

Computer Assisted Orthopaedic Surgery

Neurosurgery

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

Frame based Stereotaxy : Clarke et Horsley - 1806

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

Computer Assisted Orthopaedic Surgery

1990 1995 2000

Spine Surgery

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

Pedicular screwing

05/22/98
04:59:56

59

4.69 mR
1.07 kV

OEC

Computer Assisted Orthopaedic Surgery

1990
1995
2000

Robots for Hip

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

First generation : ROBODOC and CASPAR


Femoral drilling

Out of business

Cost

Invasiveness

No added value



Computer Assisted Orthopaedic Surgery

1990
1995
2000

Orthopaedic Surgery

Introduction

History

Basics

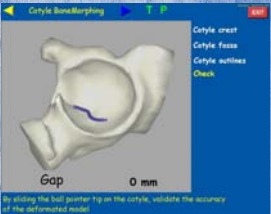


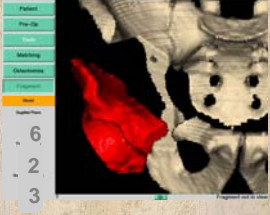
TKA

HTO

ACL

THA

Conclusion

| Computer Assisted Orthopaedic Surgery |

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

Basics

THE PERCEPTION - DECISION - ACTION LOOP

| Computer Assisted Orthopaedic Surgery |

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

PRE-OP

Decision

Perception

Action

PER-OP

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics


TKA

HTO

ACL

THA

Conclusion




Guiding systems

PASSIVE SYSTEMS
Navigation systems

3D localizers

Real-time feed back on the location of :

- Therapeutic objects
- Surgical instruments



Computer Assisted Orthopaedic Surgery

Introduction

History

Basics


TKA

HTO

ACL

THA

Conclusion

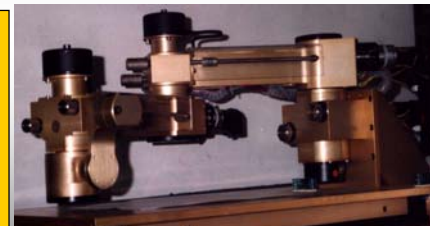


Guiding systems

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

Padyc

- Synergistic robots
- Collaborative robots
- Impeachment robots



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

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Action

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

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



Computer Assisted Orthopaedic Surgery


Action

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



Computer Assisted Orthopaedic Surgery

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



3D LOCALIZERS

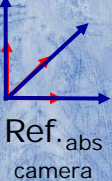
Computer Assisted Orthopaedic Surgery

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

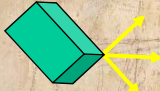
3D Localizers

Localization : non deformable Objects

- Bones or surgical tools
 - Location
 - Orientation



Ref_{abs}
camera



Ref_{rb}

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

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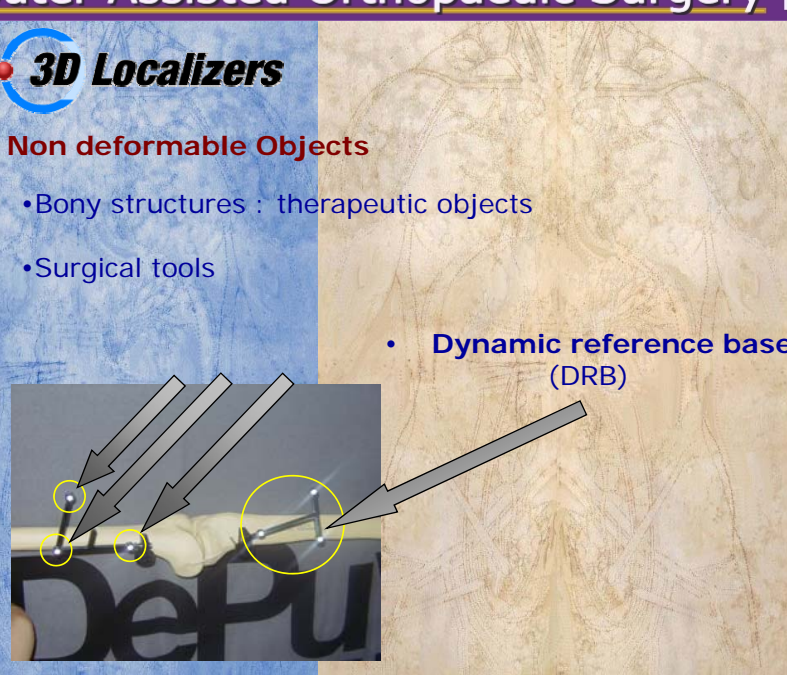
- Introduction
- History
- Basics
- TKA
- HTO
- ACL
- THA
- Conclusion

3D Localizers

Non deformable Objects

- Bony structures : therapeutic objects
- Surgical tools

Dynamic reference base (DRB)



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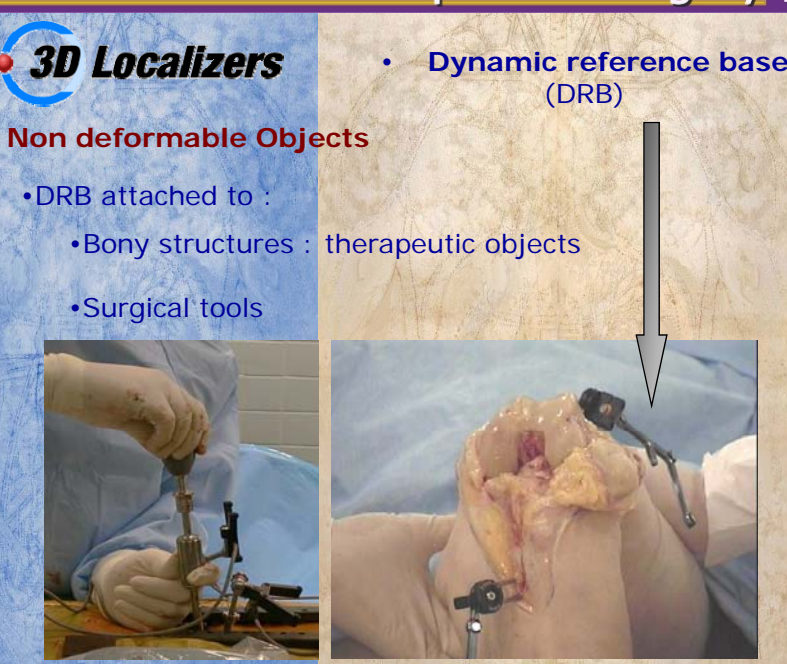
- Introduction
- History
- Basics
- TKA
- HTO
- ACL
- THA
- Conclusion

3D Localizers

Non deformable Objects

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

Dynamic reference base (DRB)



Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

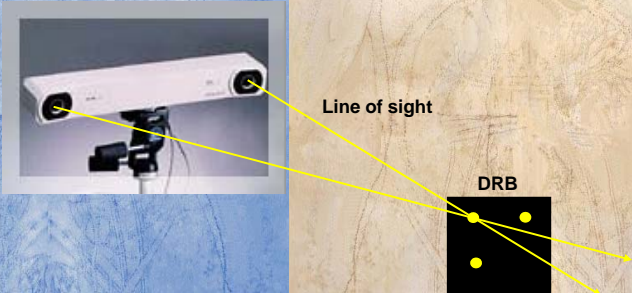
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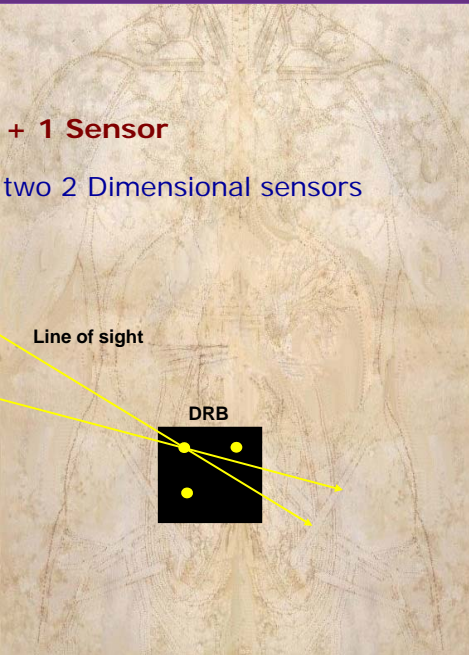
Conclusion

3D Localizers

Localizer = 1 Source + 1 Sensor

- Optical localizer with two 2 Dimensional sensors





Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL


THA

Conclusion

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	

Computer Assisted Orthopaedic Surgery

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

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion




Computer Assisted Orthopaedic Surgery

3D Localizers

Optical systems

- Active systems

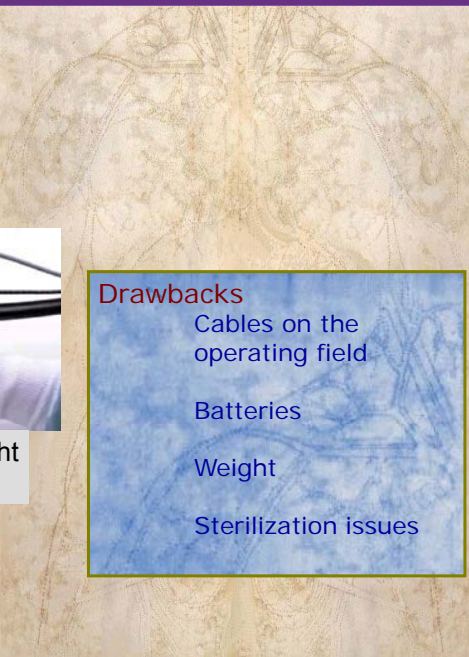


Active emission of light
= source of energy

Drawbacks

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

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion



| Computer Assisted Orthopaedic Surgery |

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

3D Localizers

Optical systems

- Passive system

Passive = reflectors

Drawbacks

- Single use
- Sensitive to surrounding light

Pros

- Cheap
- Light
- Can be set on any type of instrument

| Computer Assisted Orthopaedic Surgery |

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

3D Localizers

Optical systems

- Vision of the camera

Vision of the optical system

Surgical scene

| Computer Assisted Orthopaedic Surgery |

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

Application : TKA

40 000 TKA / Year / France
8 000 Uni / Year / France

| Computer Assisted Orthopaedic Surgery |

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

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

| Computer Assisted Orthopaedic Surgery |

Introduction

History

Basics

TKA

HTO

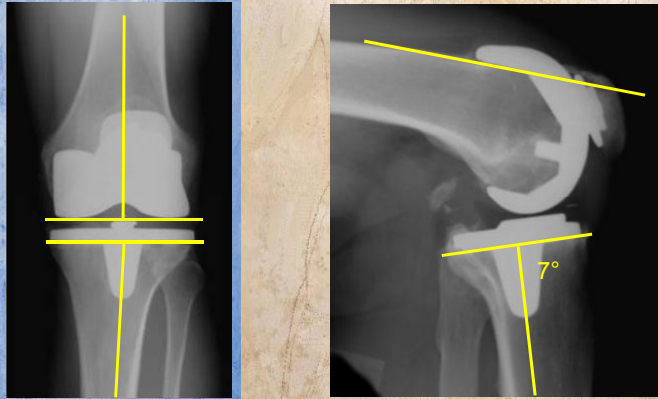
ACL

THA

Conclusion

The challenges

- The challenges : two faces
- Mechanical axes :



| Computer Assisted Orthopaedic Surgery |

Introduction

History

Basics

TKA

HTO

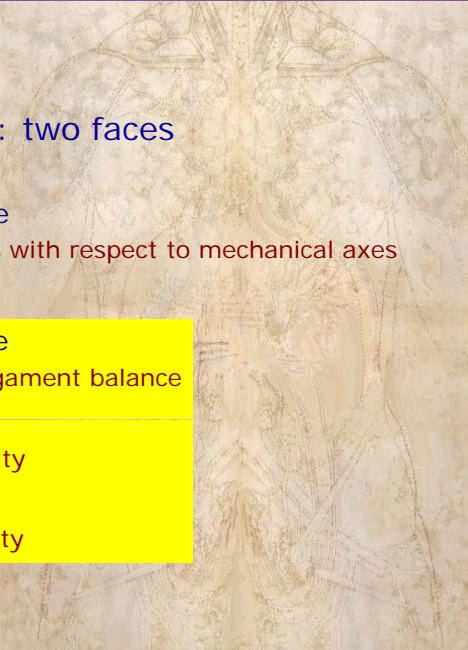
ACL

THA

Conclusion

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

| Computer Assisted Orthopaedic Surgery |

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

The challenges

- Functional challenge
- Ligament balancing




| Computer Assisted Orthopaedic Surgery |

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

The challenges

- Functional challenge
- Ligament balancing



• Lift-off = wear

• Instability

| Computer Assisted Orthopaedic Surgery |

- Functional challenge
- Ligament balancing

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

The diagram illustrates two knee models from a posterior view. The left model has a blue rectangular cut across the distal femur. The right model has a green rectangular cut across the distal femur. A horizontal dashed line connects the two cuts. A green line is drawn across the right cut, indicating a good cut.

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- Functional challenge
- Ligament balancing

• Well align knee (HKA ~ 180°): Excessive cuts

The diagram illustrates two knee models from a posterior view. The left model has a green rectangular cut across the distal femur with a wavy line above it. The right model has a green rectangular cut across the distal femur with a white line above it. A horizontal dashed line connects the two cuts. A white line is drawn across the right cut, and a label "Gap" points to it, indicating excessive cuts.

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- Functional challenge
- Ligament balancing

• Well align knee (HKA ~ 180°): Excessive cuts

• Gap

• Increase PE.

• Laxity in extension

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- Functional challenge
- Ligament balancing

• Well align knee (HKA ~ 180°): Insufficient cuts

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- Functional challenge
- Ligament balancing

• Well align knee (HKA ~ 180°): Insufficient cuts

• Excessive constraint

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- Functional challenge
- Ligament balancing

• Misalignment (Varus or Valgus):

• Distraction

• Retraction

• Constraint

• Laxity

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- Functional challenge
- Ligament balancing

• Misalignment (Varus or Valgus):

• Retraction

• Release

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- Functional challenge
- Ligament balancing

• Misalignment (Varus or Valgus):

• Risks

- Unbalance knee
- Residual laxity / Excessive constraints
- Overcorrection / Hypocorrection

| Computer Assisted Orthopaedic Surgery |

Introduction
 History
 Basics
TKA
 HTO
 ACL
 THA
 Conclusion

Application : TKA

The solutions

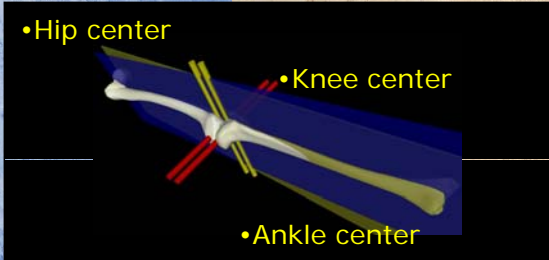
| Computer Assisted Orthopaedic Surgery |

Introduction
 History
 Basics
TKA
 HTO
 ACL
 THA
 Conclusion

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



• Hip center
 • Knee center
 • Ankle center

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

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

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

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

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)

Registration

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

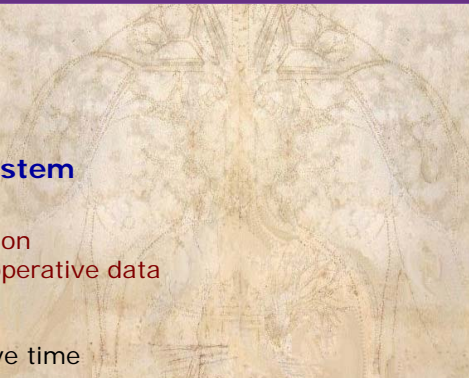
THA


Conclusion

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





En glissant la pointe du palpateur sur le tibia, vérifier la information



En glissant la pointe du palpateur sur le femur, vérifier la information

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA


HTO

ACL

THA

Conclusion

Non image based



Computer Assisted Orthopaedic Surgery

Introduction

History

Basics


TKA

HTO



ACL

THA

Conclusion



- 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

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics


TKA

HTO

ACL


THA

Conclusion



- None image based approach

Hip center



Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Perception

•None image based approach

-Kinematics approach

•Search of a point C of R_{fem} with the minimum trajectory during the acquisition motion

Hip center

Hip Center

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Perception

•None image based approach

-Morphologic approach

Knee center

Computer Assisted Orthopaedic Surgery


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

Perception

- None image based approach
- Percutaneous digitization of points

Ankle center

-Geometric approach



Computer Assisted Orthopaedic Surgery

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

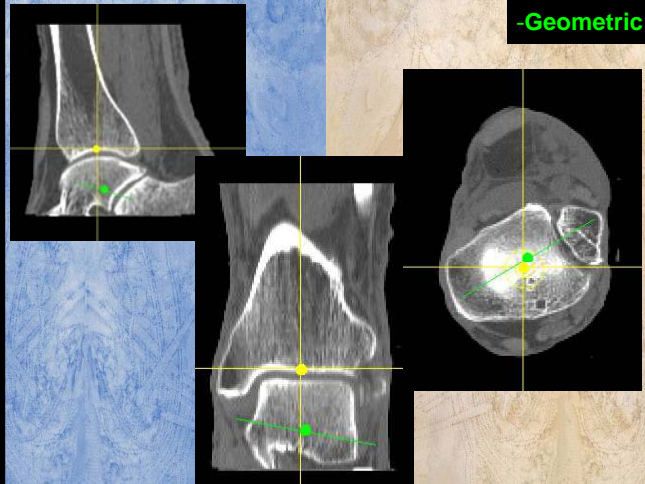
Perception

- None image based approach

Ankle center

-Geometric approach

- Error
- Slope
- Varus
- Valgus



Computer Assisted Orthopaedic Surgery

Introduction

History

Basics


TKA

HTO

ACL

THA


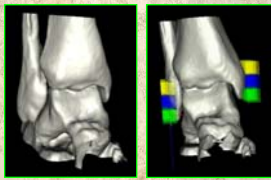
Conclusion

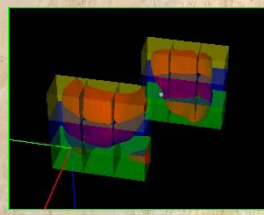


Perception

-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.

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics


TKA

HTO

ACL

THA

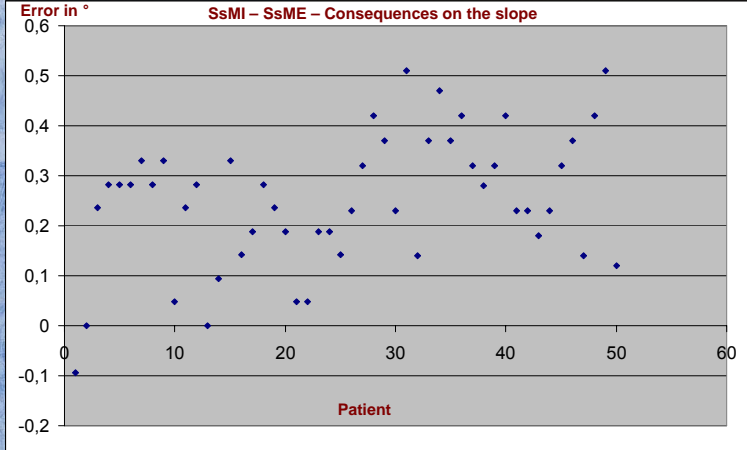
Conclusion



Perception

•None image based approach

Ankle center



Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

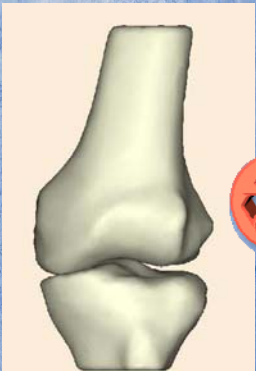

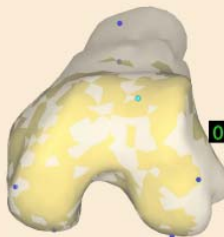
ACL

THA

Conclusion

Perception

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

DePuy ACQUISITION FTPG EXIT

- Hanche
- Cheville
- Epine
- Echancrure
- Corticale
- Condyle
- Surface fémur
- Giène
- TTA
- Surface tibia

0.6 mm

En glissant la pointe du palpeur sur le fémur, vérifier la précision du modèle déformé

Morphology

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

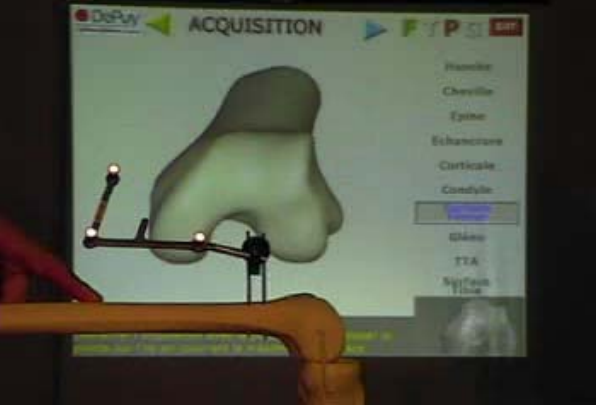
ACL

THA

Conclusion

Perception

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



Morphology

Computer Assisted Orthopaedic Surgery

Perception

Morphology

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

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Non image based

Decision

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Decision

•Level 1 : based on morphologic data

DePuy Planning Tibia LCS Gauche FTPG EXIT

Taille implant: 4
Hauteur de coupe: 6 mm
Pente tibiale: 7°
Varus: 0°
Latéral: 0 mm
Antéro / Postérieur: 0 mm
Rotation axiale: 0°

ML
Tibia=78.4 mm
(3.5, -2.2)
Fémur=Std+

Vérifier la proposition de planning, éventuellement ajuster la position et l'orientation de l'implant

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Decision

•Level 2 : based on dynamic per-operative data

Sensor

Software

Spacer

Alignment

HKPA: 181°

Valgus: 1.0°

Flexion: 5°

Rotation tibia: 2°

Quantitative data on GAPS: 12.0mm, 10.0mm

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Decision

- **Level 2 : based on dynamic per-operative data**
- **Test residual laxity**
 - Varus Max.
 - Valgus Max.
- **If the residual laxity is over a threshold**

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Decision

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

Ligament balance

Int. laxity	HKA	Ext. laxity
2.0 mm	179.1°	5.2 mm

Int. wedge
1 mm

Ext. wedge
6 mm

Base
10 mm

Press on the yellow pedal to reperform laxity testing with the above spacer.

Reperform

Press on the blue pedal to continue the protocol and plan the femoral implant with these parameters

Accept

30

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics


TKA

HTO

ACL



THA

Conclusion



Decision

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

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

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion



Decision

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




Positionner le palpeur sur la coupe tibiale. Démarrer l'acquisition avec la pédale bleue et glisser la pointe du palpeur sur le plan tibial coupé.

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Decision

• Femoral planning

Verify the proposed planning, possibly adjust the position and orientation of the implant

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion


Non image based

| Computer Assisted Orthopaedic Surgery |

Action


Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

Active system : robots



Passive system : navigation

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




| Computer Assisted Orthopaedic Surgery |

Action

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

•Robotized cutting guides



| Computer Assisted Orthopaedic Surgery |

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

Action

- Robotized milling guides




This slide features a purple header with the title "Computer Assisted Orthopaedic Surgery". On the left, a black vertical bar contains a white table of contents with "TKA" highlighted in yellow. To the right of the table of contents is a blue textured background with the word "Action" in a white circle and a red dot. Below this, a red bullet point lists "Robotized milling guides". The main content area is a collage: the top right shows a 3D wireframe model of a knee joint; the bottom right shows a close-up photograph of a surgeon's gloved hands using a robotic instrument to mill a patient's knee bone.

| Computer Assisted Orthopaedic Surgery |

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

Action

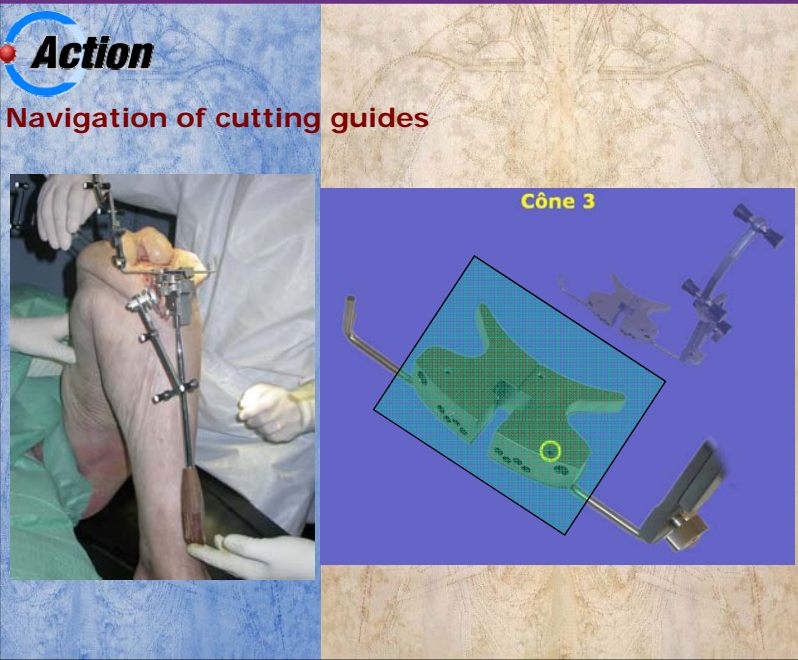


This slide has the same purple header and table of contents as the first slide, with "TKA" highlighted. The "Action" section is represented by a collage of three images: a photograph of a surgeon in a green cap and mask working in an operating room; a 3D wireframe model of a knee joint; and a photograph of a surgical instrument tray filled with various metal tools.

Computer Assisted Orthopaedic Surgery

Action
Navigation of cutting guides

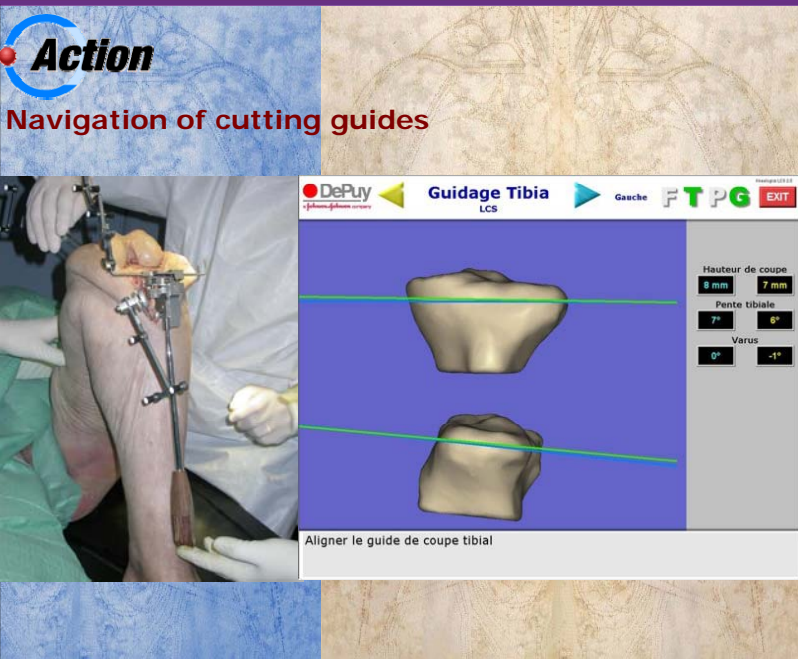
Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion



Computer Assisted Orthopaedic Surgery

Action
Navigation of cutting guides

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion



| Computer Assisted Orthopaedic Surgery |

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

Application : HTO

7 000 cases / Year / France

| Computer Assisted Orthopaedic Surgery |

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

• Integration of bricks

- Hip center : Same brick
- Knee center : Specific solution
- Ankle center : Same brick
- 3D Planning

Computer Assisted Surgical Protocol - CASP

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

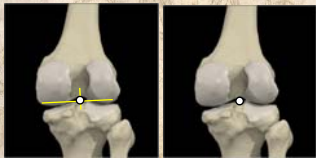
Conclusion

•Knee center

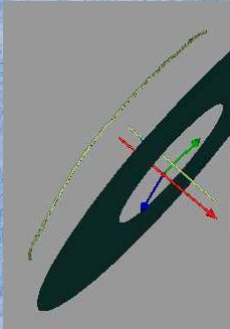
-No access to the joint

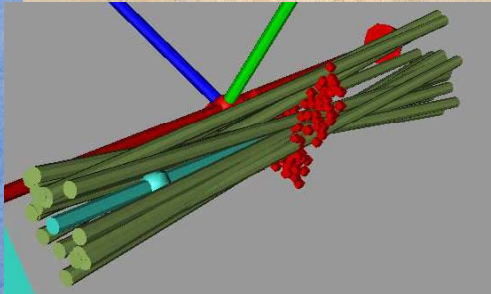
-Mixed approach

-Man / Machine synergy



SOMMER, H.J., Determination of first and second order instant screw parameters from landmark trajectories.
Mechanical Design, 1990: p. 141-142.





Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

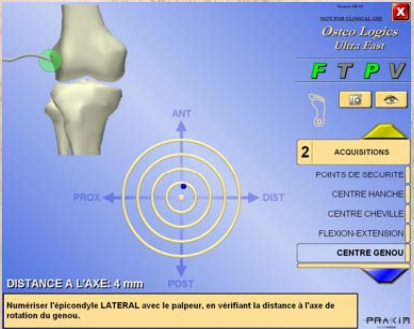
Conclusion

•Knee center

-No access to the joint

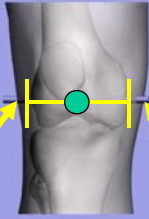
-Mixed approach


-Man / Machine synergy



DISTANCE A L'AXE: 4 mm

Numériser l'épicondyle LATERAL avec le palpier, en vérifiant la distance à l'axe de rotation du genou.






Expert steering

| Computer Assisted Orthopaedic Surgery |

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

•In the OR



| Computer Assisted Orthopaedic Surgery |

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

Application : ACL

| Computer Assisted Orthopaedic Surgery |

Introduction

History

Basics

TKA

HTO

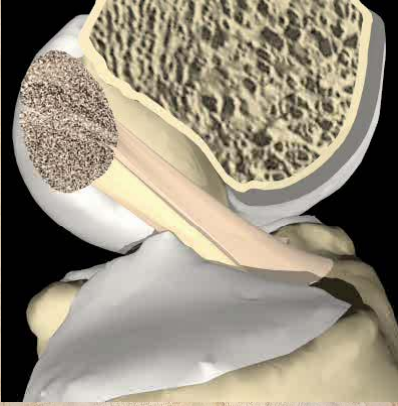
ACL

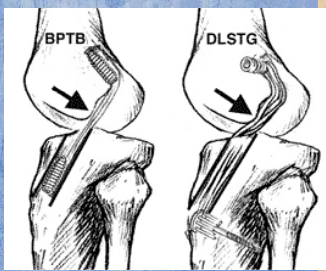
THA

Conclusion

•Anterior Cruciate Ligament Replacement

- The challenges
 - Isometry
 - Avoid impingement





| Computer Assisted Orthopaedic Surgery |

Introduction

History

Basics

TKA

HTO

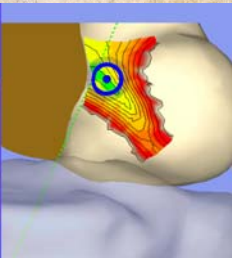
ACL

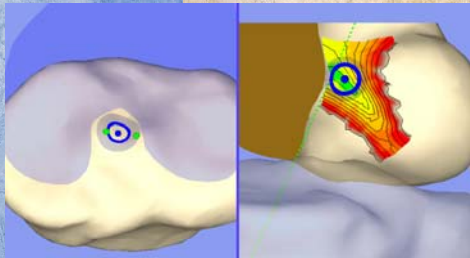
THA

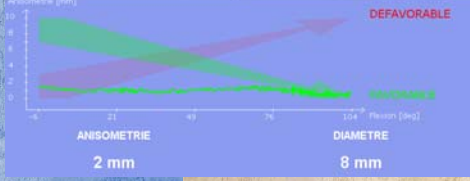
Conclusion

•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

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

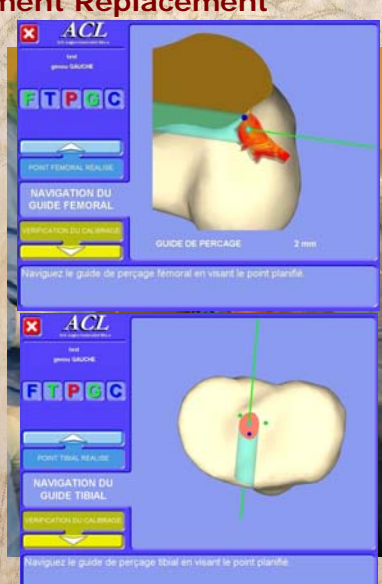
THA

Conclusion

•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

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

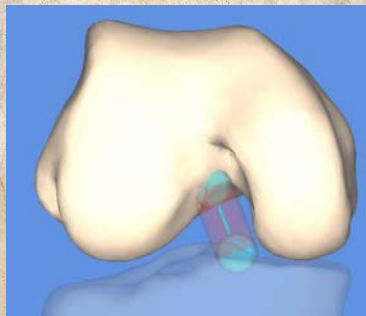

ACL

THA

Conclusion

•Anterior Cruciate Ligament Replacement

•Impingement

- Digitized the anterior fiber of the graft

| Computer Assisted Orthopaedic Surgery |

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

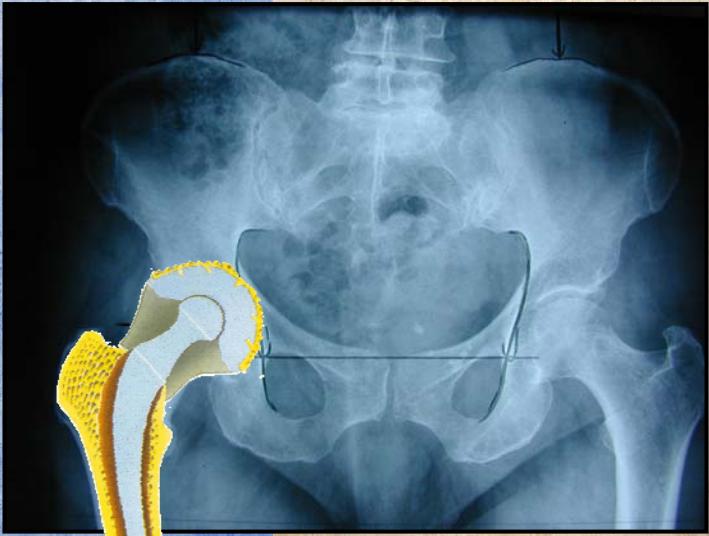
Application : THA

100 000 cases / Year / France

| Computer Assisted Orthopaedic Surgery |

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

•Total Hip Arthroplasty

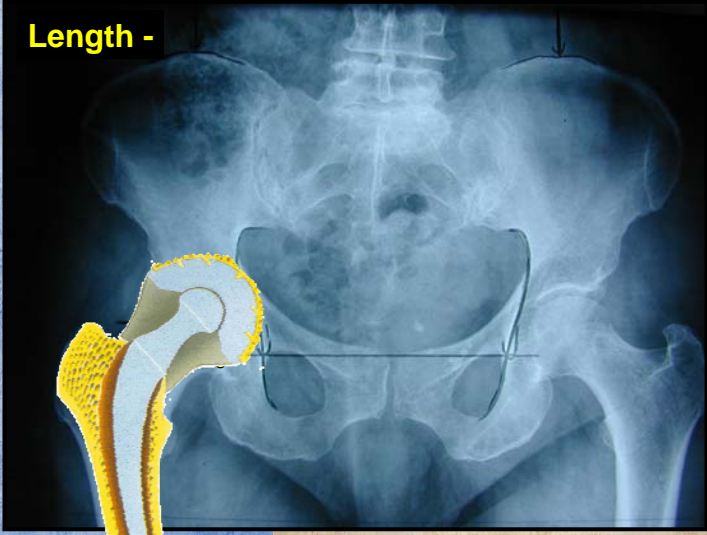


| Computer Assisted Orthopaedic Surgery |

•Total Hip Arthroplasty

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

Length -



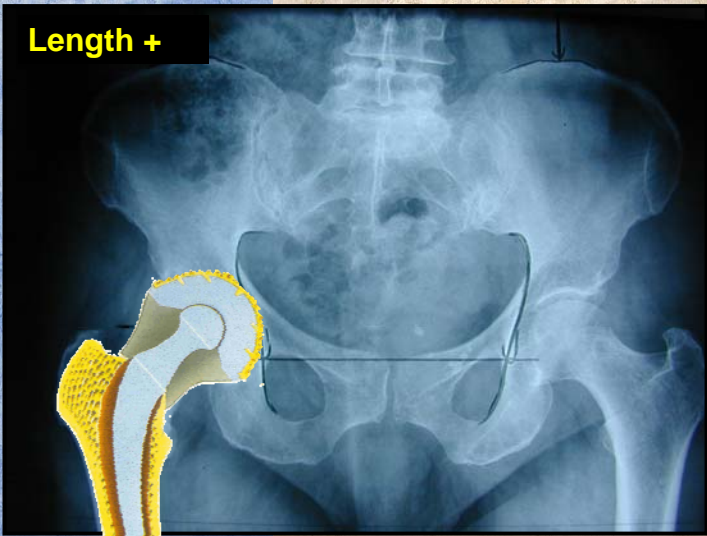
This slide illustrates a hip X-ray with a 3D model of a total hip prosthesis. The femoral stem is shown to be shorter than the natural femur, labeled "Length -".

| Computer Assisted Orthopaedic Surgery |

•Total Hip Arthroplasty

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

Length +



This slide illustrates a hip X-ray with a 3D model of a total hip prosthesis. The femoral stem is shown to be longer than the natural femur, labeled "Length +".

Computer Assisted Orthopaedic Surgery

- Total Hip Arthroplasty

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

Offset

Computer Assisted Orthopaedic Surgery

- Total Hip Arthroplasty

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

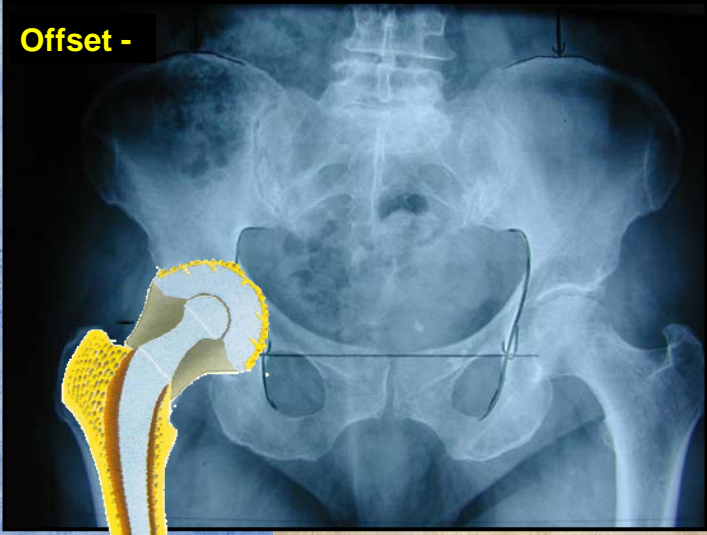
Offset +

Computer Assisted Orthopaedic Surgery

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

•Total Hip Arthroplasty

Offset -



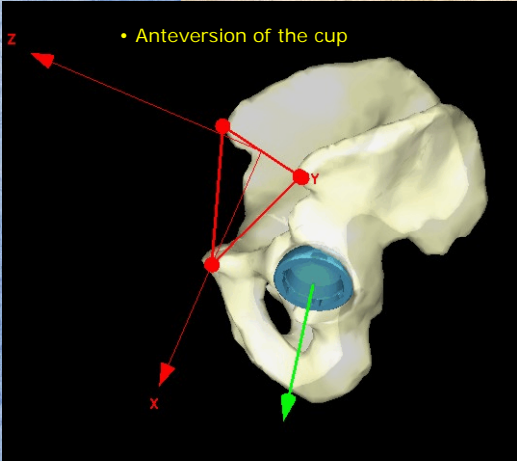
Computer Assisted Orthopaedic Surgery

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

•Total Hip Arthroplasty

- Length
- Centre of rotation
- Offset
- Stability

• Anteverision of the cup



Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

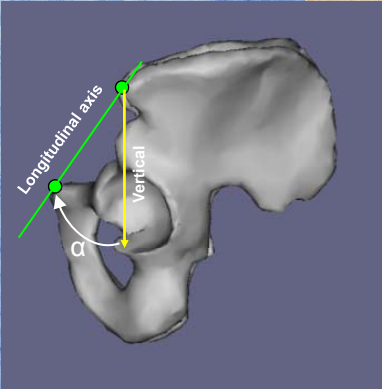
ACL

THA

Conclusion

• Total Hip Arthroplasty

-Reference plane



- Not an absolute reference
- Can be define on an X-Ray
- Change in supine position
- Influence anteversion values

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

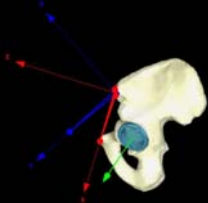
ACL

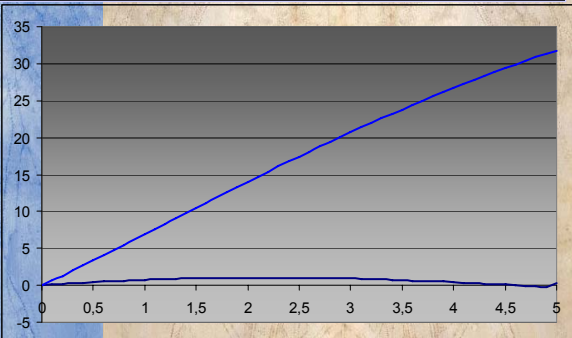
THA

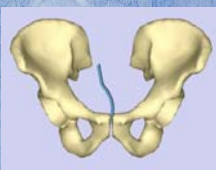


Conclusion

• Total Hip Arthroplasty

-Reference plane



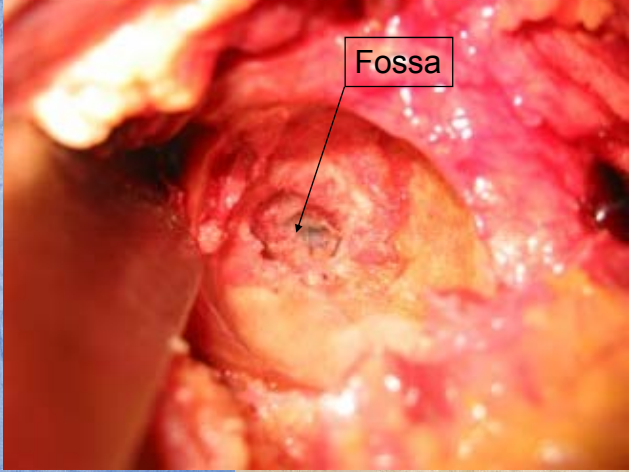


Computer Assisted Orthopaedic Surgery

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

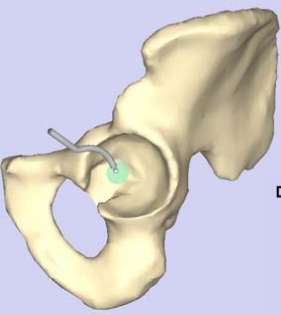
- Total Hip Arthroplasty
 - Local bone morphing instead of global
 - View of the acetabulum fossa before reaming



Computer Assisted Orthopaedic Surgery

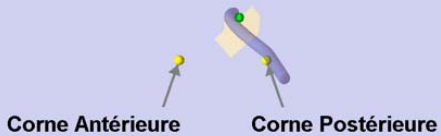
- Introduction
- History
- Basics
- TKA
- HTO
- ACL
- THA**
- Conclusion

- Total Hip Arthroplasty
 - Local bone morphing instead of global



Distance à la surface osseuse : 0.6 mm

Nombre de points acquis: 108




Computer Assisted Orthopaedic Surgery

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

• Total Hip Arthroplasty

- Local bone morphing instead of global




Computer Assisted Orthopaedic Surgery

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

• Total Hip Arthroplasty

- Fine tuning of the implants

• Final hip center location



Computer Assisted Orthopaedic Surgery

•Total Hip Arthroplasty

-Fine tuning of the implants

CUPULE	Longueur-Latéralisation
<p>Inclinaison: 36°</p>	
<p>Antéversion: 32°</p>	

Computer Assisted Orthopaedic Surgery

Introduction

History

Basics

TKA

HTO

ACL

THA

Conclusion

Conclusion

| Computer Assisted Orthopaedic Surgery |

Introduction
History
Basics
TKA
HTO
ACL
THA
Conclusion

Blind surgery or quantitative surgery ?

Code Marol
la Palitesse