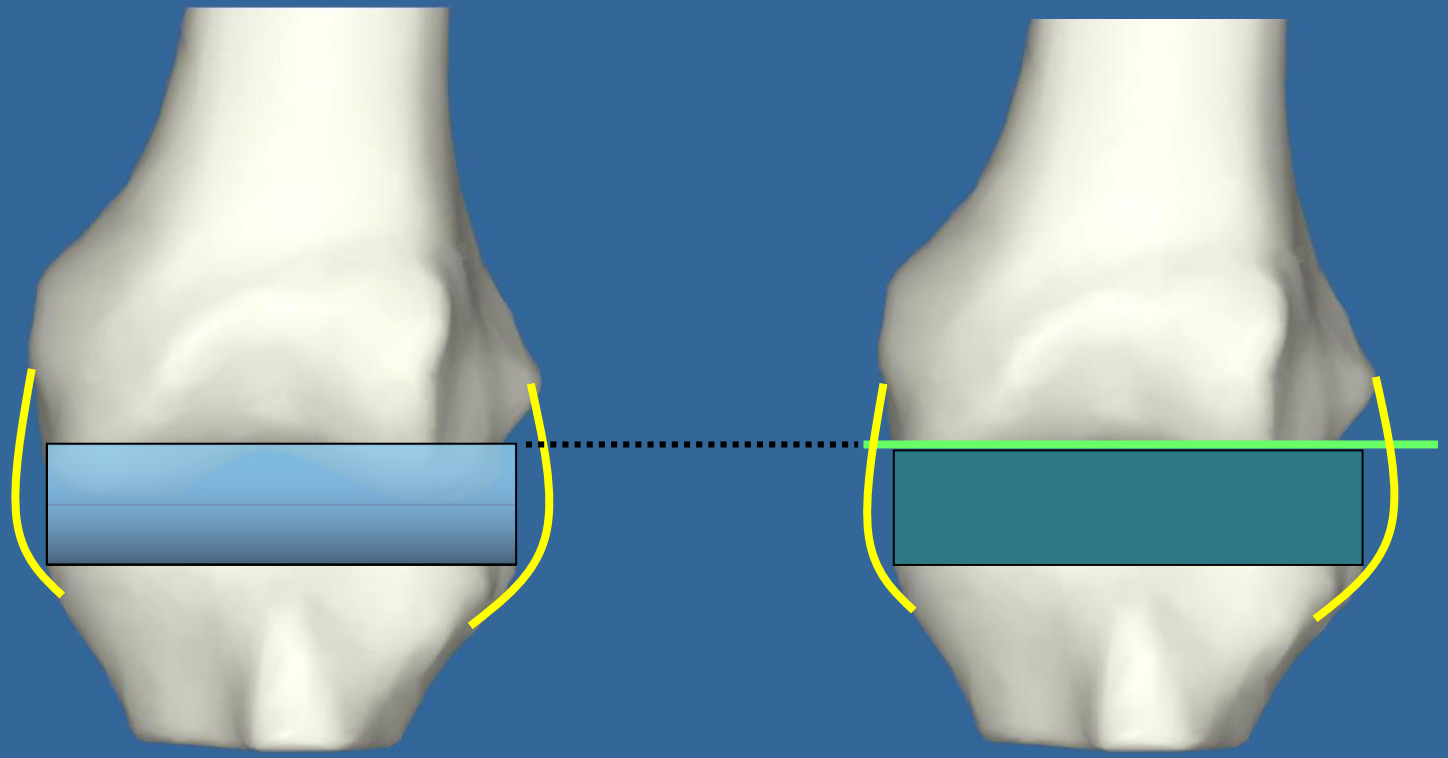
- Lift-off = wear



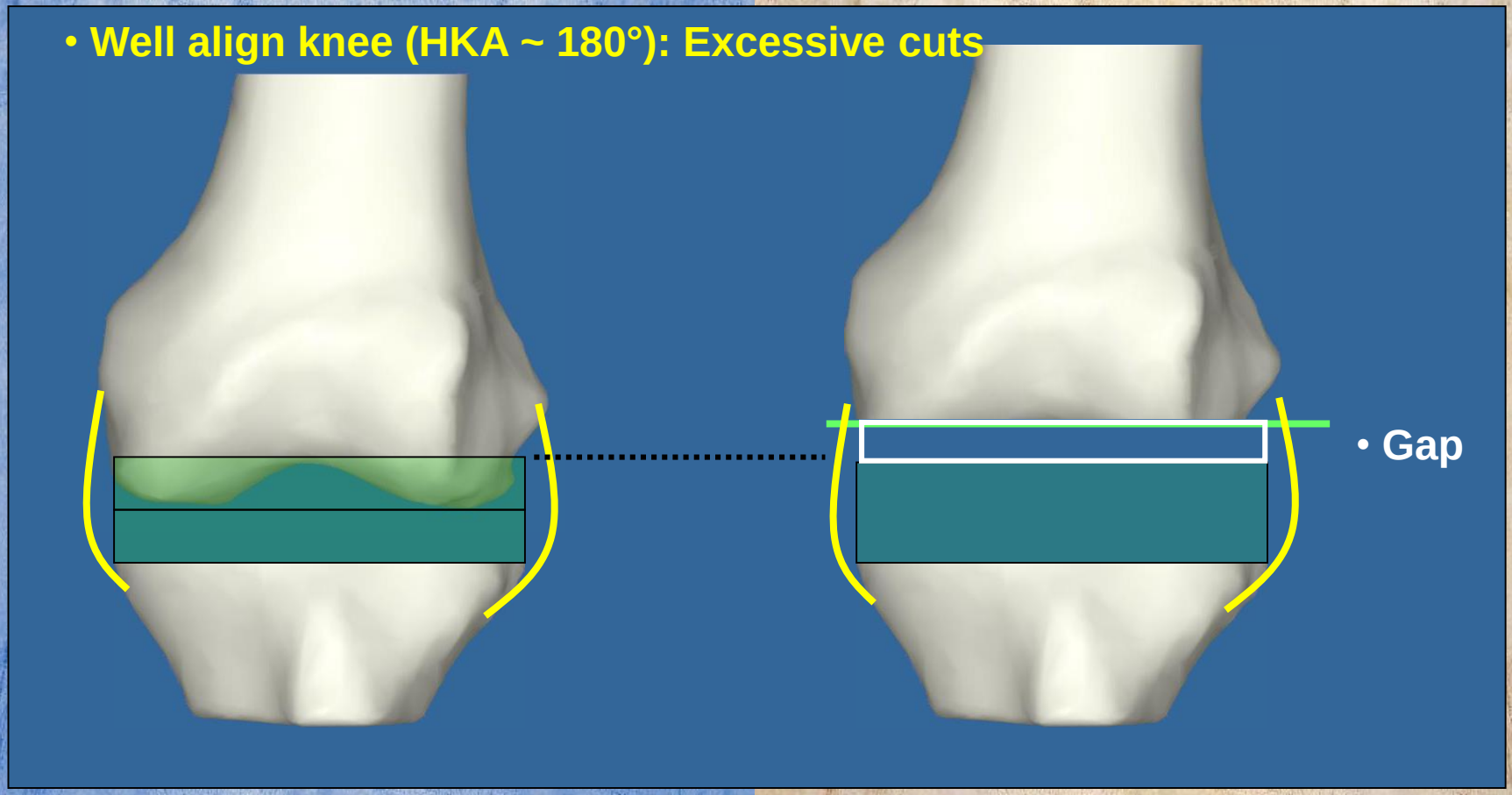
- Instability

- Functional challenge
  - Ligament balancing

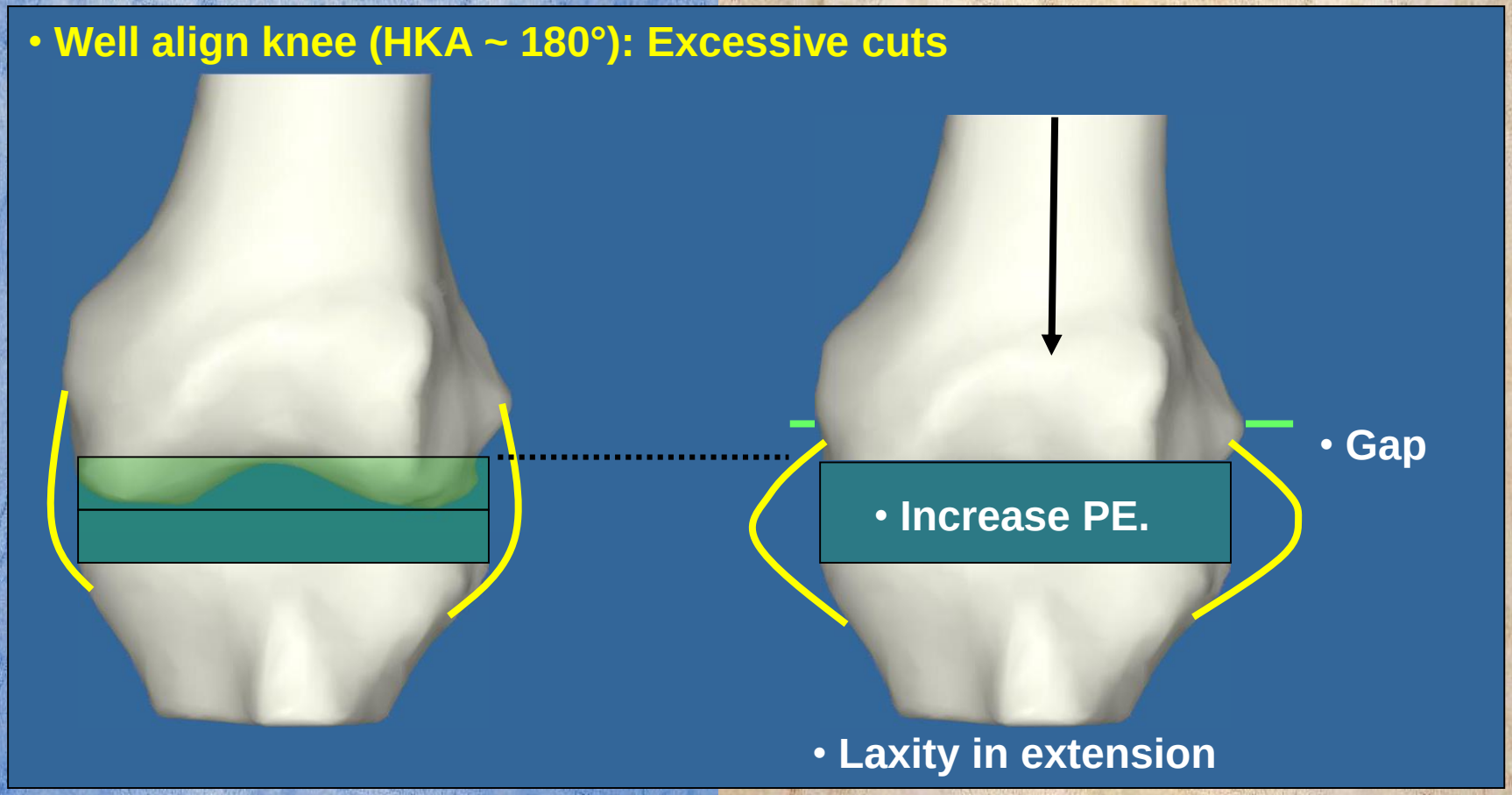
- **Well align knee (HKA ~ 180°): Good cuts**



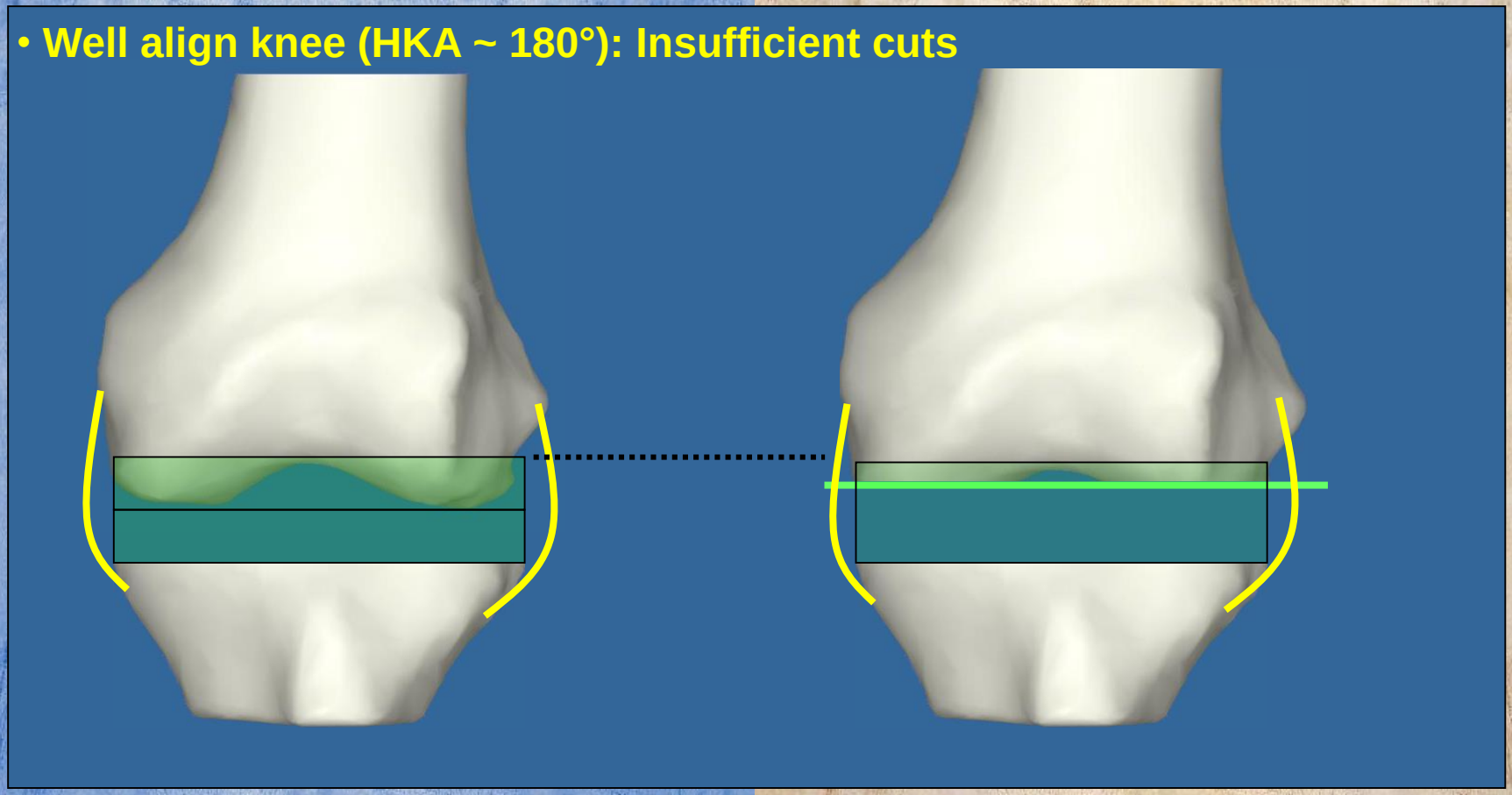
- Functional challenge
  - Ligament balancing



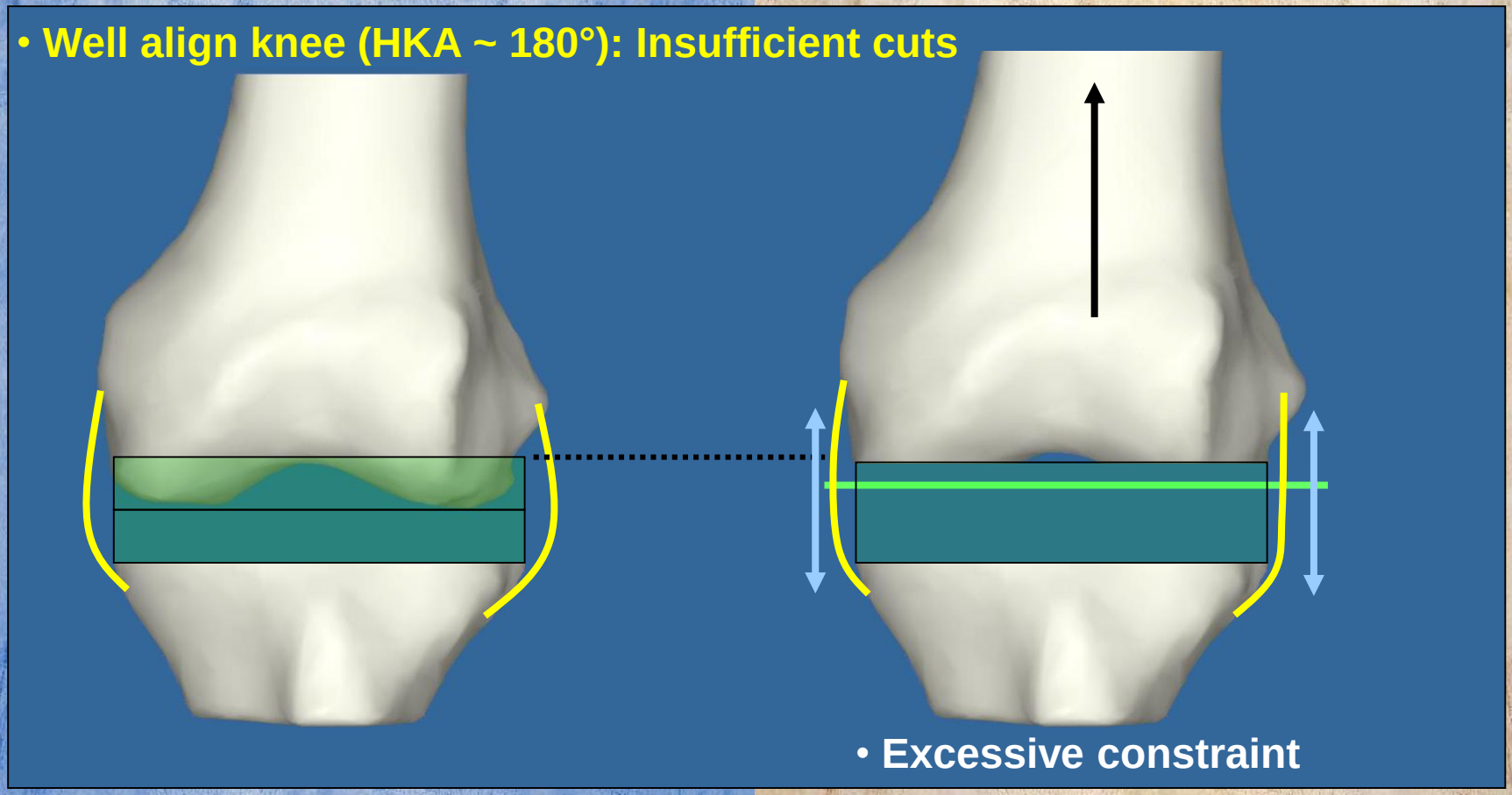
- Functional challenge
  - Ligament balancing



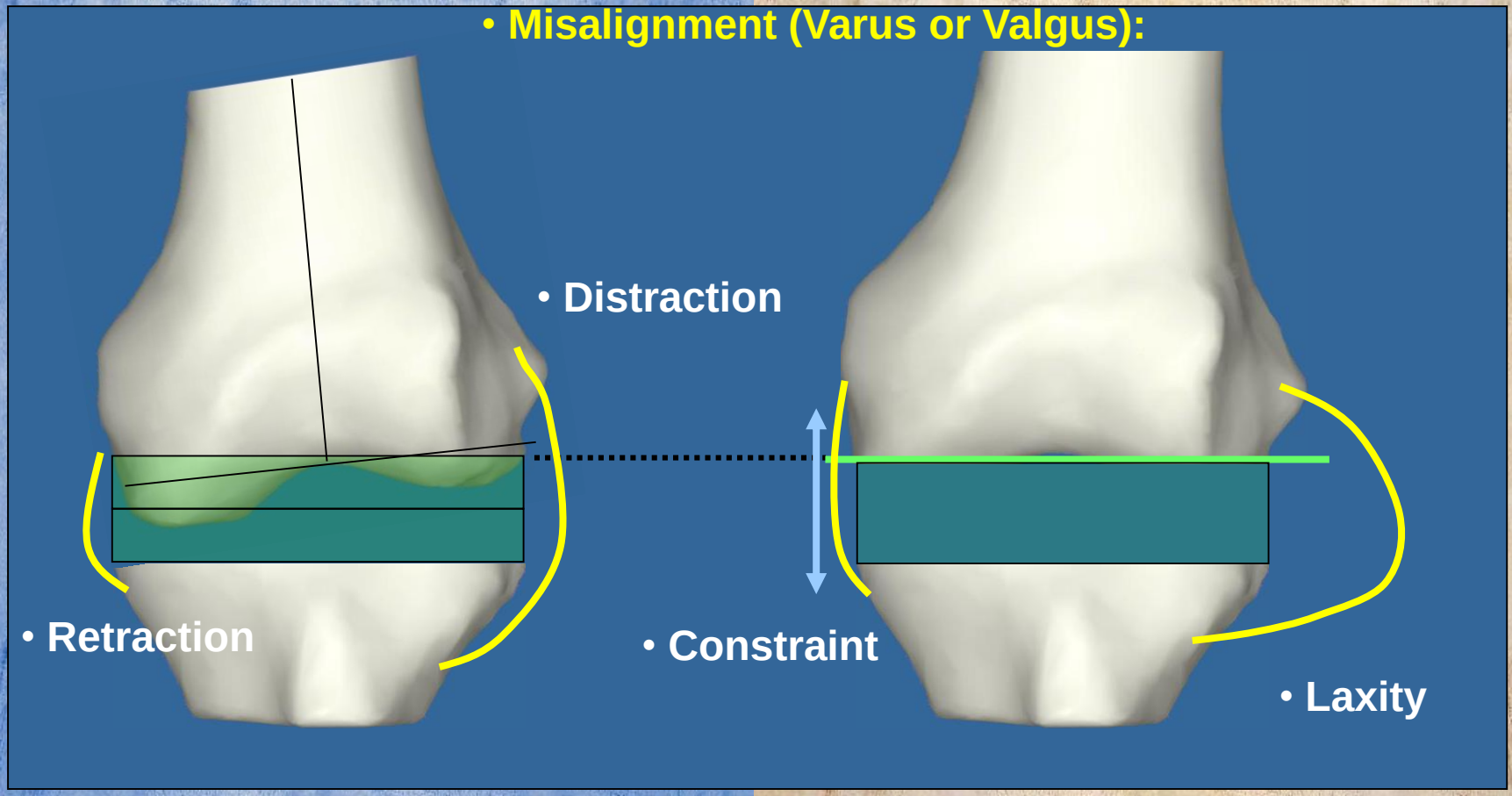
- Functional challenge
  - Ligament balancing



- Functional challenge
  - Ligament balancing

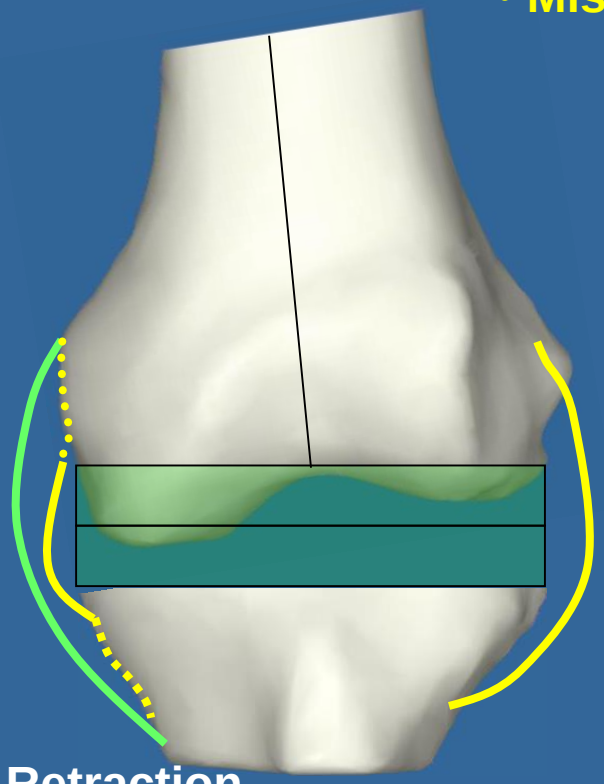


- Functional challenge
  - Ligament balancing

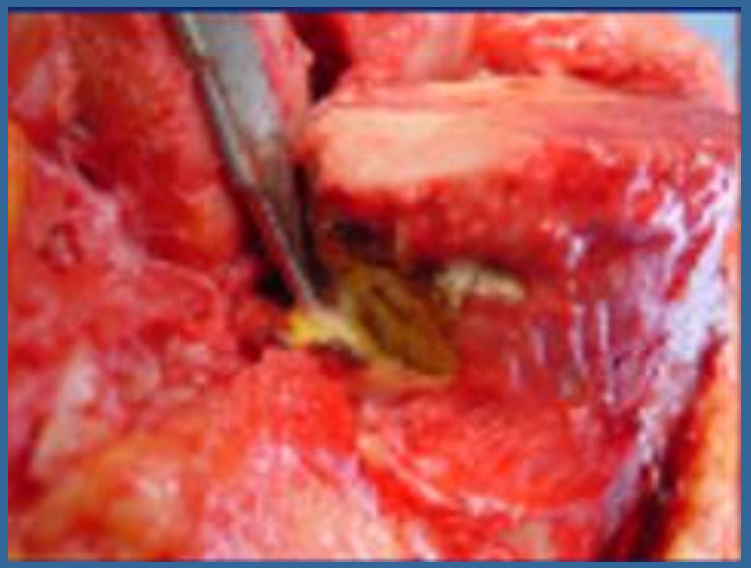


- Functional challenge
  - Ligament balancing

• **Misalignment (Varus or Valgus):**

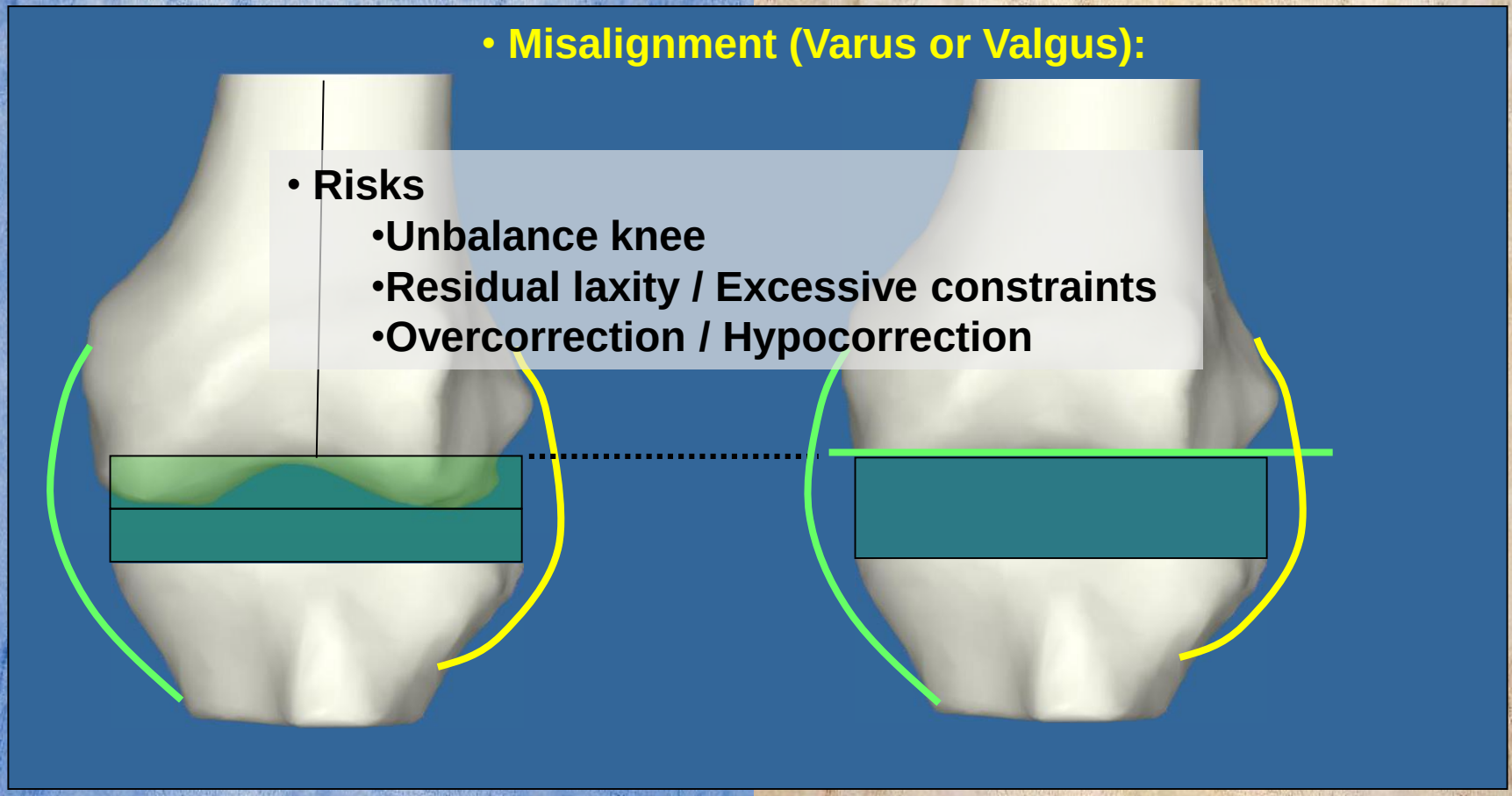


• **Retraction**



• **Release**

- Functional challenge
  - Ligament balancing



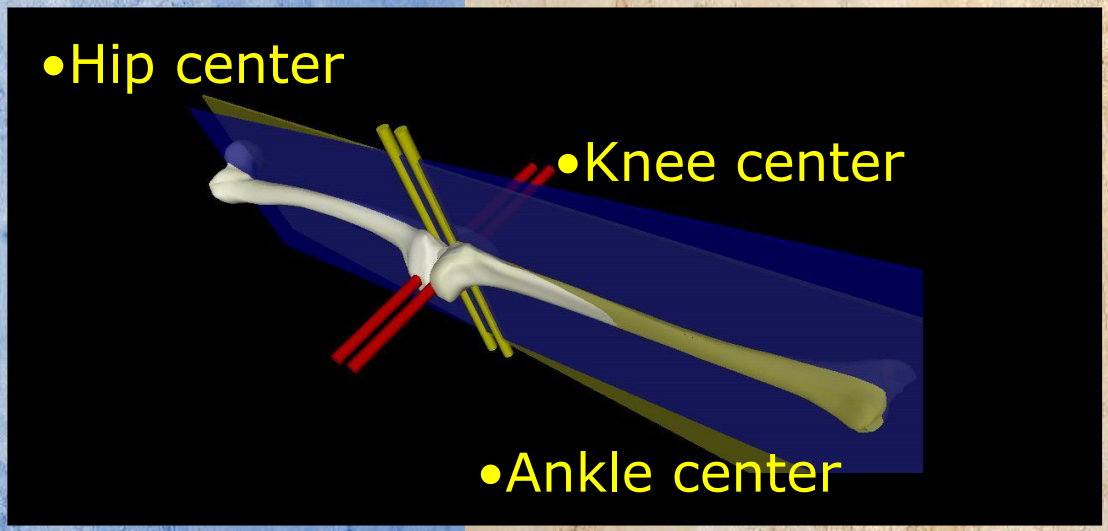
Application : TKA

The solutions

The solutions

Build a **SPECIFIC** model of the patient under surgery

- Build the specific GEOMETRY of this patient
  - Align the prosthesis with respect to the patient axes



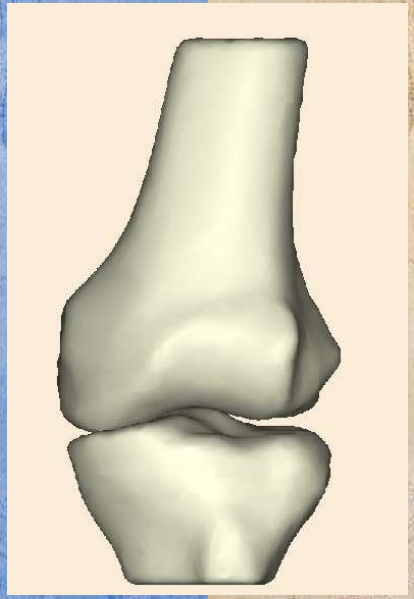
- Localize **in 3D** the joint centers
- Build reference planes

The solutions

Build a **SPECIFIC** model of the patient under surgery

- Build the specific MORPHOLOGY of this patient

Local adjustment to the bones
Ligament balance can only be made with local data



The solutions

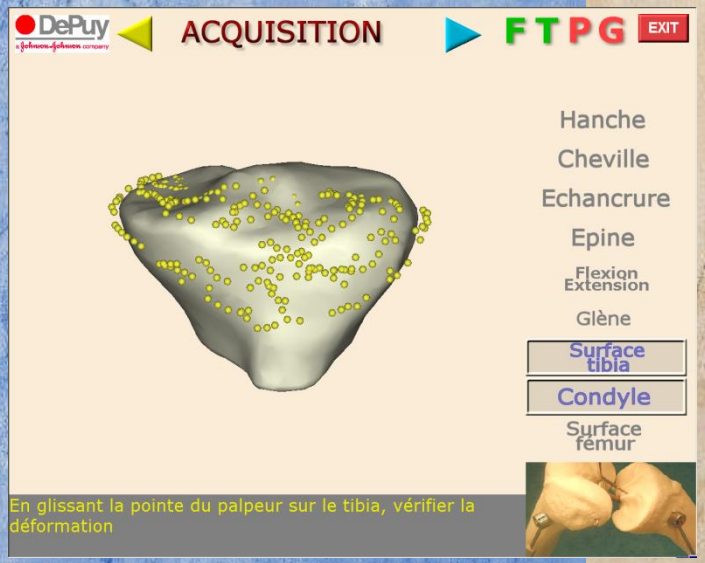
Pros and Cons

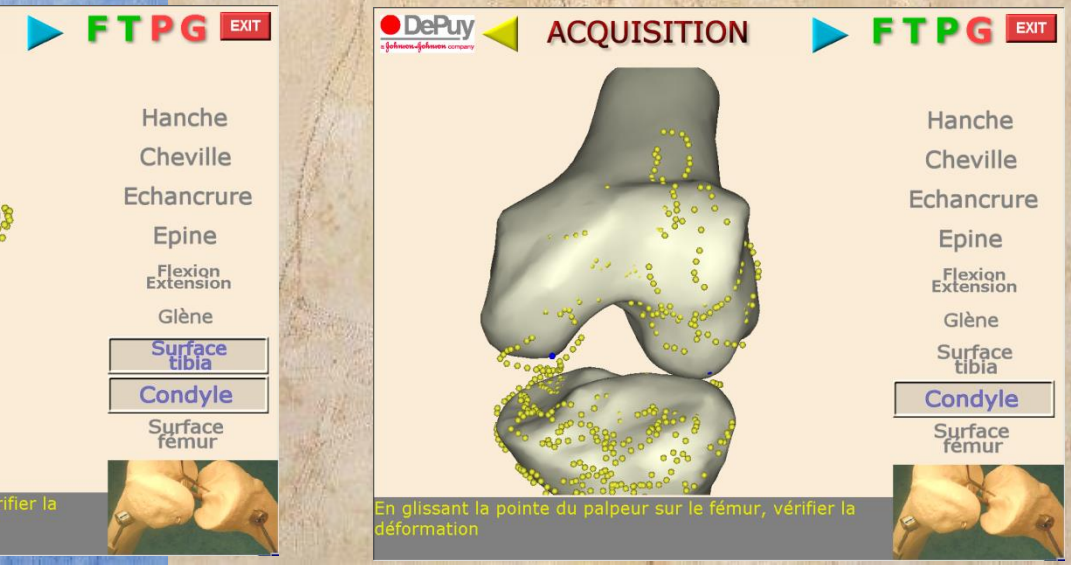
- CT based approach
  - Pre-operative planning
  - Cost – Radio protection issues
  - Archiving and communication of images : PACS
  - No increasing time for acquisition and planning
- CT including Hip – Knee - Ankle
- Setup time
- Intra-operative registration (time consuming/accuracy issues)

The solutions

Pros and Cons

- **Non image based system**
  - Simple
  - Low cost – No radiation
  - Integration of intra-operative data
  - No registration issue
  - Increase the operative time





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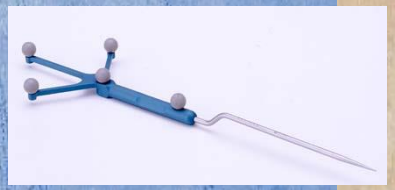
Non image based

Perception

- **No pre-operative images**
- Build a specific model of the patient : Acquisition

- Geometric data
  - Axes
    - Hip center
    - Knee center
    - Ankle center



- Morphologic data
  - Bone surfaces

- **Digitization of points with a 3D probe**

Perception

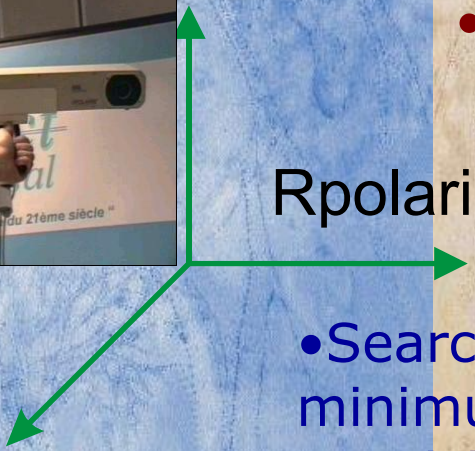
Hip center

- **None image based approach**

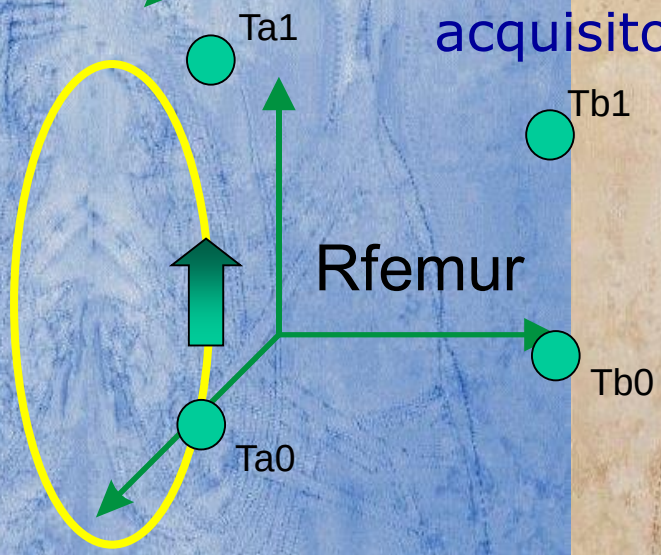
Perception

Hip center

- **None image based approach**
  - **-Kinematics approach**



- Search of a point C of R_{fem} with the minimum trajectory during the acquisiton motion



Perception

Knee center

- **None image based approach**

Rpolaris

-Morphologic approach

Perception

Ankle center

- **None image based approach**
- Percutaneous digitization of points

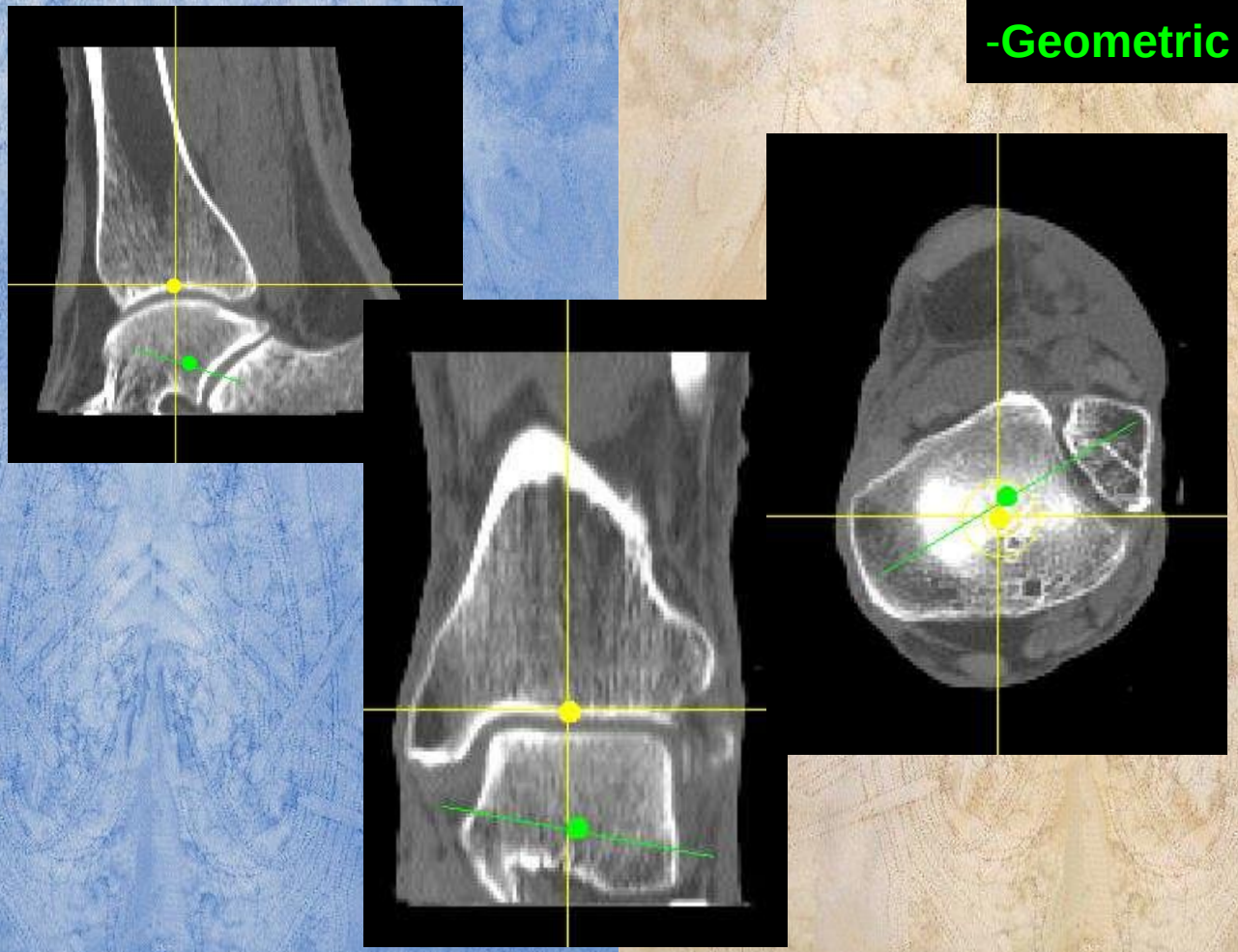
-Geometric approach

Perception

Ankle center

- None image based approach

-Geometric approach

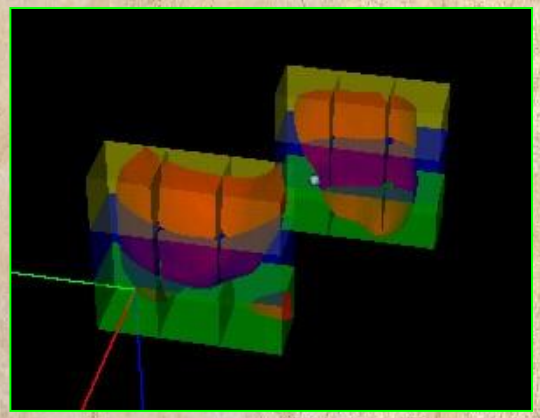


- Error
- Slope
- Varus
- Valgus

Perception

-Geometric approach

Ankle center

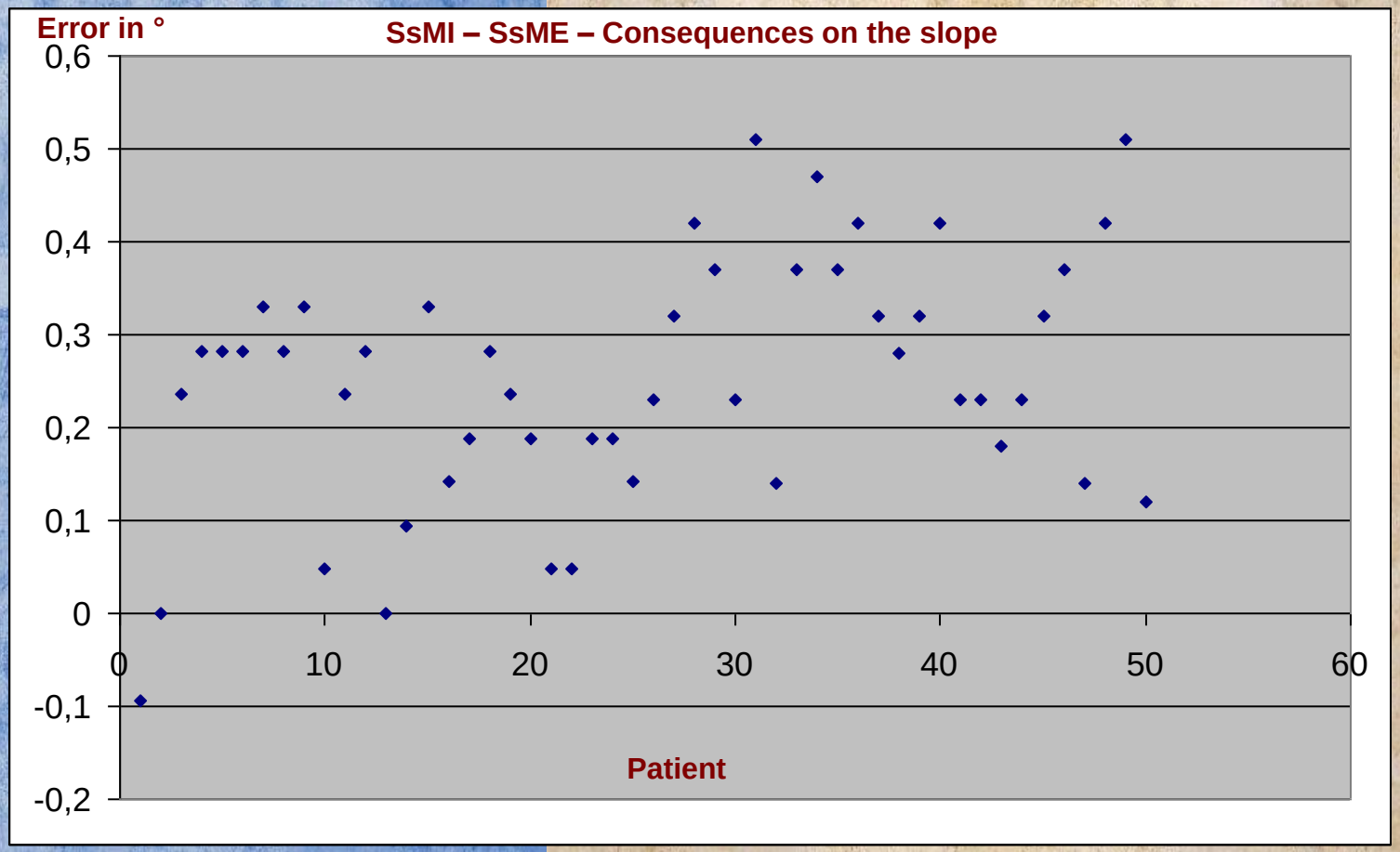


E. STINDEL, et Al., The center of the ankle in ct less based navigation system.
What is really important to detect?
CAOS Santa fee 19-22 Juin 2002.

Perception

Ankle center

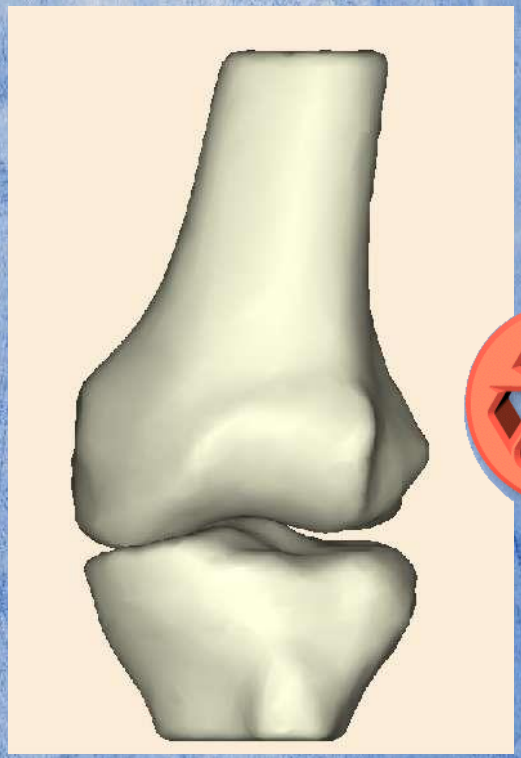
- **None image based approach**

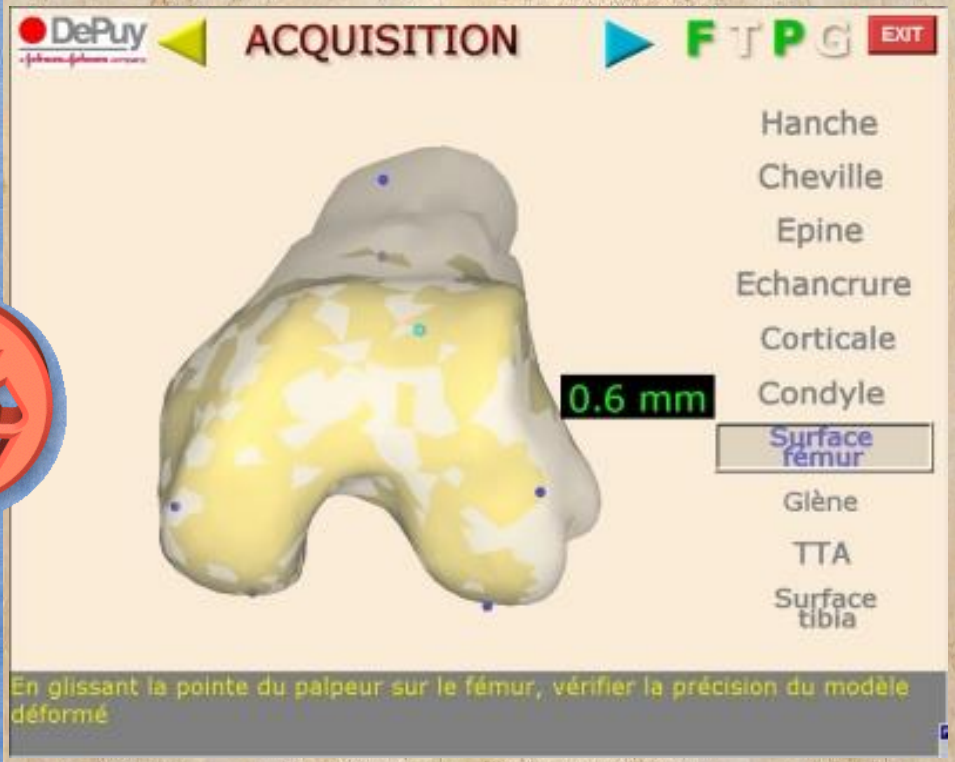


Perception

Morphology

- **Femoral and tibial shape : Bone morphing**
- Use of statistical deformable models

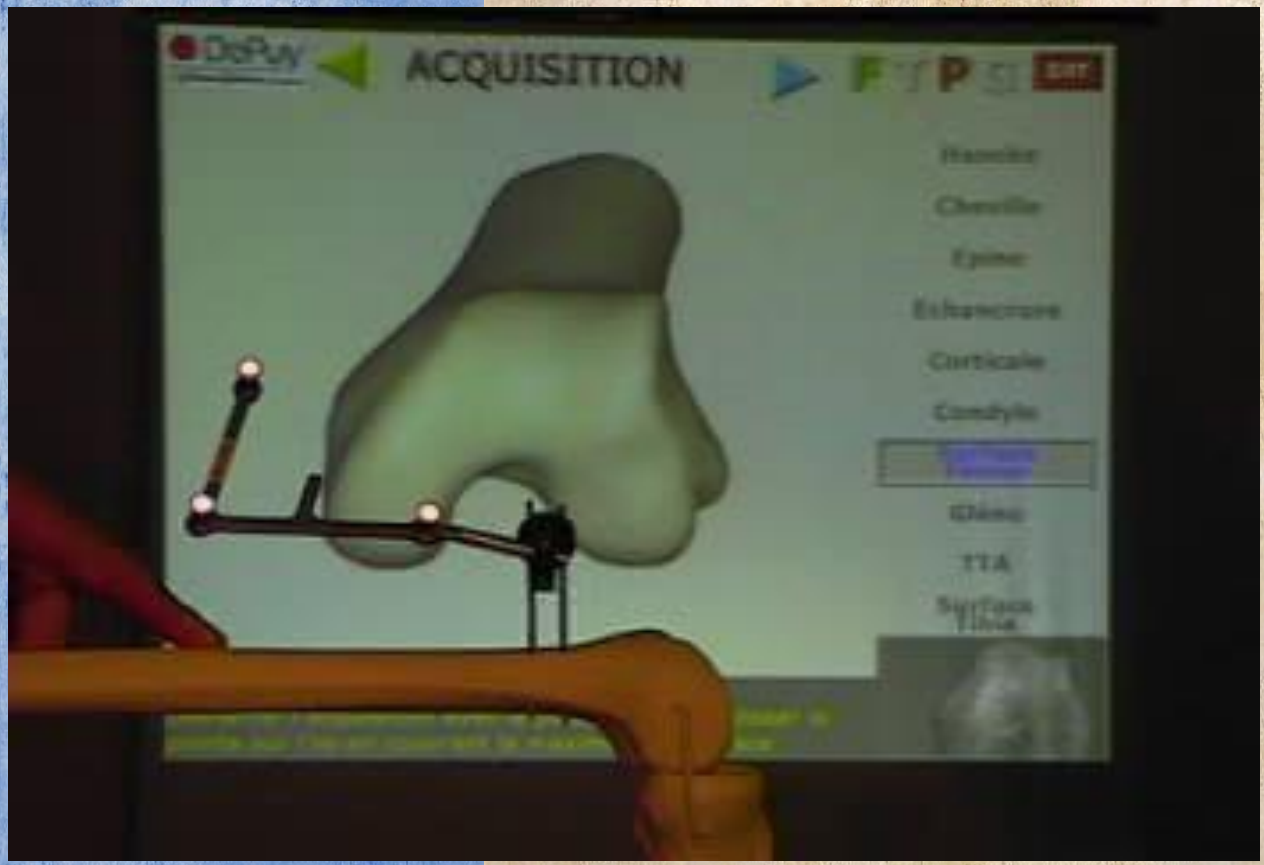




Perception

Morphology

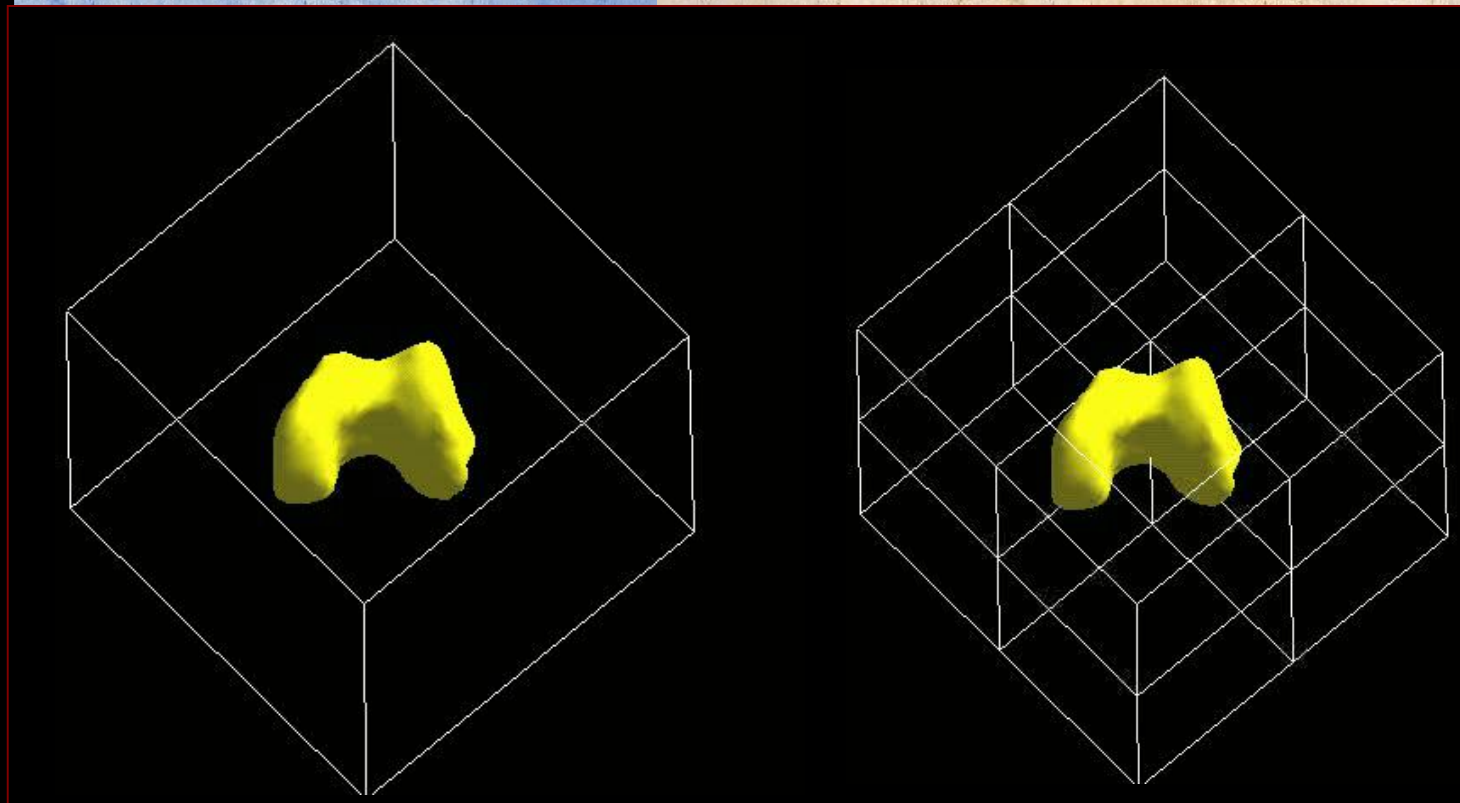
- **Femoral shape : Bone morphing**
- Acquisition – Deformation – Quality control



Perception

Morphology

- **Femoral shape : Bone morphing**
- Quadtree (Lavallée) : hierarchical division of the 3D volume to apply global and local deformation



| Computer Assisted Orthopaedic Surgery |

Introduction

History

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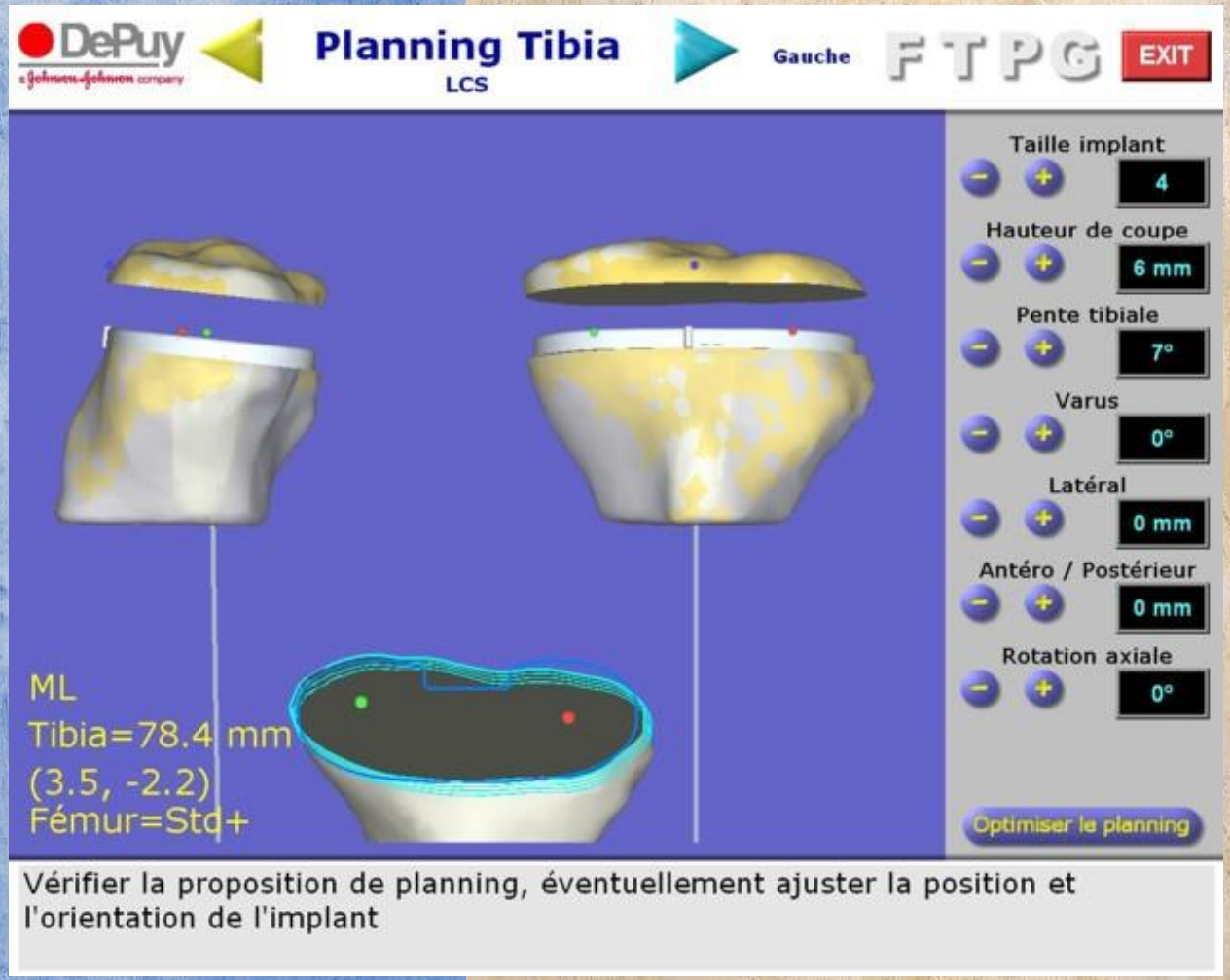
Non image based

Decision

- **Level 1 : based on morphologic data**



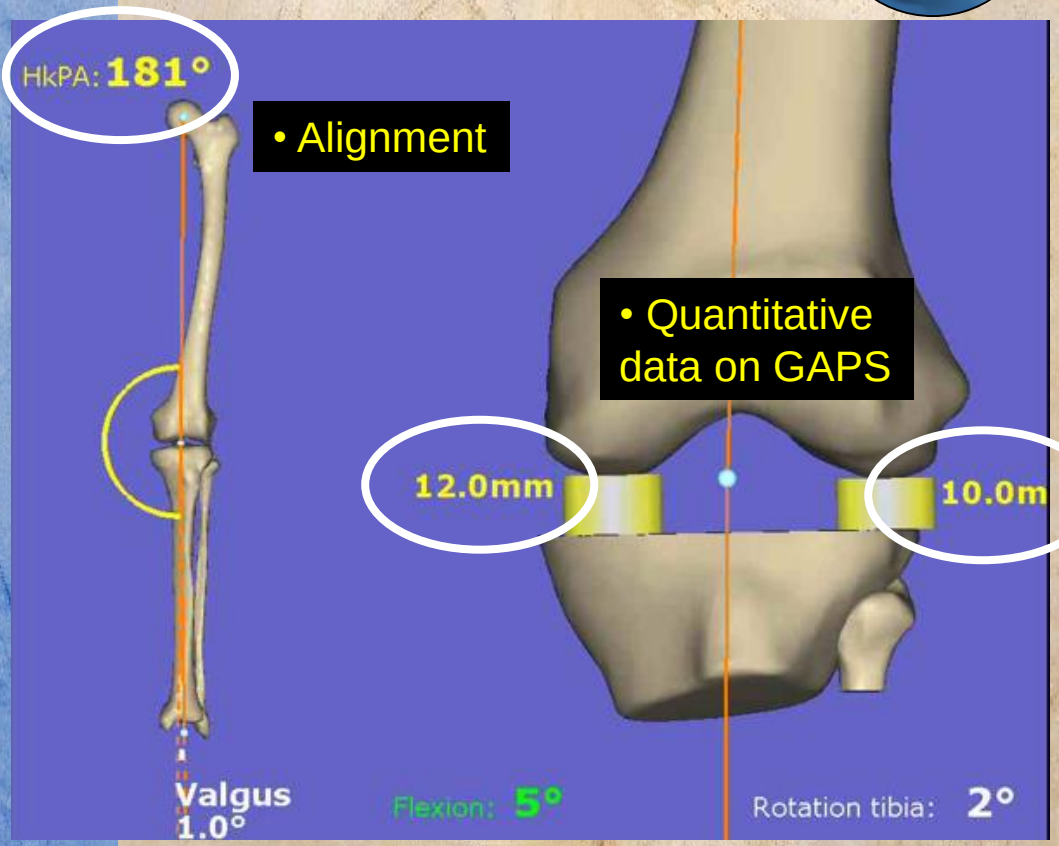
Decision

- **Level 2 : based on dynamic per-operative data**

Sensor

Software

Spacer

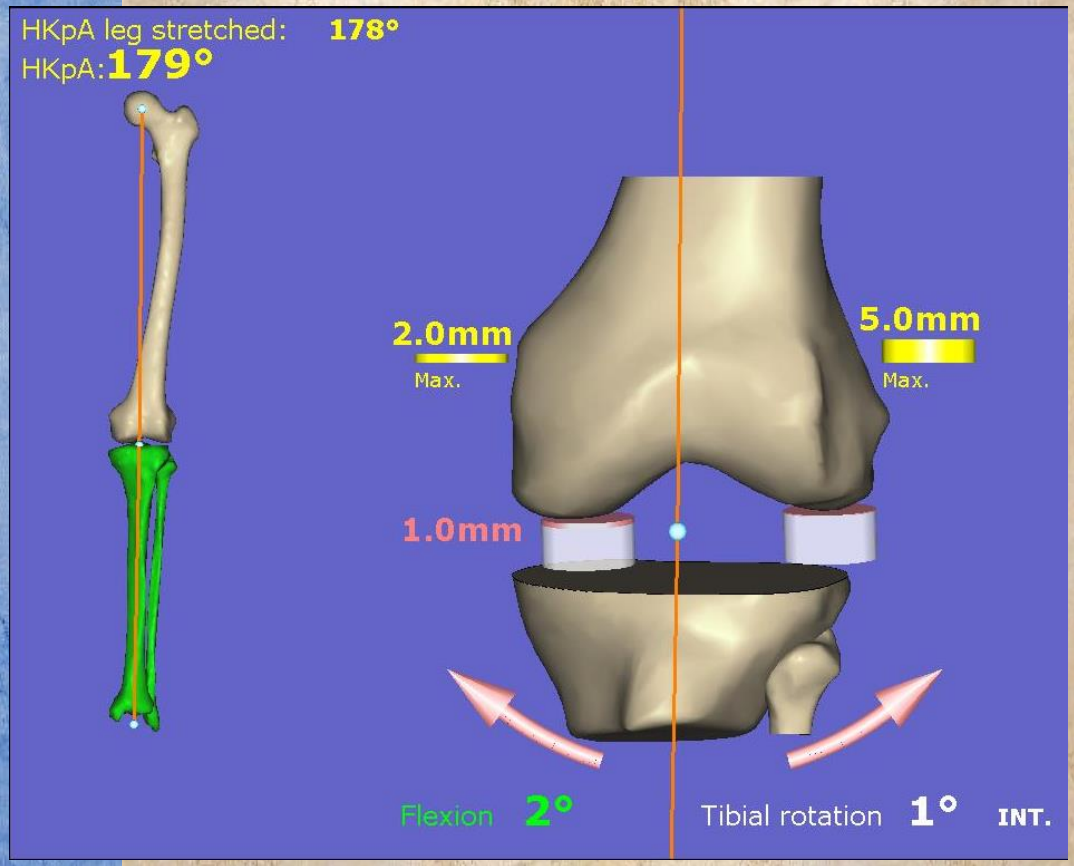


Decision

- **Level 2 : based on dynamic per-operative data**

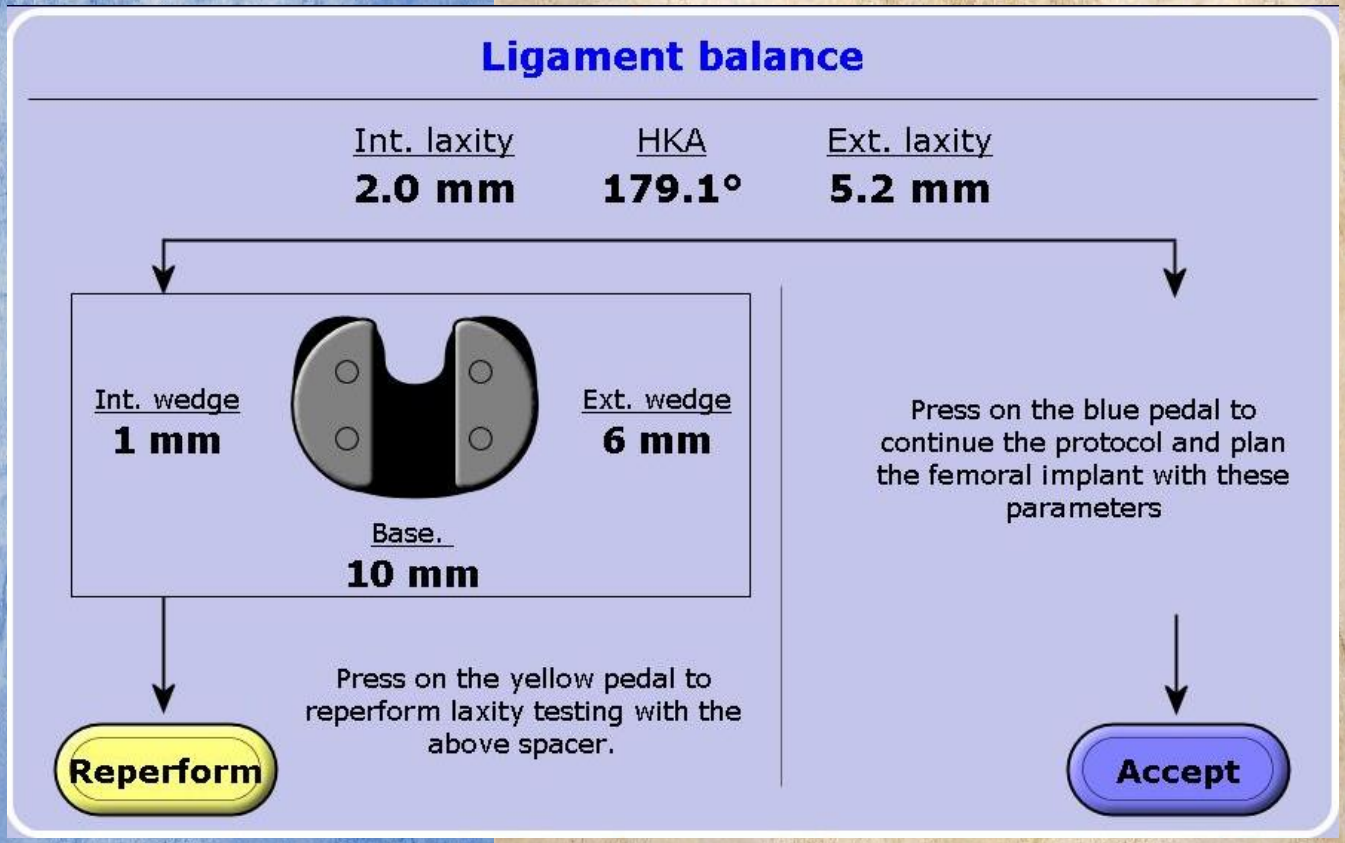
- **Test residual laxity**
  - **Varus Max.**
  - **Valgus Max.**

- **If the residual laxity is over a threshold**



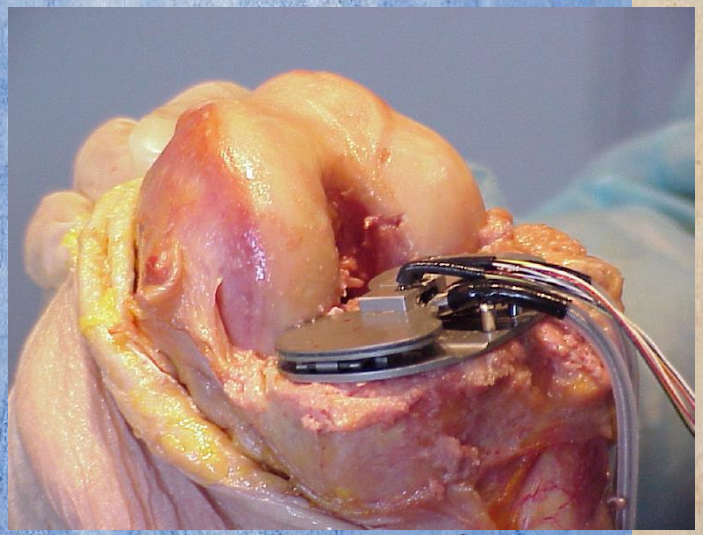
Decision

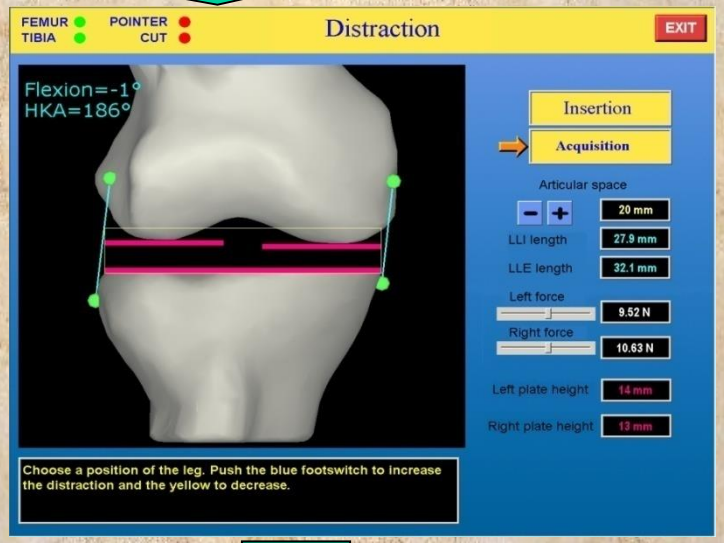
- **Level 2 : based on dynamic per-operative data**
  - **Loop until the threshold is reached**



Decision

- **Level 2 : based on dynamic per-operative data**
  - **Loop until the threshold is reached**

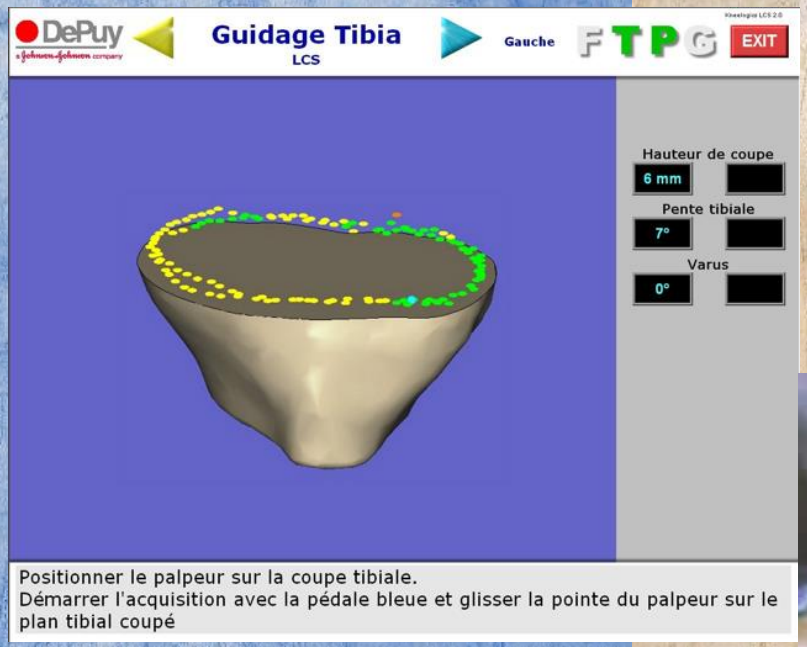


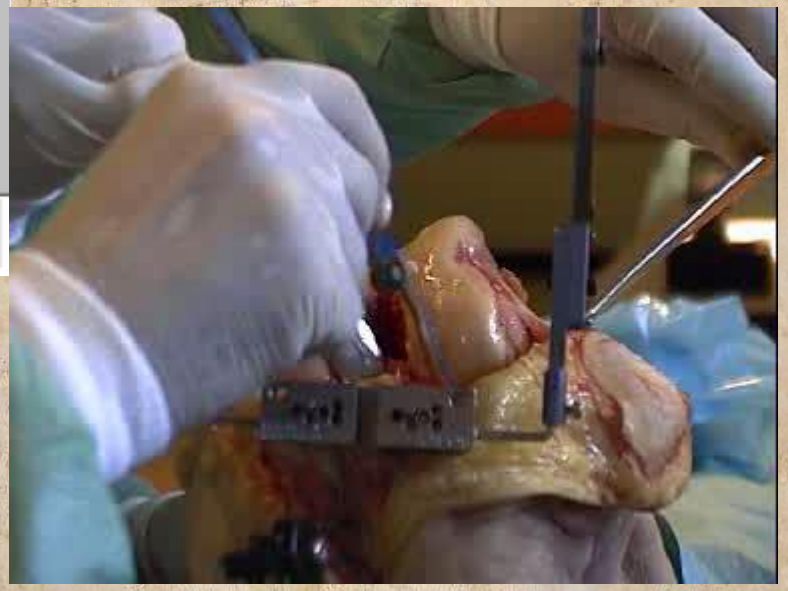


- **Courtesy of Christophe Marmignon and Philippe Cinquin – TIMC - Grenoble**

Decision

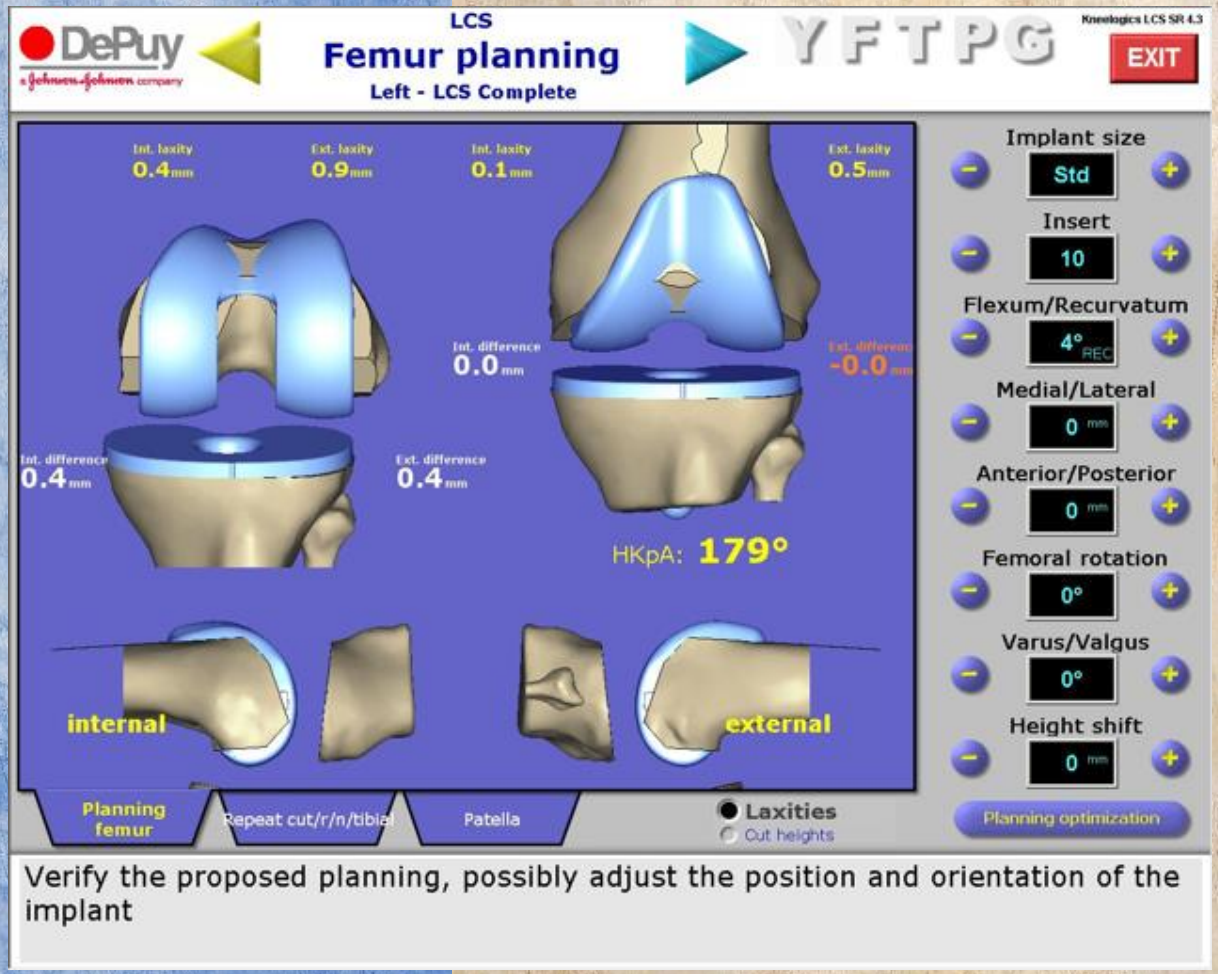
- **Level 3 : Integration of quality control in the decision loop**





Decision

- **Femoral planning**



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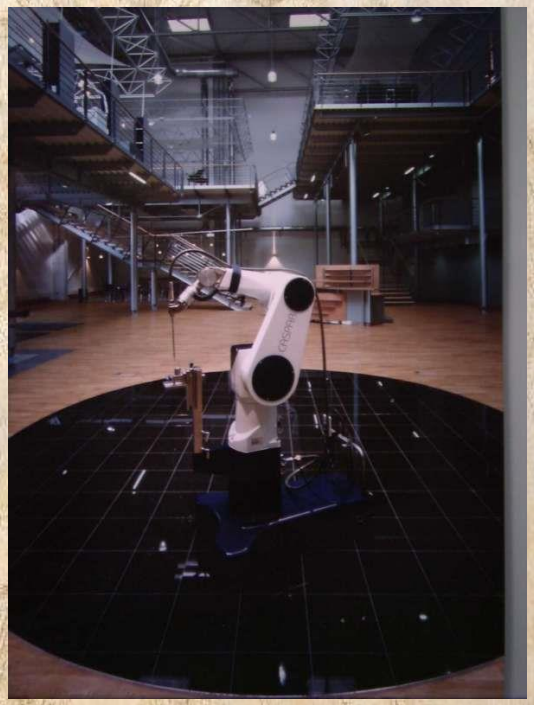
Active system : robots



Passive system : navigation

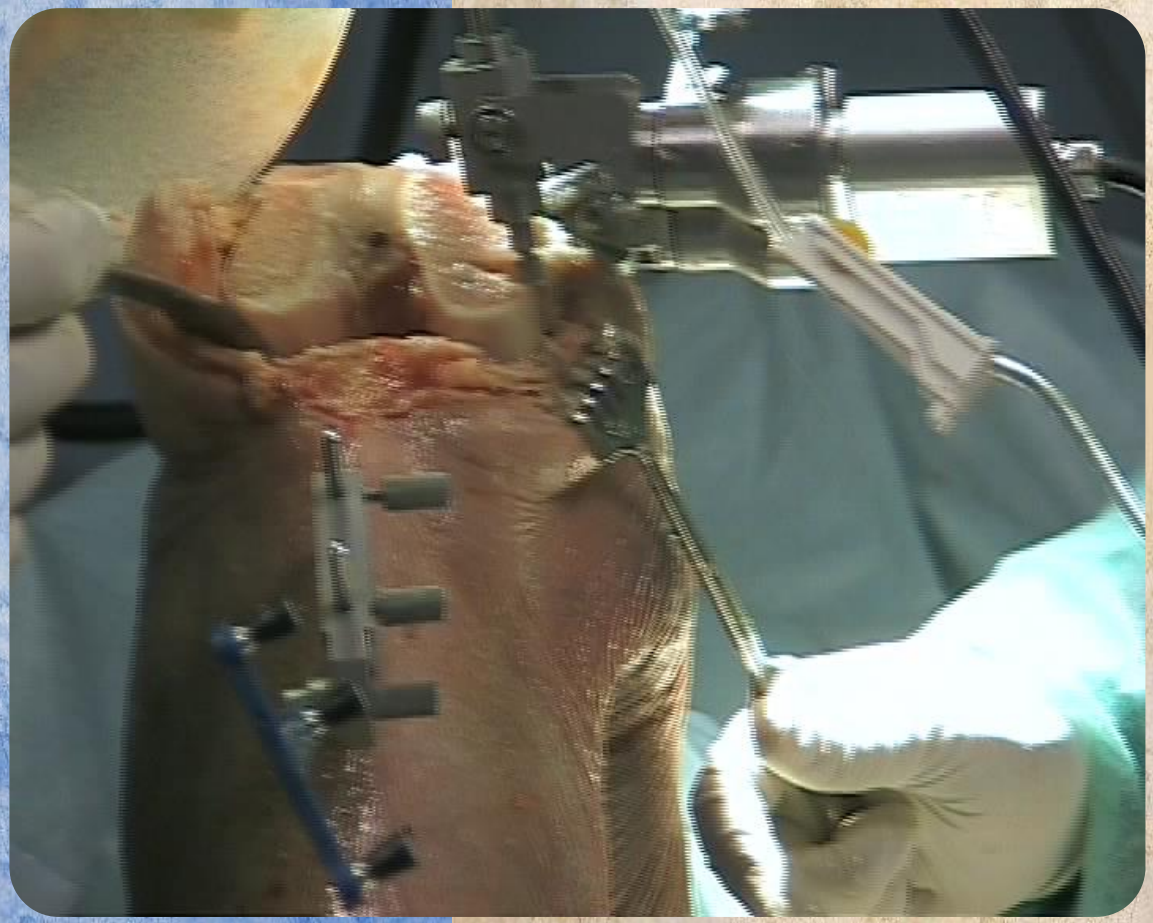
- Freehand
- Tools are localized in the 3D space in real time with respect to the bones

Action

- **Robotized cutting guides**

Action

- **Robotized milling guides**



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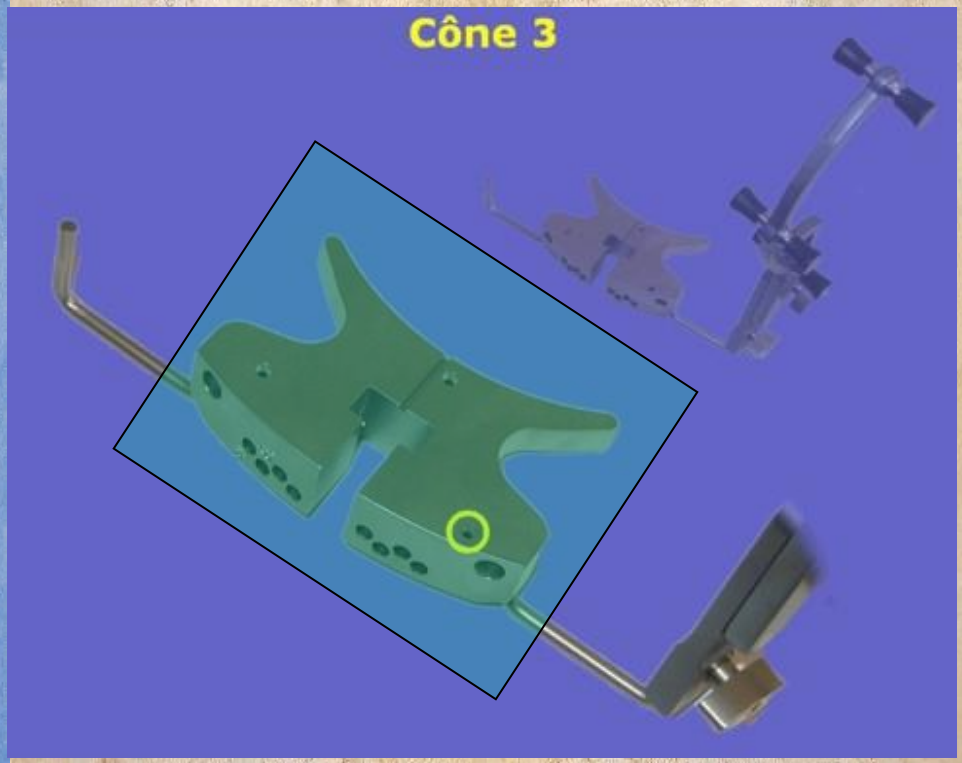
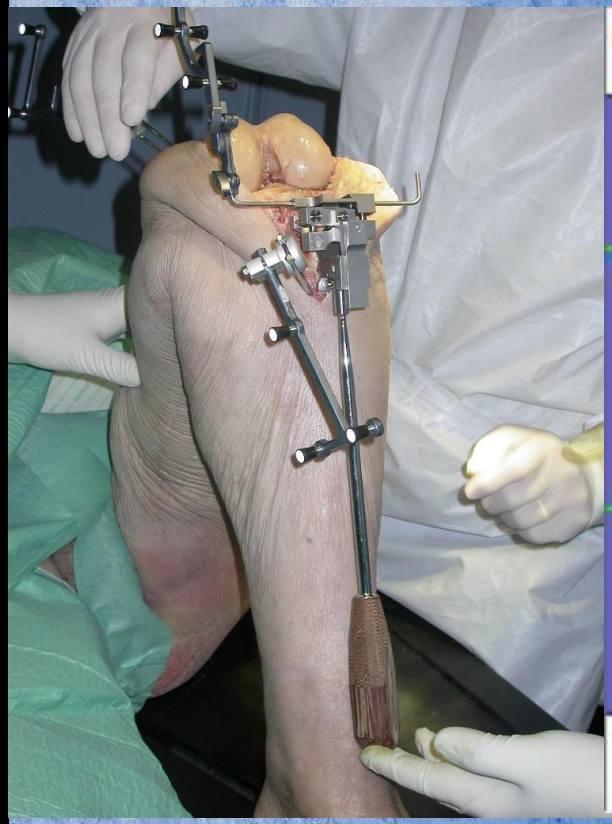
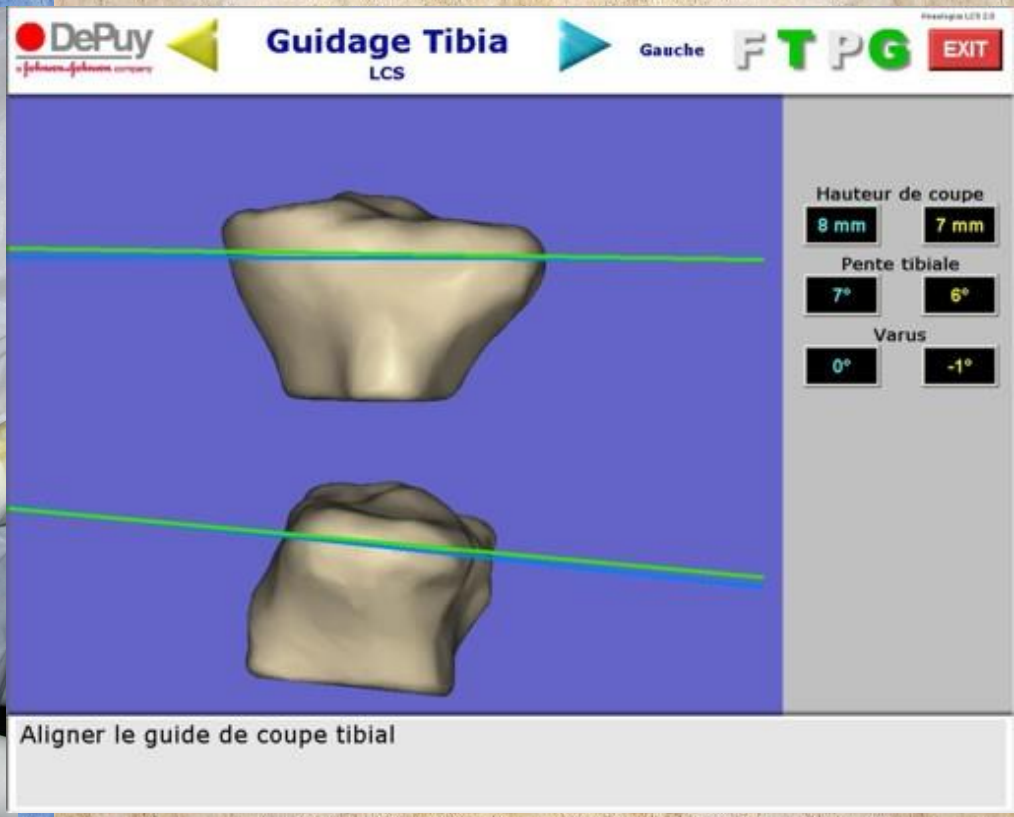
Navigation of cutting guides



Action

Navigation of cutting guides





Application : HTO

7 000 cases / Year / France

- **Integration of bricks**

-Hip center : Same brick

-Knee center : Specific solution

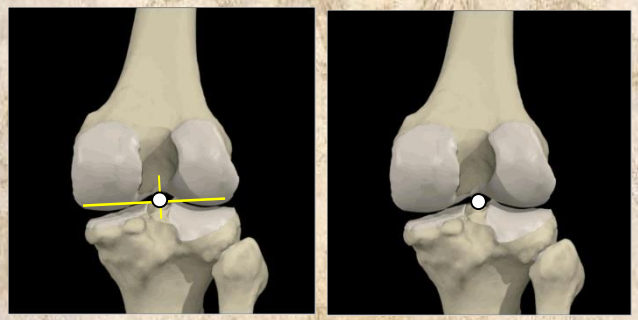
-Ankle center : Same brick

-3D Planning

Computer Assisted Surgical Protocol - CASP

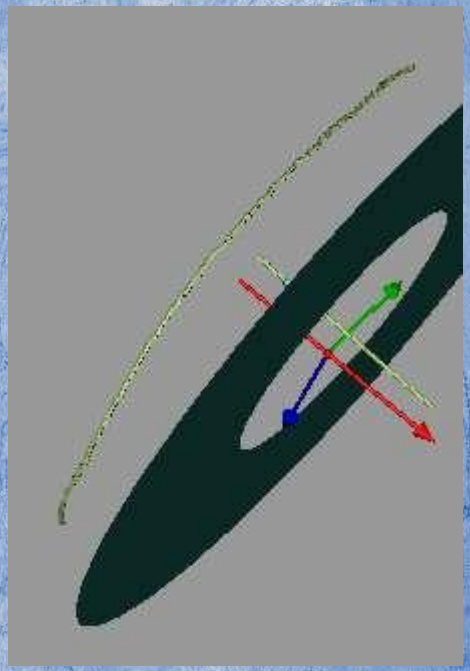
- **Knee center**

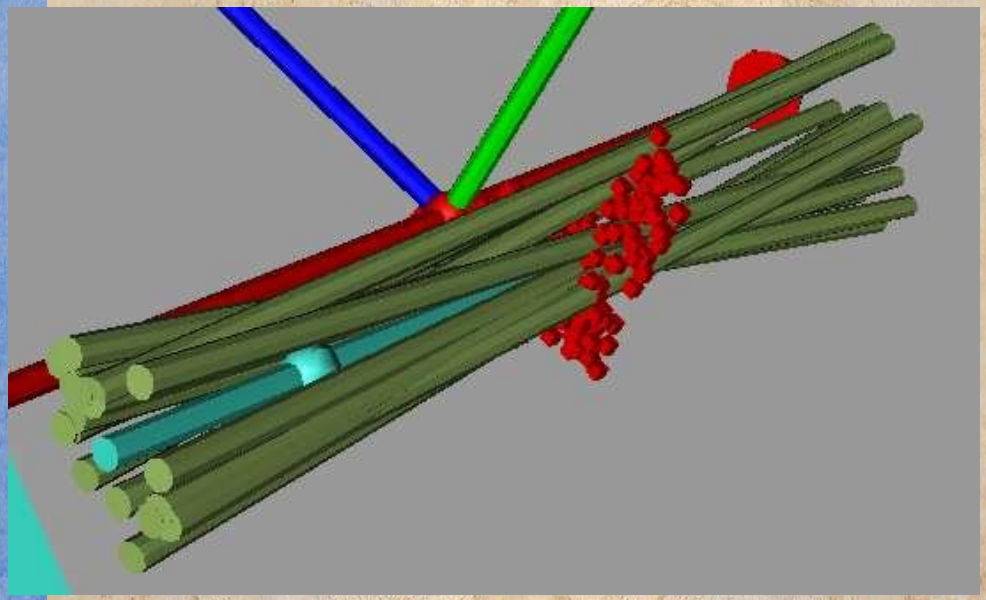
-No access to the joint
-Mixed approach
-Man / Machine synergy



SOMMER, H.J., Determination of first and second order instant screw parameters from landmark trajectories.

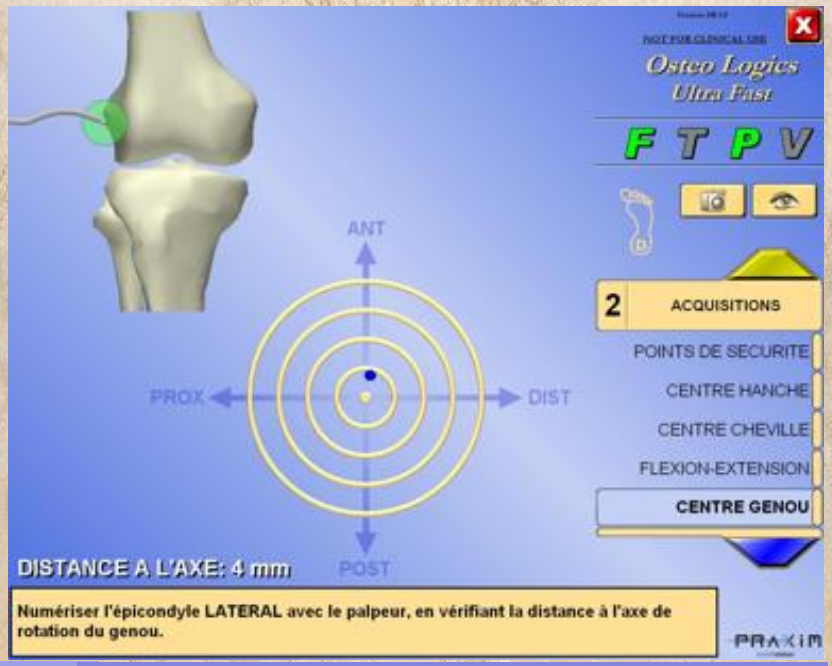
Mechanical Design, 1990: p. 141-142.

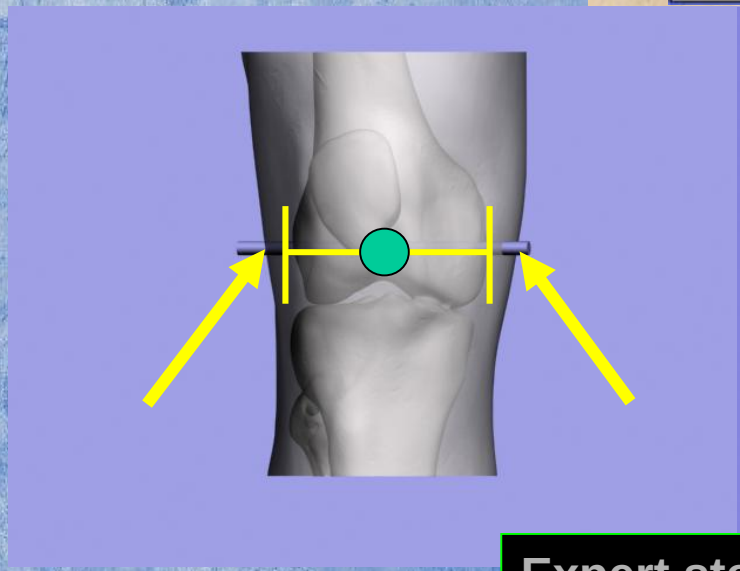




•Knee center

-No access to the joint
-Mixed approach
-Man / Machine synergy





Expert steering

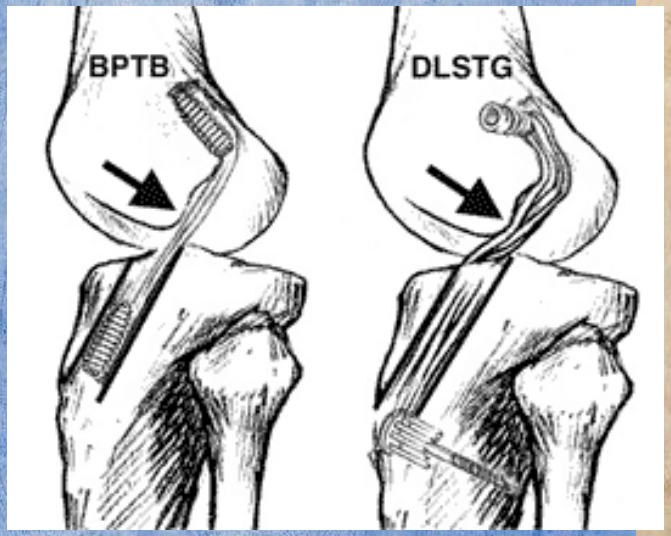
- **In the OR**

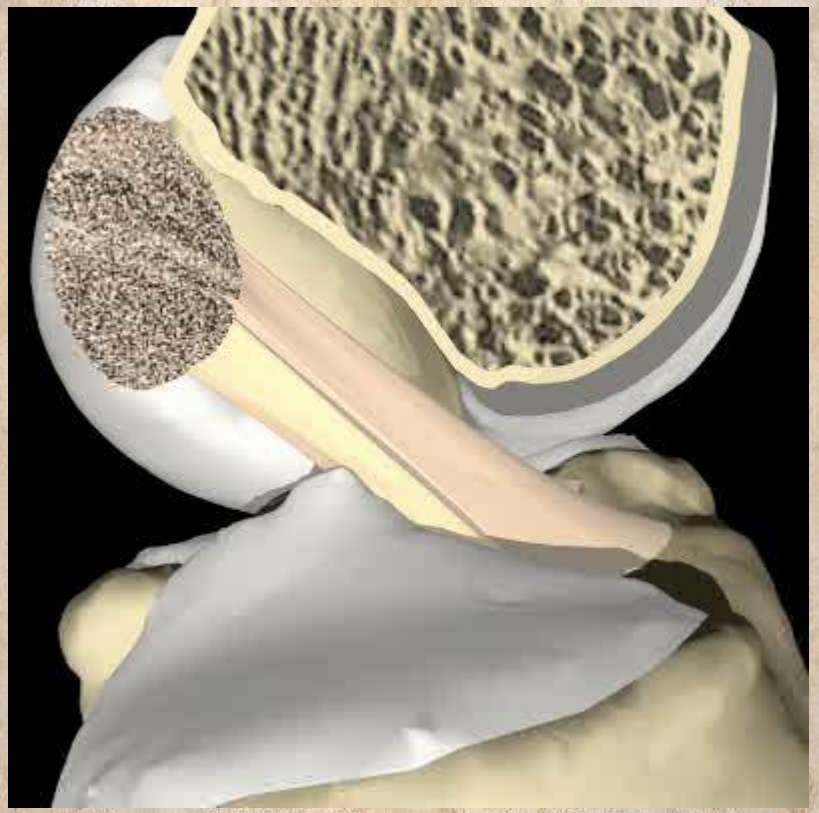
Application : ACL

•Anterior Cruciate Ligament Replacement

•The challenges

- •Isometry
- •Avoid impingement

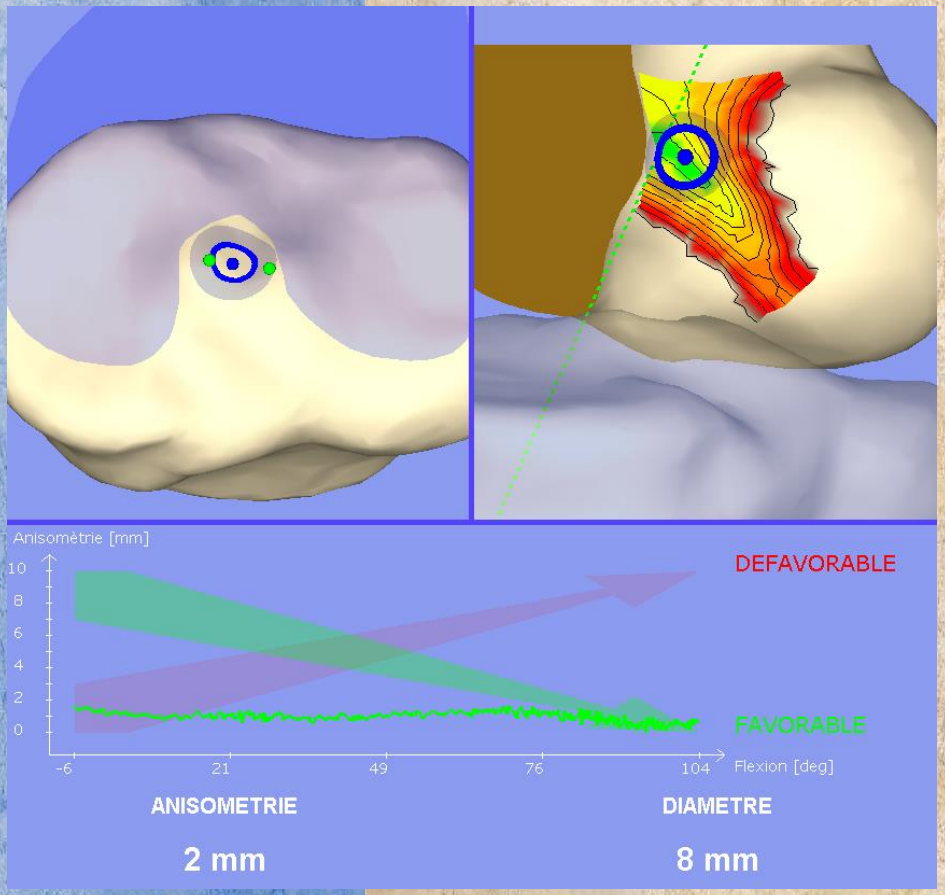




•Anterior Cruciate Ligament Replacement

•Planning

- Projection of the tibial point / Femoral notch projection
- Compute the anisometry map

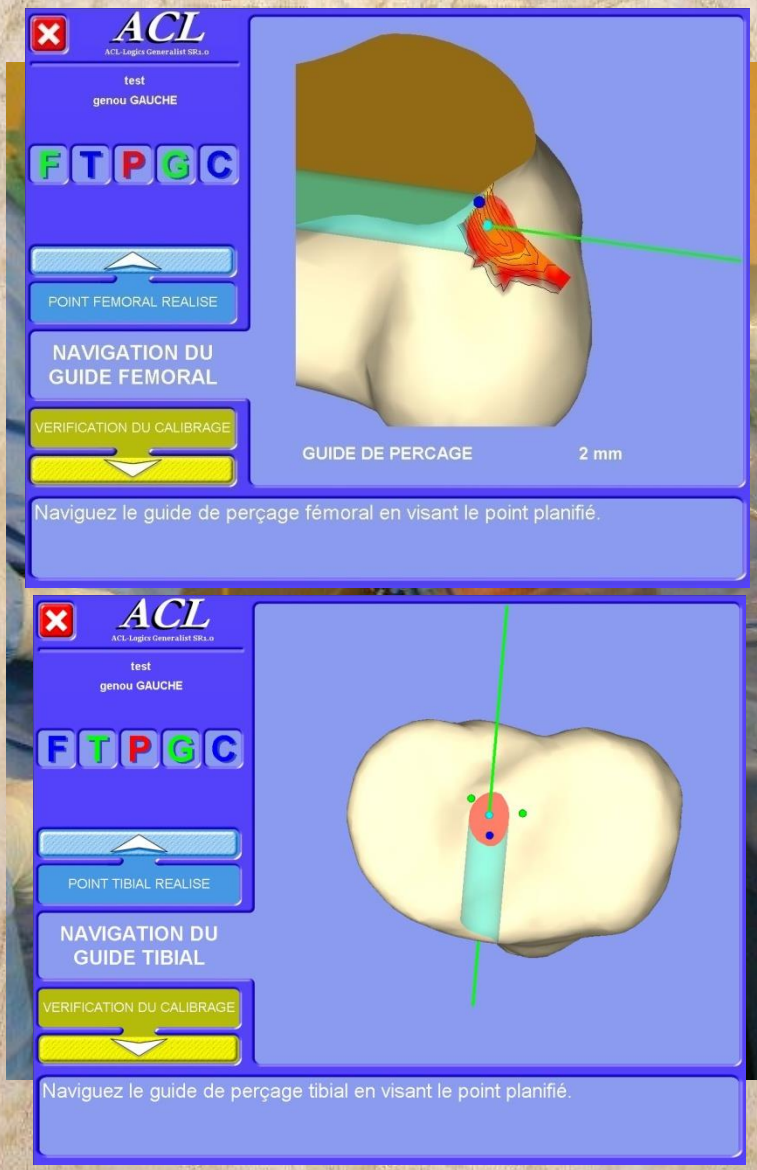


•For a specific tibial point choose the best location of the femoral point

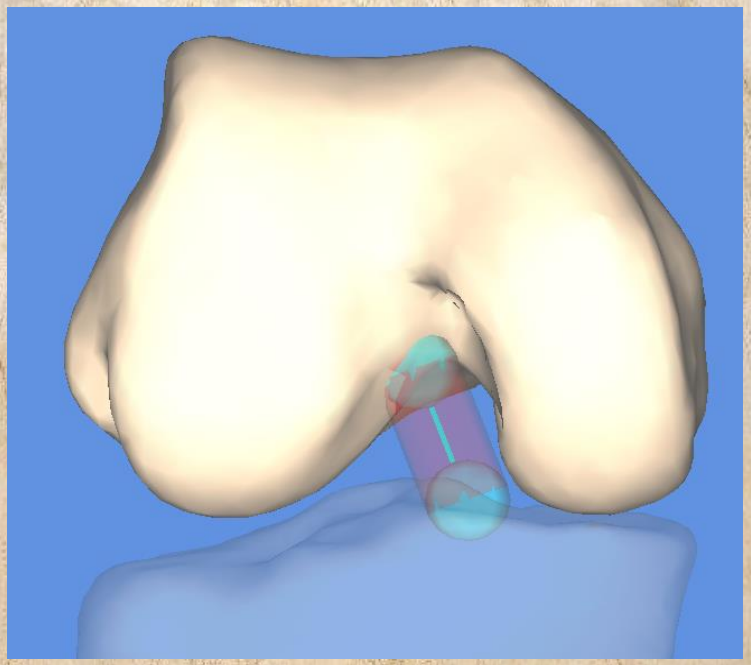
•Anterior Cruciate Ligament Replacement

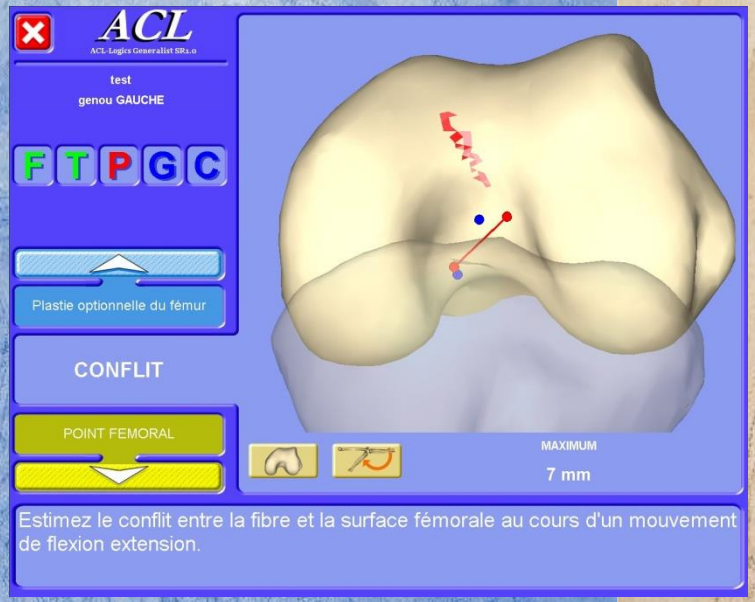
•Action

- Take the usual guide
- Attache a rigid body
- Perform the calibration
- Drill the tunnels with the help of the GUI



- **Anterior Cruciate Ligament Replacement**
  - **Impingement**





- Digitized the anterior fiber of the graft

Conclusion

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