

Navigation and Robotic in Surgery

R. Burgkart

**Klinik für Orthopädie und Unfallchirurgie, TUM
(Direktor: Prof. Dr. R. Gradinger)**

Outline

- **Basics of Navigation/Robotic**
- **Data as Prerequisite**
- **Pre/Intraoperative Planning**
- **Visualization**
- **Pros & Cons**

Basics

Why Navigation / Robots?

modern imaging modalities (CT, MRI,...)

Navigation / Robots

Lack of intraoperativ knowledge transfer



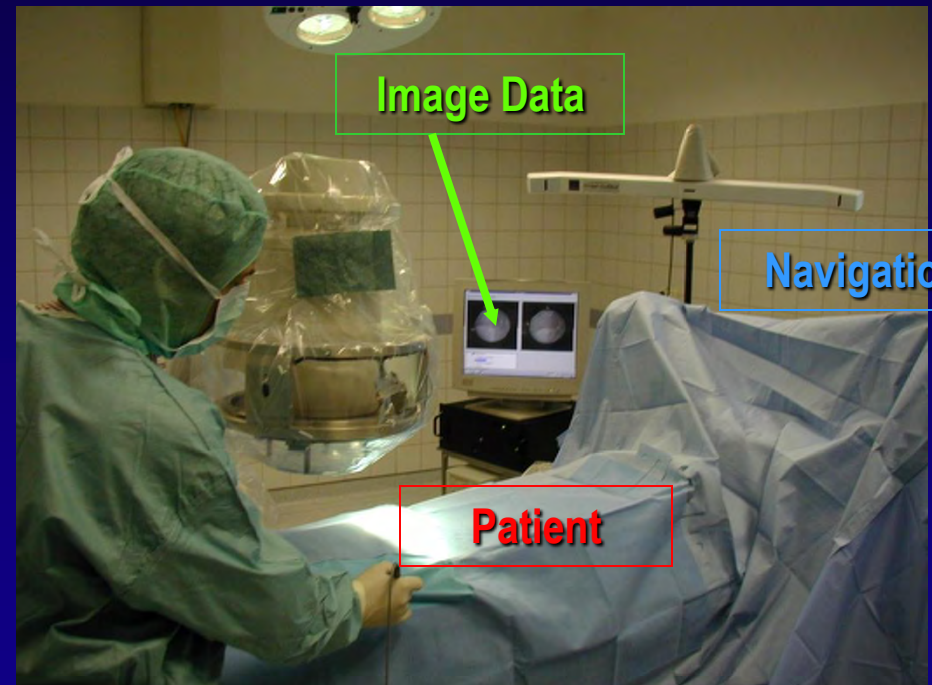
Basics

Image-based Intraoperativ Navigation Systems

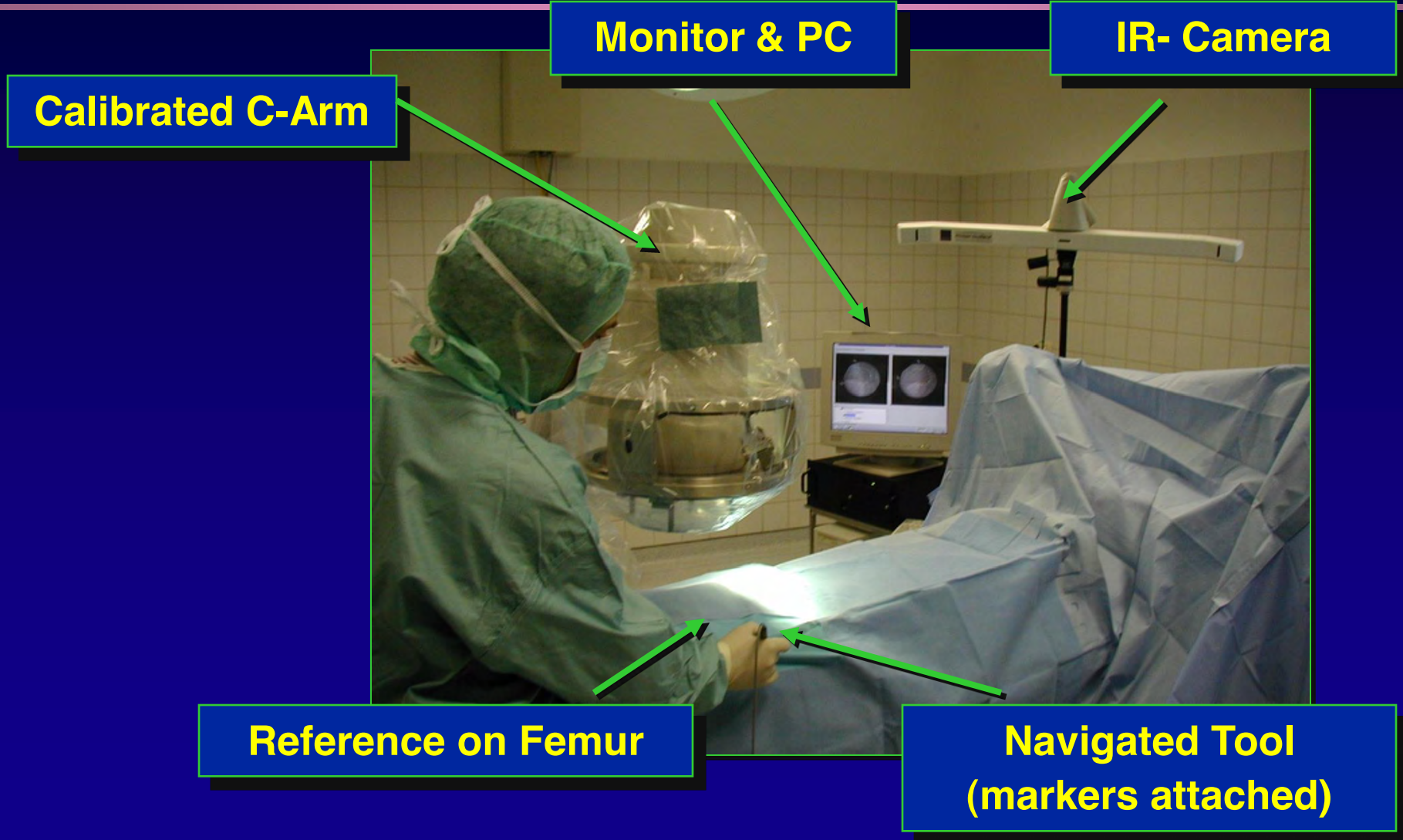
Therapeutic Object (Patient)

Virtual Object (CT data,...)

Navigation System



Computer assisted Navigation



Basics

Image-based Intraoperative Navigations Systems (Classification of Navigation/Robotic Systems)

Passive Systems

Semiactive Systems

Active Systems



Basics

Image-based Intraoperativ Navigations Systems

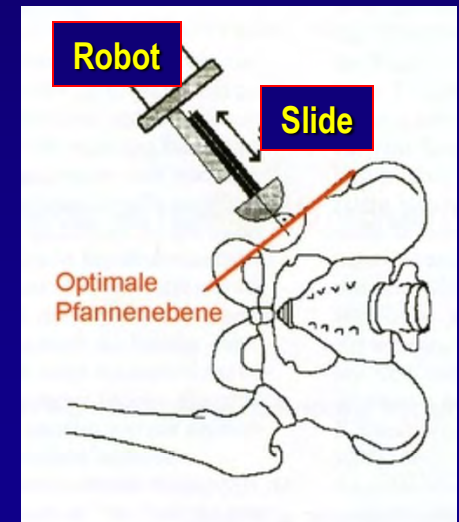
Passive Systems

Semiactive Systems

Active Systems



Robot assisting,
slide holding drill
manually moved



Grundlagen

Image-based Intraoperativ Navigations Systems

Passive Systems

Semiactive Systems

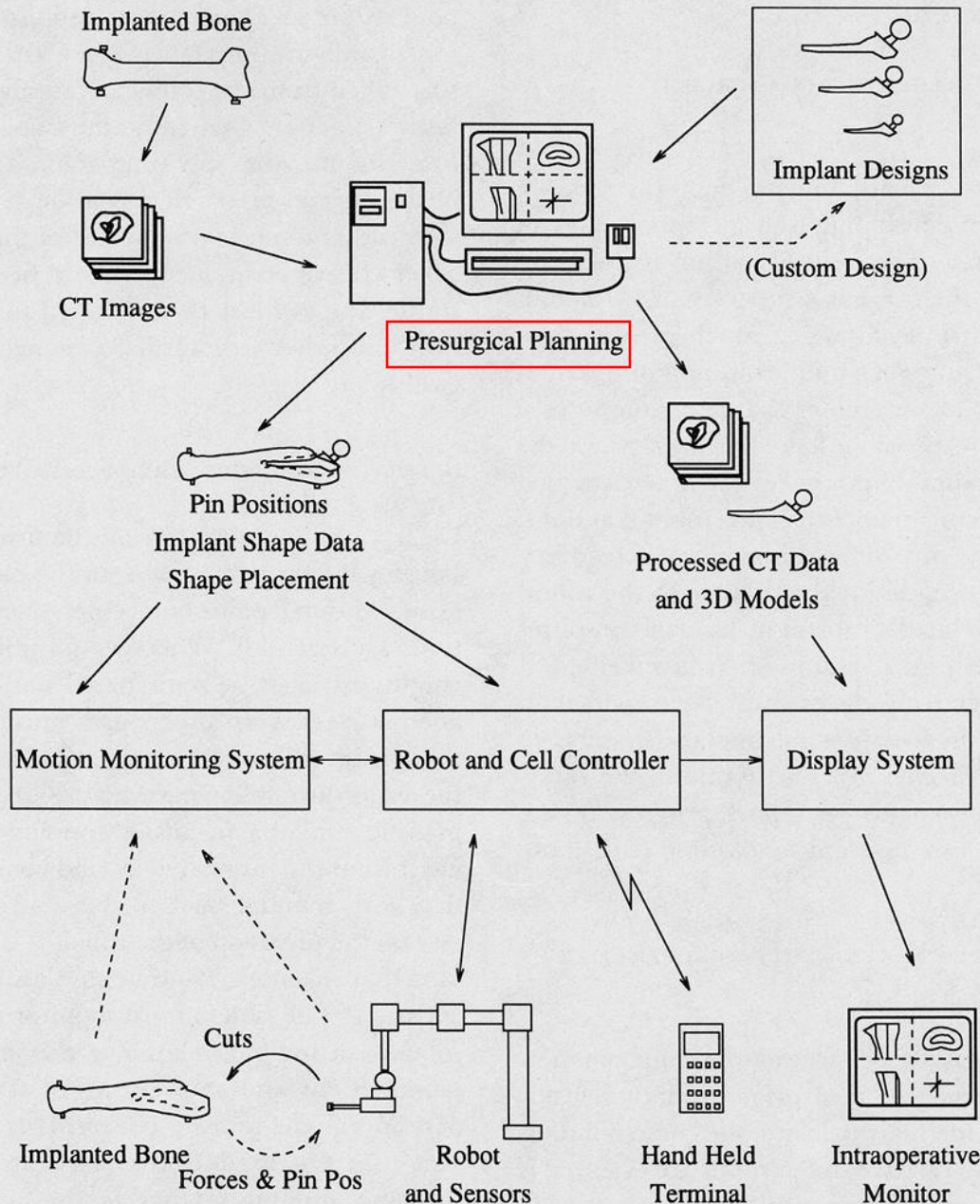
Active Systems



Workflow for a Intervention/Surgery using Navigation

When preoperative imaging is available:

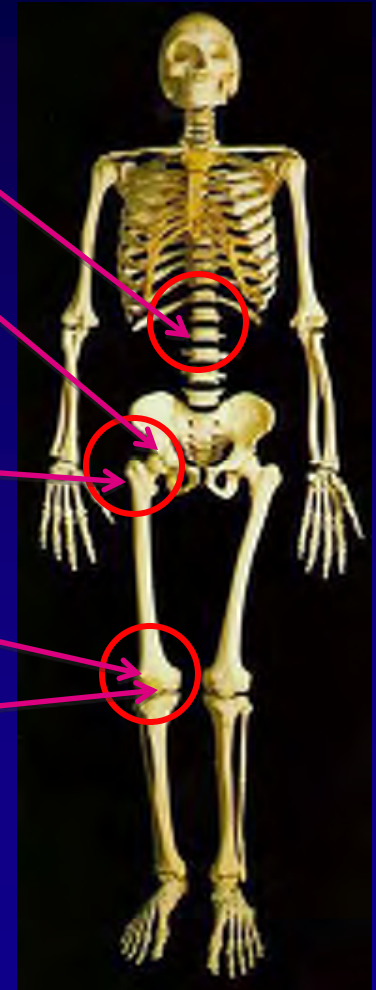
Additional possibilities to do preoperative planning.



Use in Orthopedics

Intraoperativ Navigation Systems

- ☞ **Spinal orthopedics**
- ☞ **Acetabulum navigation (for replacement)**
- ☞ **stem implantation in femur**
- ☞ **Knee arthroplasty (replacement)**
- ☞ **Anterior cruciate ligament reconstruction**
- ☞ **Biopsy/Resection of bone tumors**

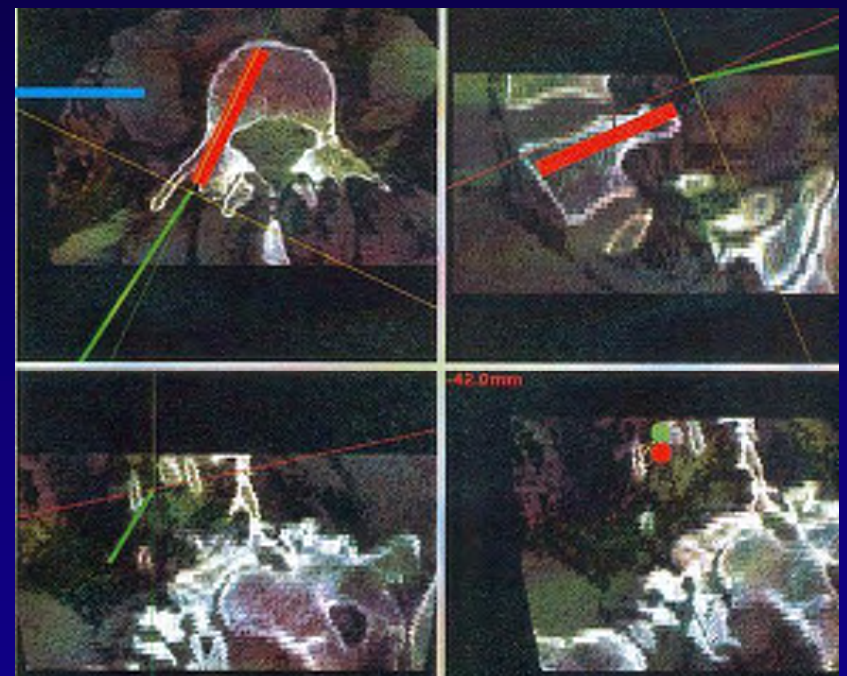


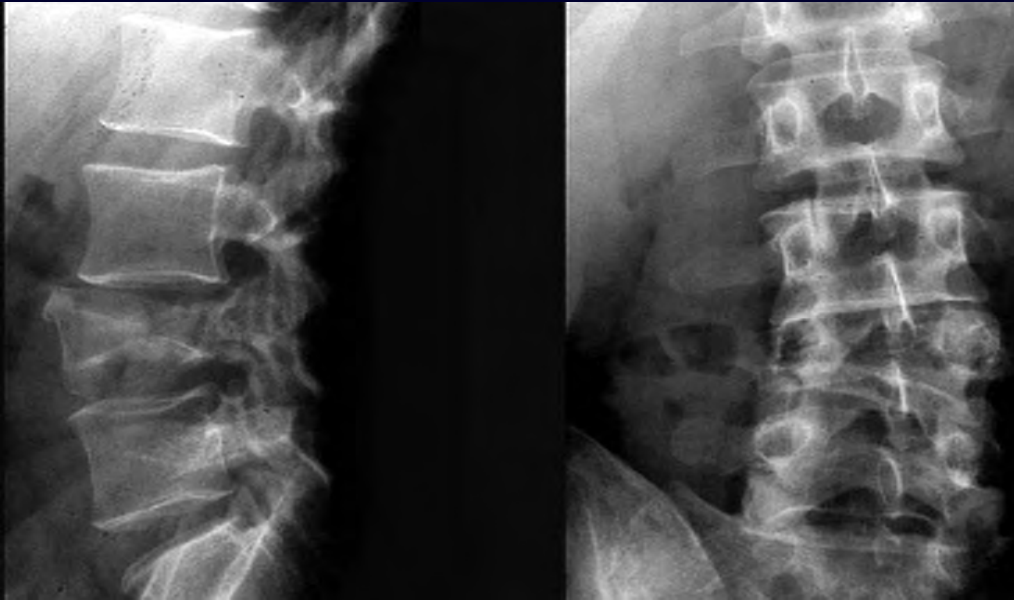
aims

- ↪ **Improvement of accuracy**
- ↪ **Reduction of operation trauma**
- ↪ **Reduction of operation time**
- ↪ **Reduction of complications during operation**
- ↪ **Improvement of long-term results**

Screw Placement - Spine

Image-based Intraoperative Navigation Systems

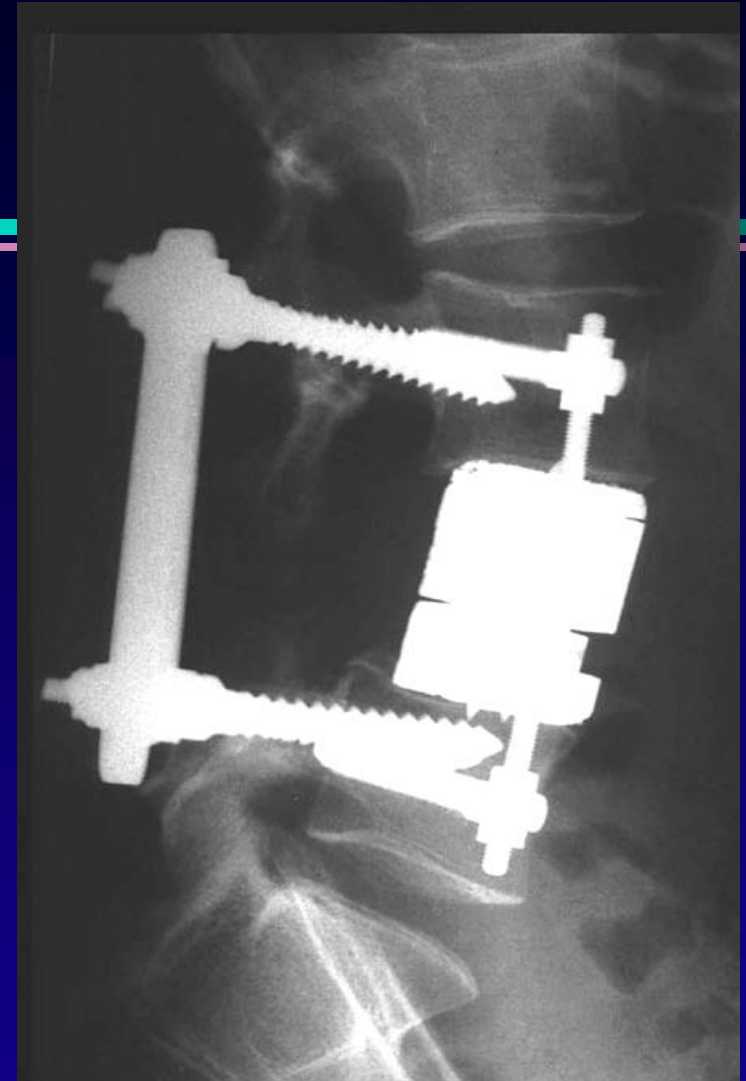
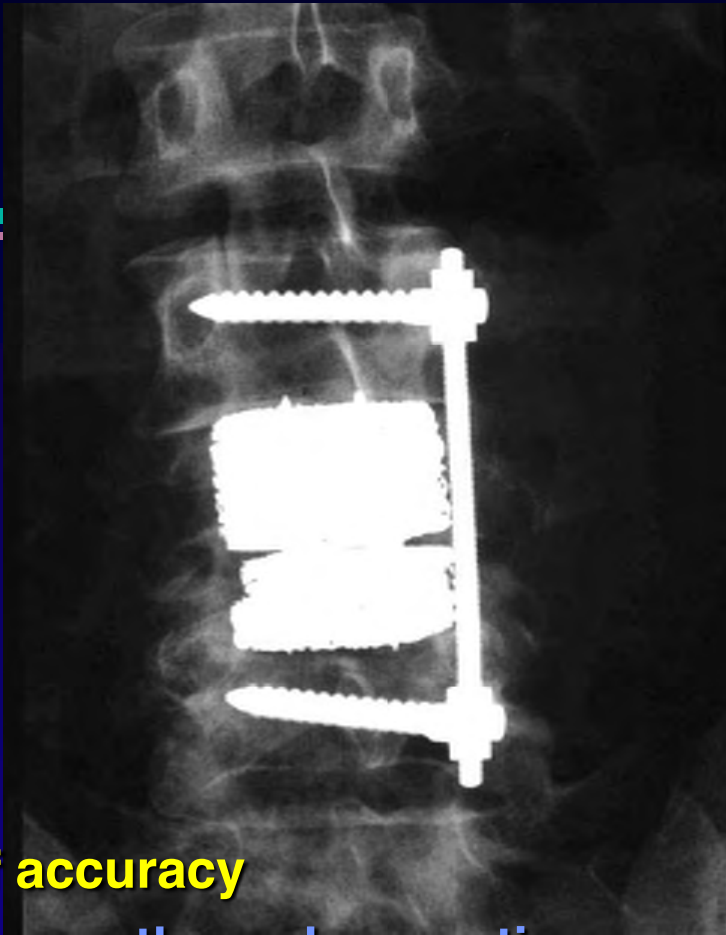




Rhabdomyosarcoma

(cancer cells thought to arise from skeletal muscle progenitors)

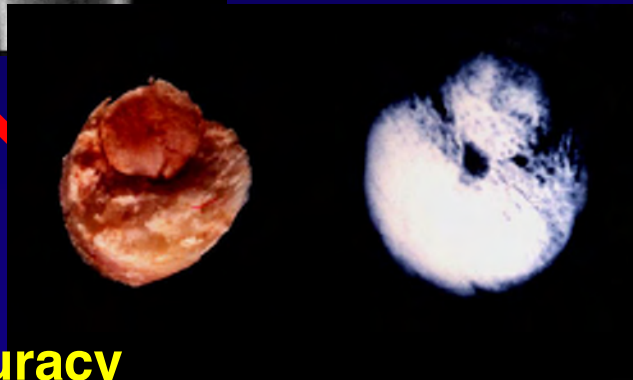
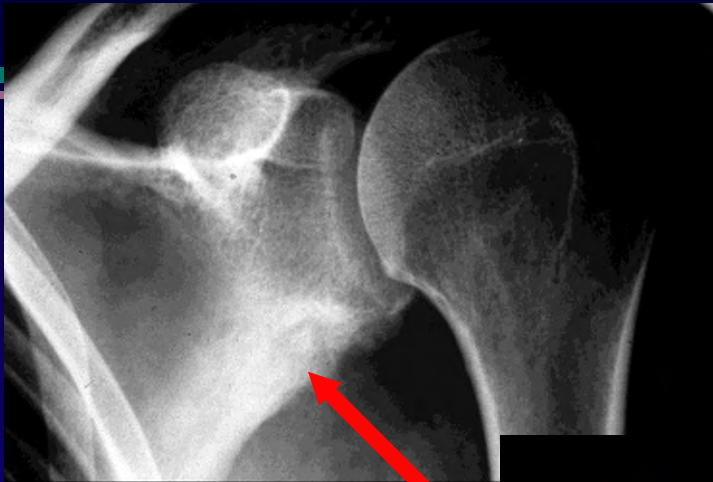




- ✓ **Improvement of accuracy**
- ✓ Reduction of trauma through operation
- ✓ Reduction of operation time
- ✓ **Reduction of complications during operation**
- ✓ **Improvement of long-term results**

Rhabdomyosarcoma

Minimal Invasive

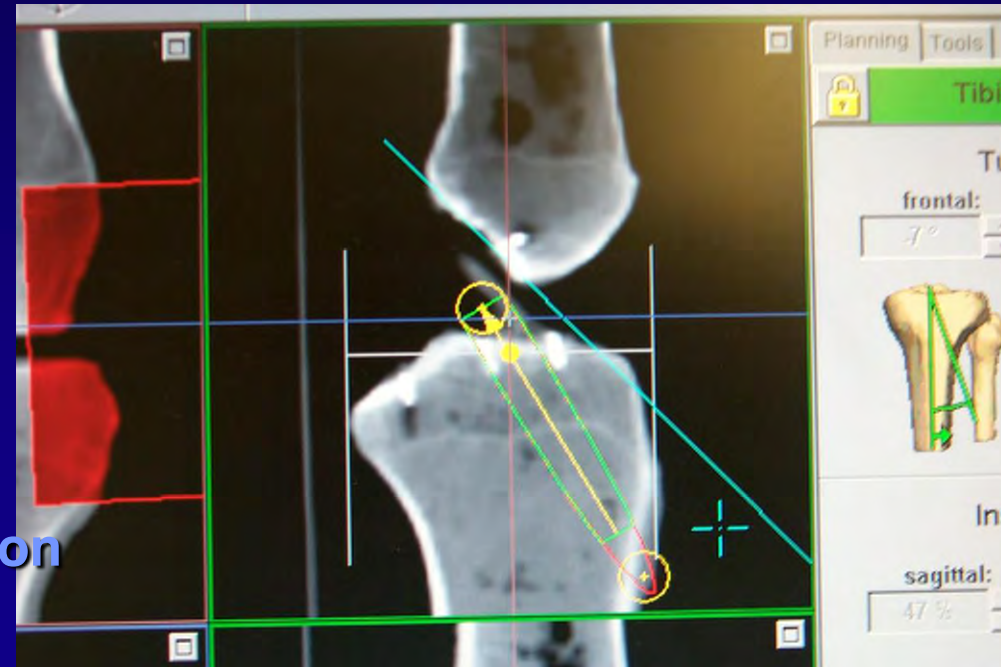


- ✓ **Improvement of accuracy**
- ✓ **Reduction of trauma through operation**
- ✓ **Reduction of operation time**
- ✓ **Reduction of complications during operation**
- ✓ **Improvement of long-term results**

Osteoidosteom li Scapula

Drill Channel (Anterior cruciate ligament reconstruction)

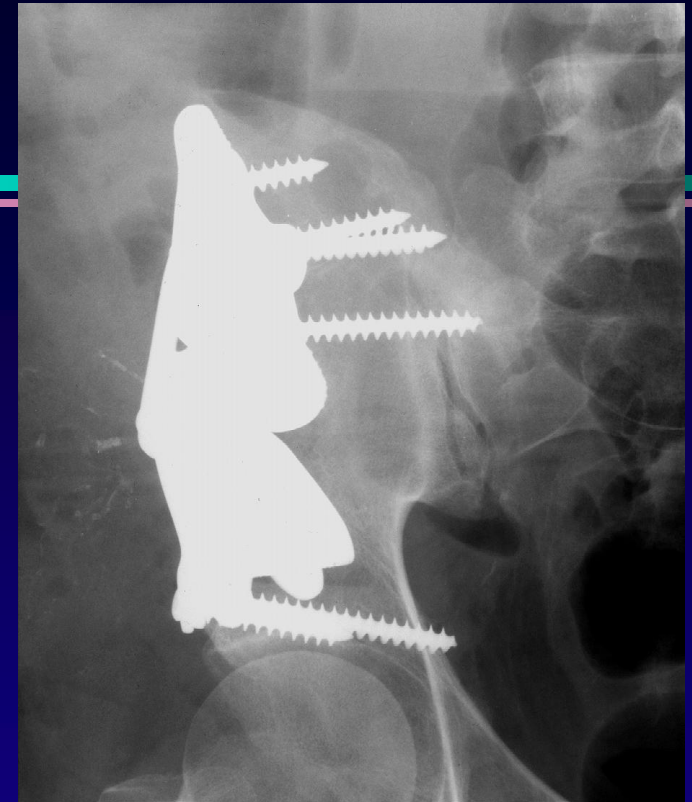
Image-based Intraoperative Navigations Systems



- 🖱 **Improvement of accuracy**
- 🖱 Reduction of trauma through operation
- 🖱 Reduction of operation time
- 🖱 Reduction of complications during operation
- 🖱 **Improvement of long-term results**



Hypernephrommetastase re. Os Ilium



- ☞ **Improvement of accuracy**
- ☞ **Reduction of trauma through operation**
- ☞ **Reduction of operation time**
- ☞ **Reduction of complications during operation**
- ☞ **Improvement of long-term results**

Robot

Use for hip surgery

Chirurg läßt den Roboter fräsen

Neue Technik verbessert Chancen bei Operationen an Gelenken

Surgeon let's Robot mill

New Technology improves Prospects in Joint Surgery



THE M E N D E R Z E I T

BERICHTE

Computergestützte Chirurgie

„Robodoc“ assistiert bei Hüftgelenkoperationen

Computer assisted Surgery

“Robodoc” assists during Acetabulum Surgery

Use during Acetabulum Operations

Milling of the femur diaphysis

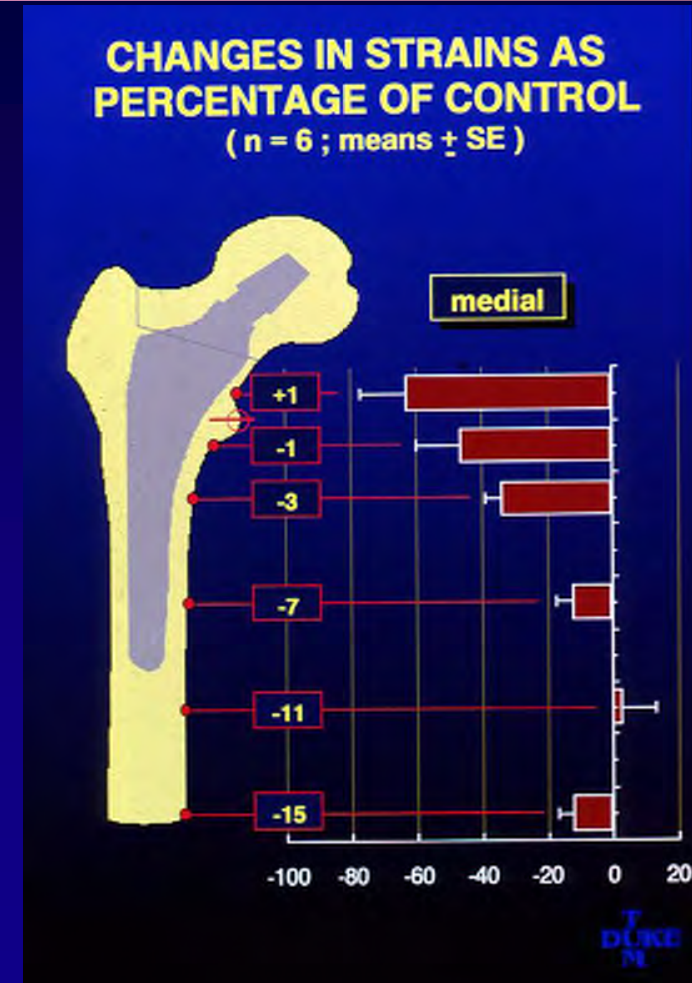
- ★ High Accuracy
- ★ tight fit of prosthesis in cortical bone (form fit)



Use during Acetabulum Operations

Problems:

- ★ Form fit causes physiological stiffness of the diaphysis
- ★ Distal increased forces => stress shielding proximal => Loosening!
- ★ stem insertion manually



Robot

Use for hip surgery



Experiences:

- 🖱 Improvement of accuracy
- ~~🖱 Reduction of trauma through operation~~
- ~~🖱 Reduction of operation time~~
- ~~🖱 Reduction of complications during operation~~
- 🖱 Improvement of long-term results

Problem

Sterility



Problem

Human – Machine Interaction



Problem

Eye – Hand Coordination



Requirements concerning Computer Assisted Technologies (Industry and Engineering)

- Improved reproducible precision to reduce rejections
- Saving time in the production flow
- Simple and secure handling
- Staff savings
- General reduction of costs
- Quick amortization of the investment

Requirements concerning Computer Assisted Technologies (Surgical Medicine)

- Exact preoperative planning
- Improved, reproducible precision
- Minimizing the operation trauma
- Secure handling
- Sterile handling
- Reduction of perioperative (pre/postoperative & recovery) complications
- **Successful clinical controlled studies** (according guidelines and abort criteria given out by an ethic commission)

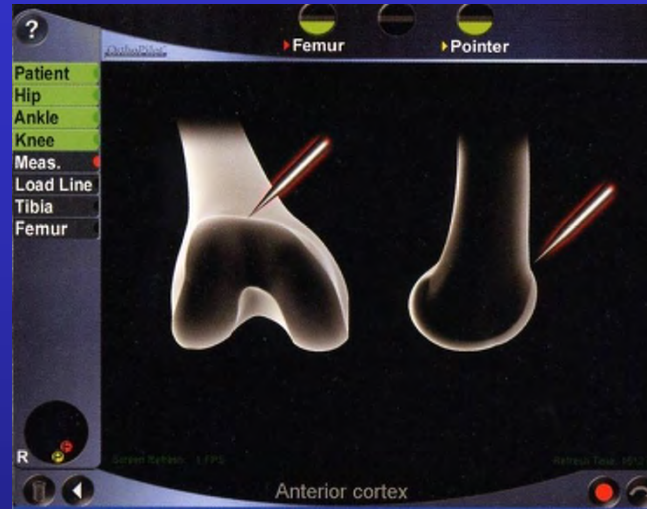
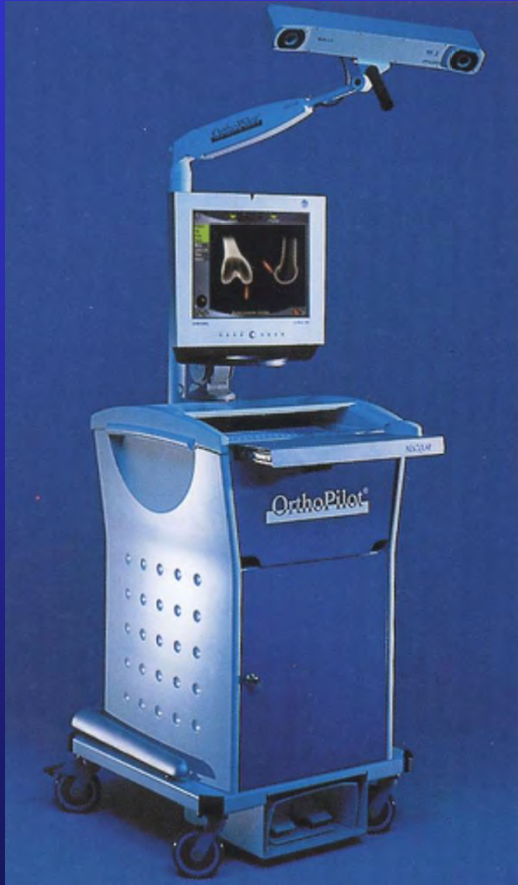
Requirements concerning Computer Assisted Technologies (Hip/Acetabulum Surgery)

- Exact preoperative planning
- Precise preparation of the implant joint (femur diaphysis stem and acetabulum)
- Precise reproducible placement of the implants
- Reduction of the operation trauma
- Reduction of the operation time
- Reduction of the peri/intraoperative complications
- Improvement of long-term results (needs to be proven in studies)

Data/Imaging as Prerequisite for Navigation Systems

- No „Imaging“
- C-Arm based Navigation
- C-Arm and CT/MRI based
- CT based Navigation
- MRI based Navigation
- Multimodal (...+ PET, MRA etc.) Navigation

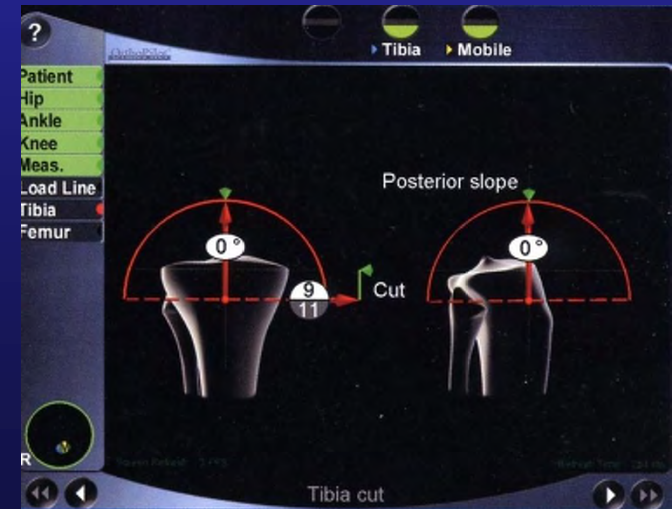
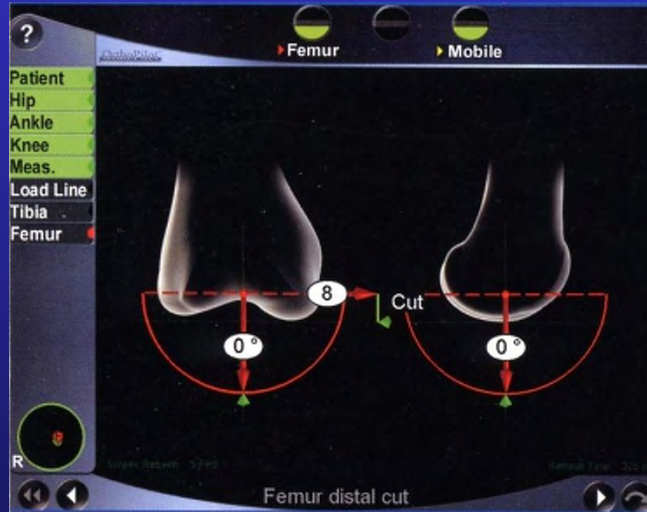
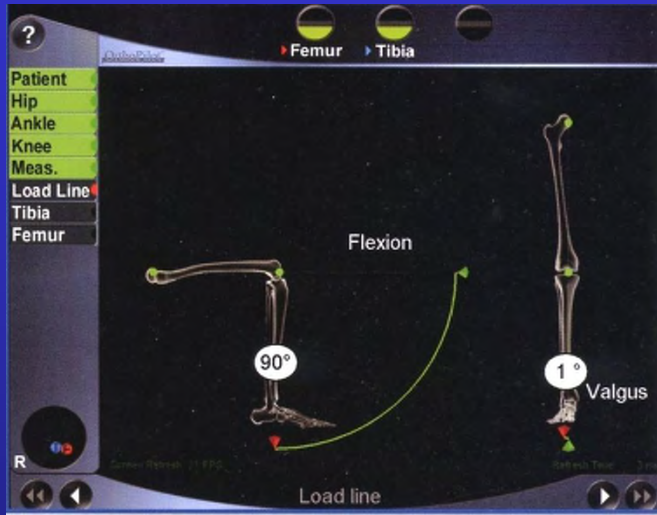
Kinematics + Geometry Data navigated



e.g.: KTEP

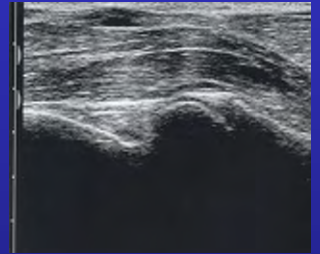


Kinematics + Geometry Data navigated



Imaging Modalities

- **X-ray**
- **Sonographie**
- **CT**
- **MRI**
- **MRA** (magnetic resonance angiography)
- **SPECT**
- **PET**



X-ray



Osteochondrom dist. Femur

C-Arm based navigated



why a mobile C-arm?



For German Professional Orthopaedic Surgeons
the most important tool for intraoperative visualization:

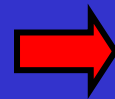
benign tumor: Osteoidosteoma

to find a target:

➤ tumors

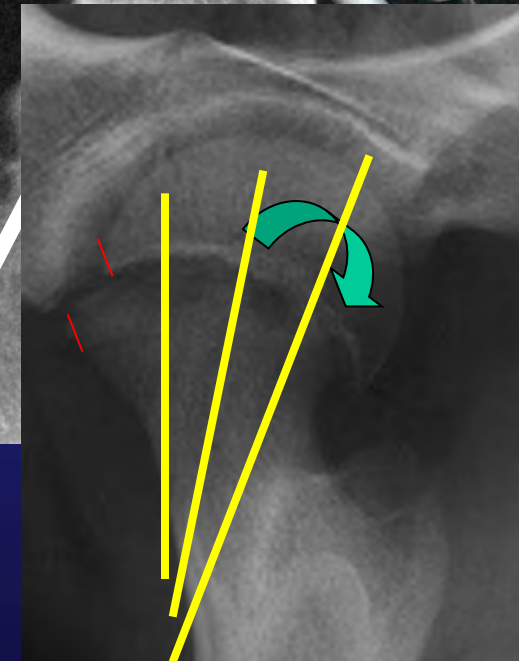
3250 operations
with C-arm

joint perforations: 8 – 62 %



Chondrolysis
(2,9 – 9,7 %)

Walters (1980), Riley (1990), Gonzales (1998), Loder (2000)



Epiphyseolysis cap. fem.



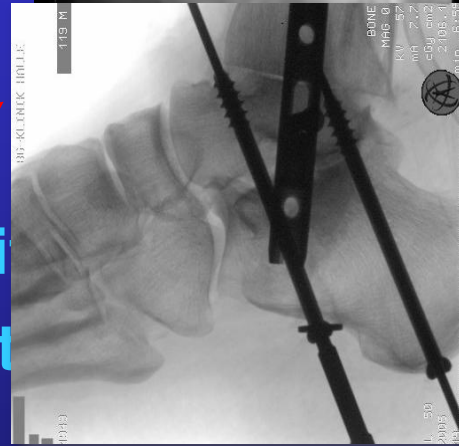
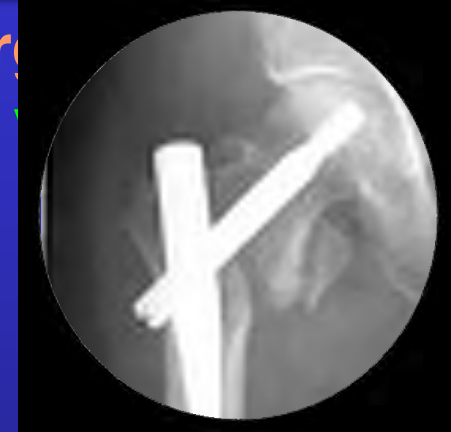
why a mobile C-arm?

For German Professional O
the most important tool for

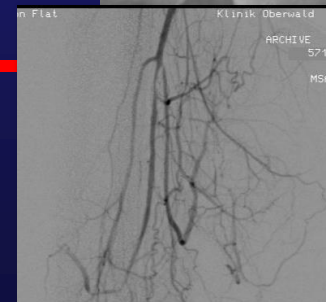
to control:

- fracture after reposition
- luxation control / art
- puncture
- implants osteosynthesis, pedicle screw
- endoprotheses and revisions
- correction osteotomies
- vascular imaging

e.g. in case of vascularized graft



alignment

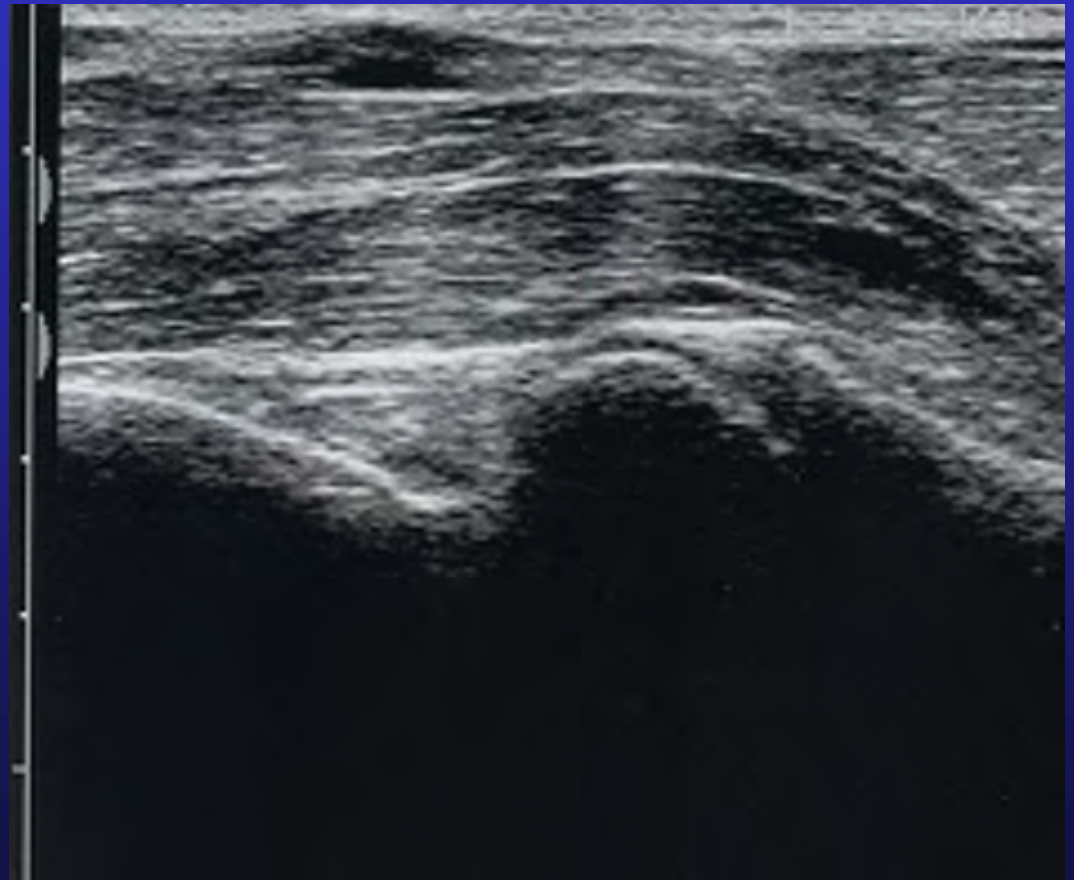


why a mobile C-arm?

benefits for patient and surgeon:

- minimal invasive
- always available
- intraoperative control
- high precision
- easy
- time efficient

Sonography



Computer Tomography

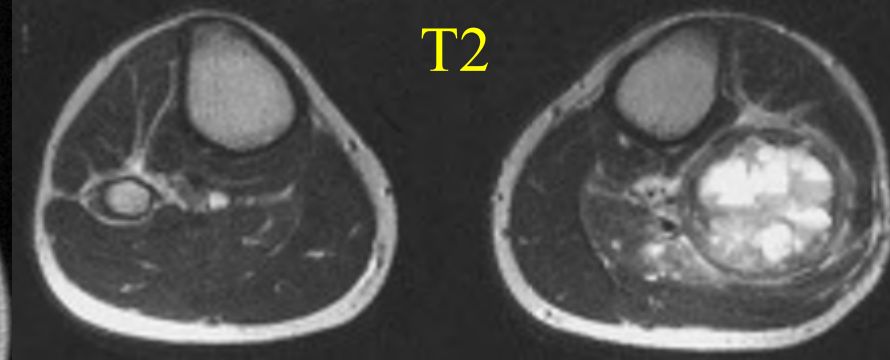
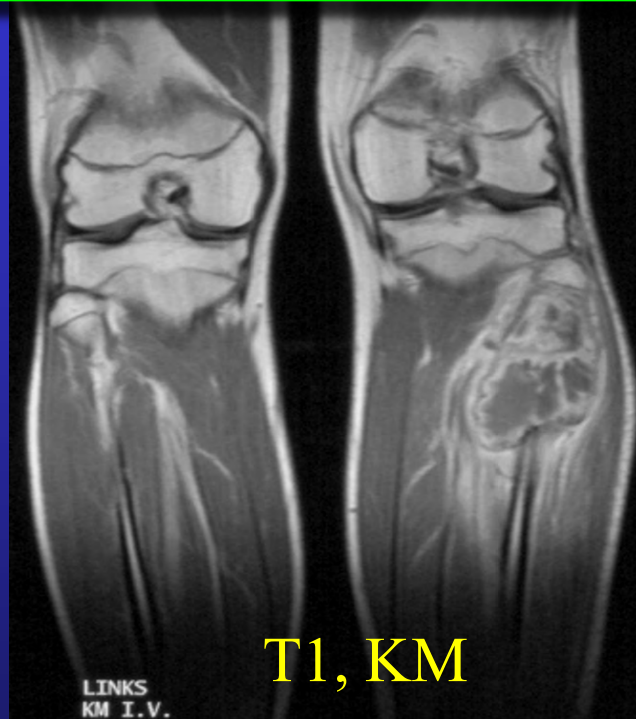


- Optimal bone detection
- True to scale (no distortion)
- easy to be segmented

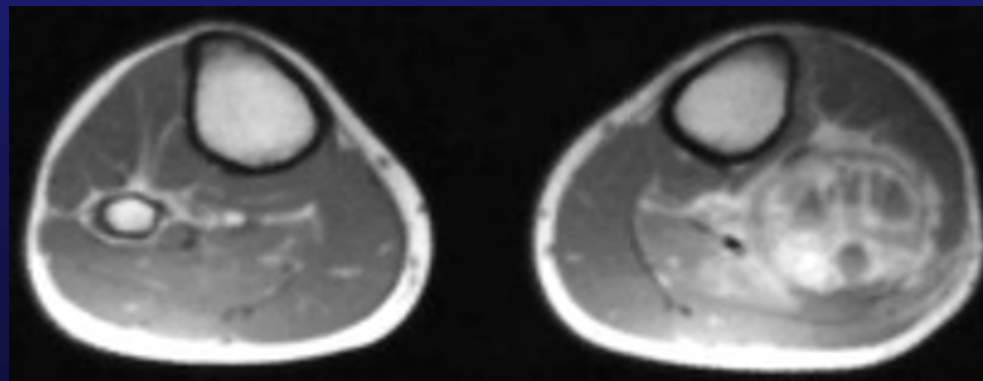
Hypernephrometastase re. Os Ilium

Magnetic Resonance Tomography (MRT)

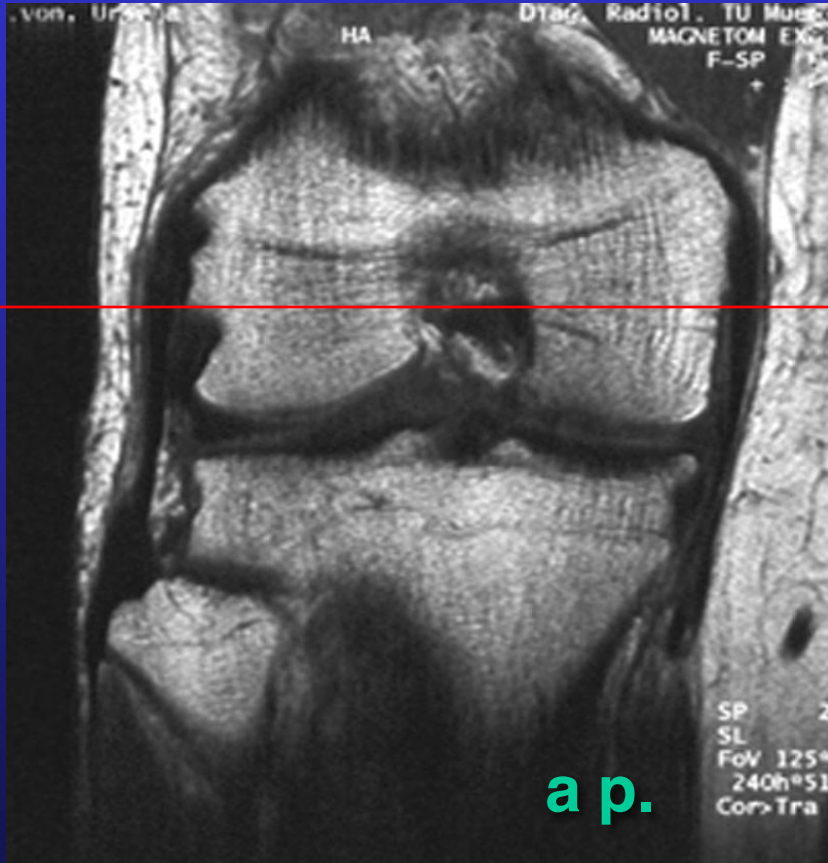
Magnetic Resonance Imaging (MRI)



AKZ; B.F., m., 18J



Magnetic Resonance Imaging



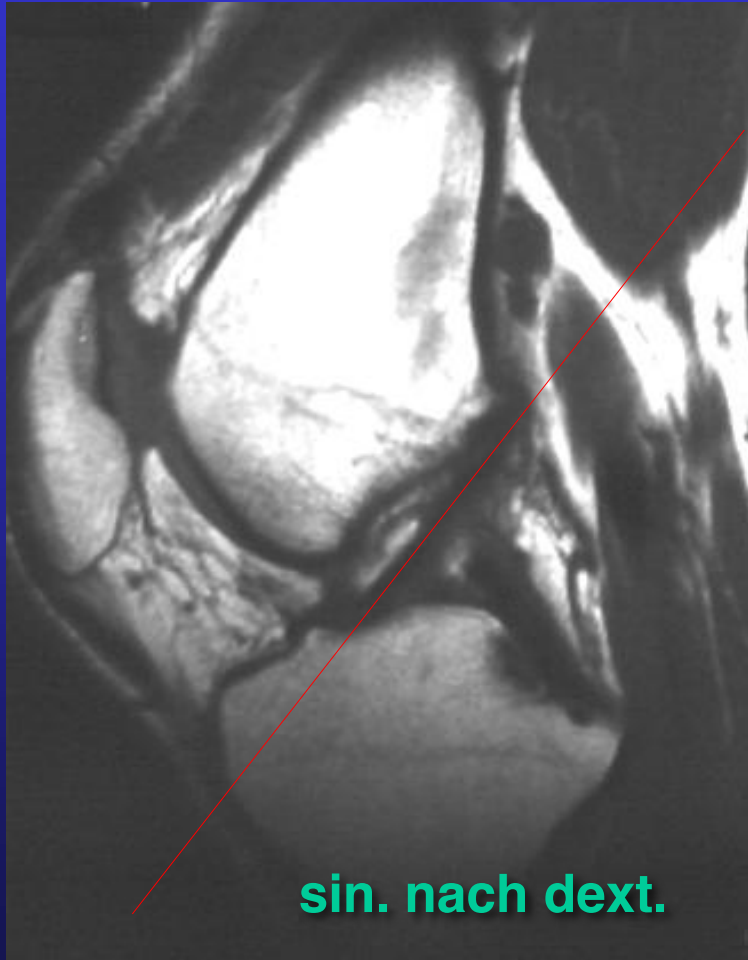
coronar



axial

Magnetic Resonance Imaging

ventral

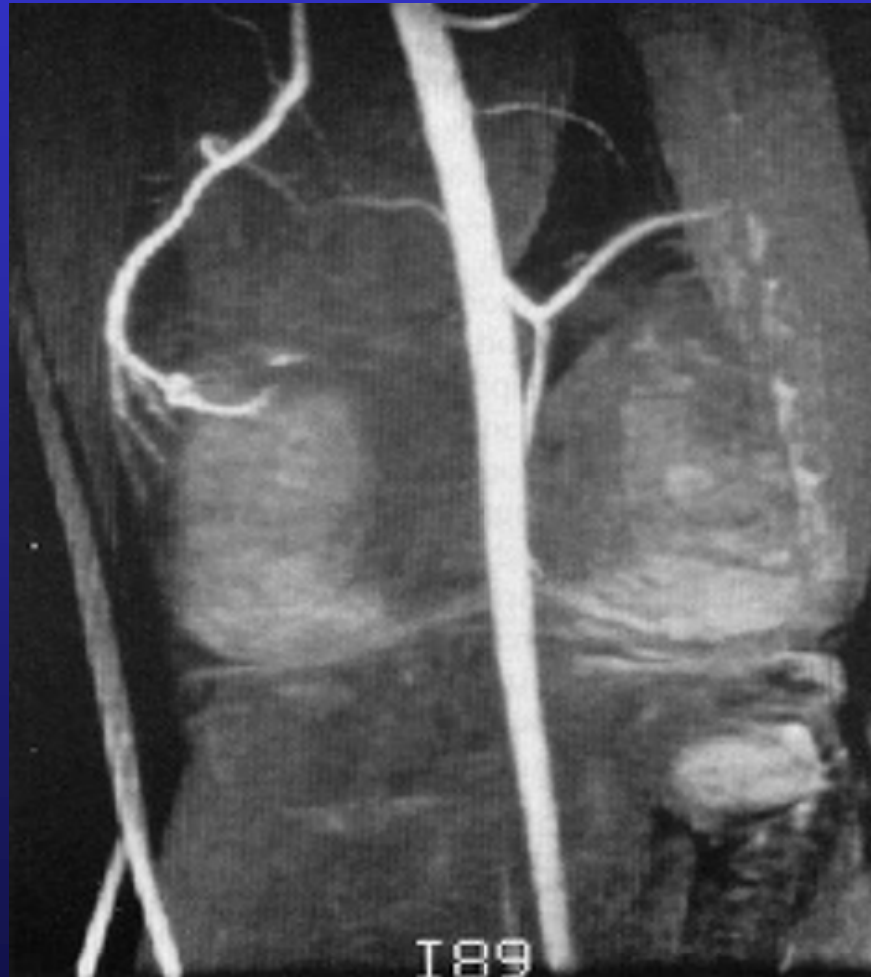


sagittal



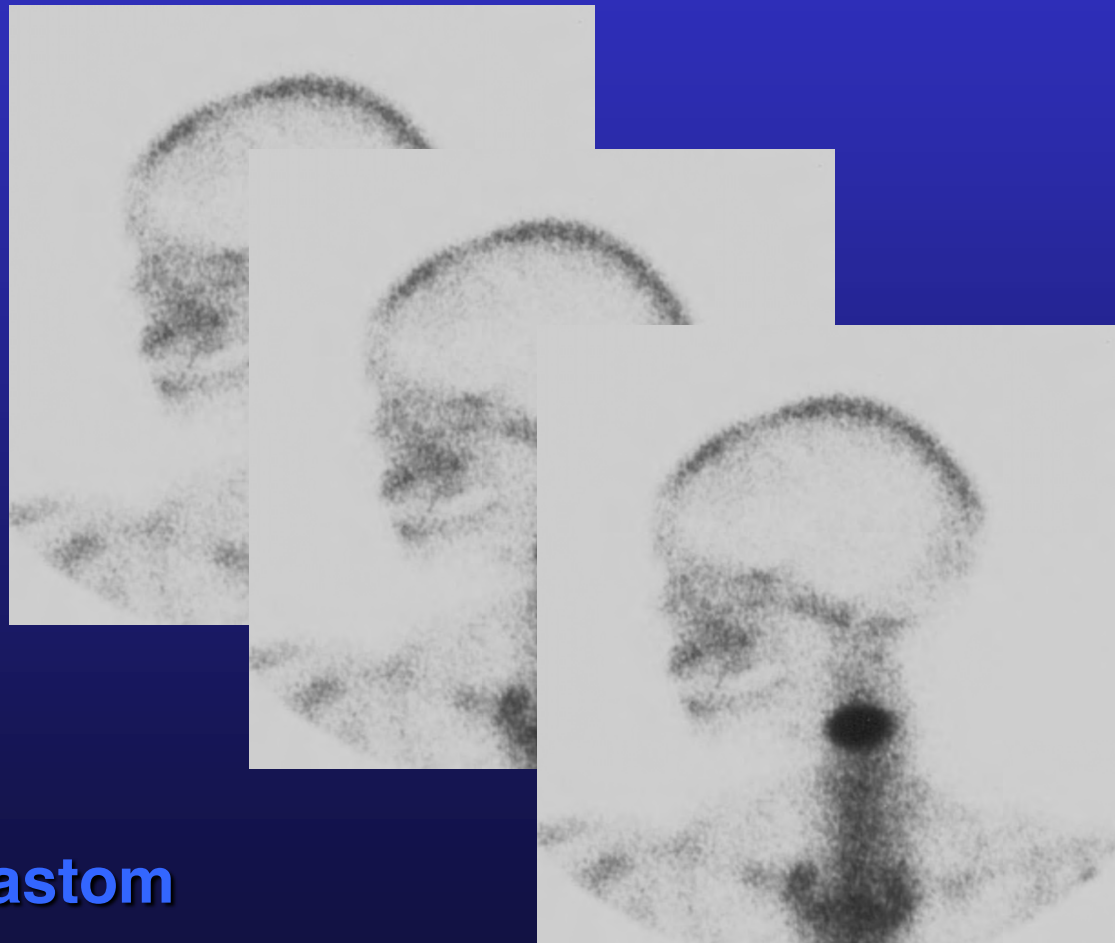
schräg coronar

MR- Angiography



SPECT

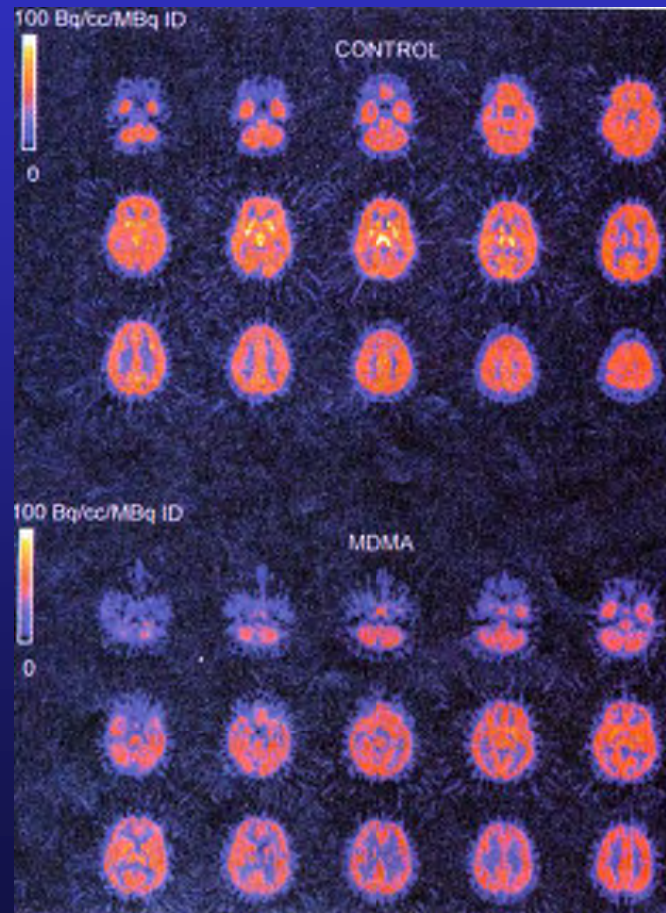
Single Photon Emission Computer Tomography



Osteoblastom

PET

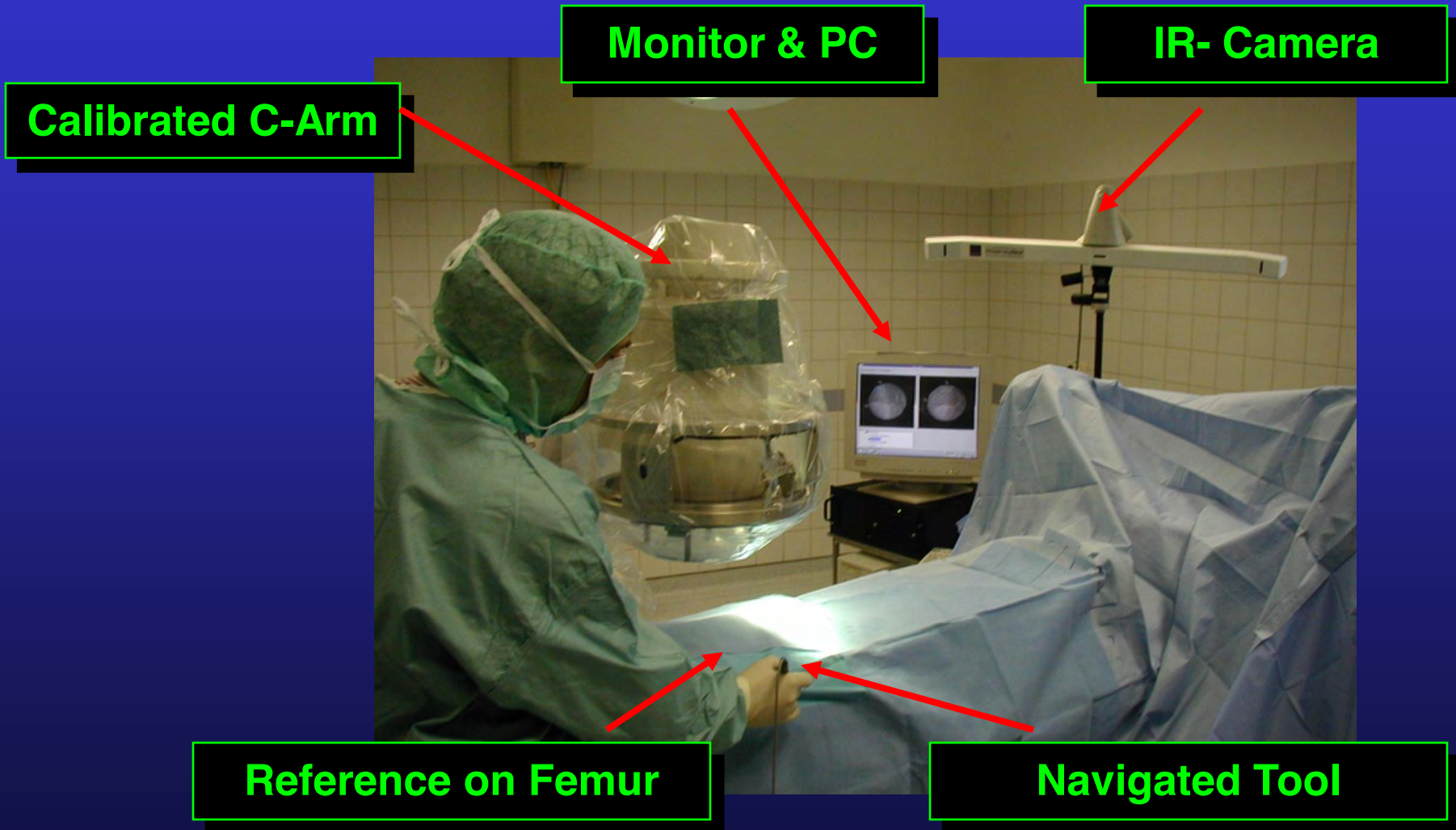
Positronen Emission Tomography



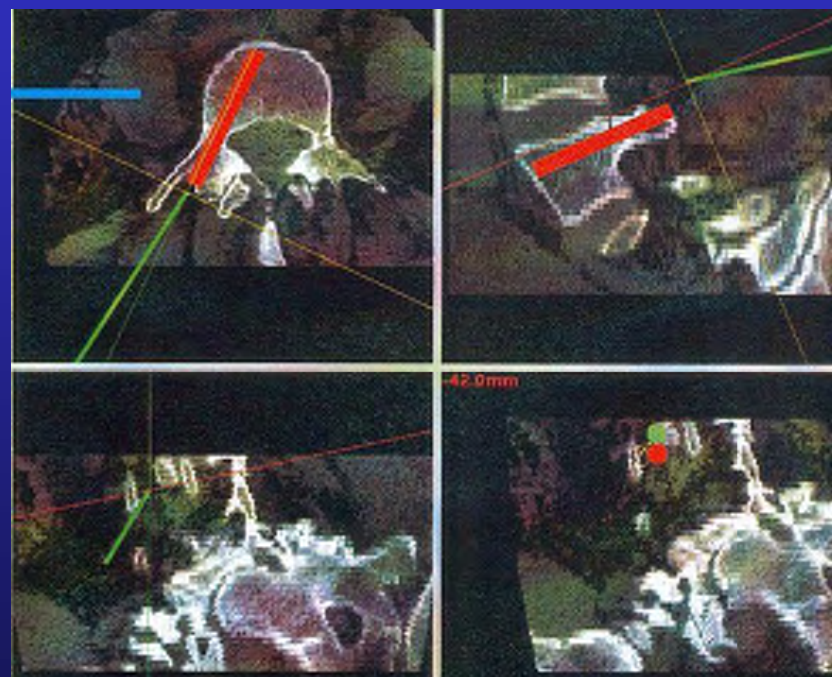
Data/Imaging as Prerequisite for Navigation Systems

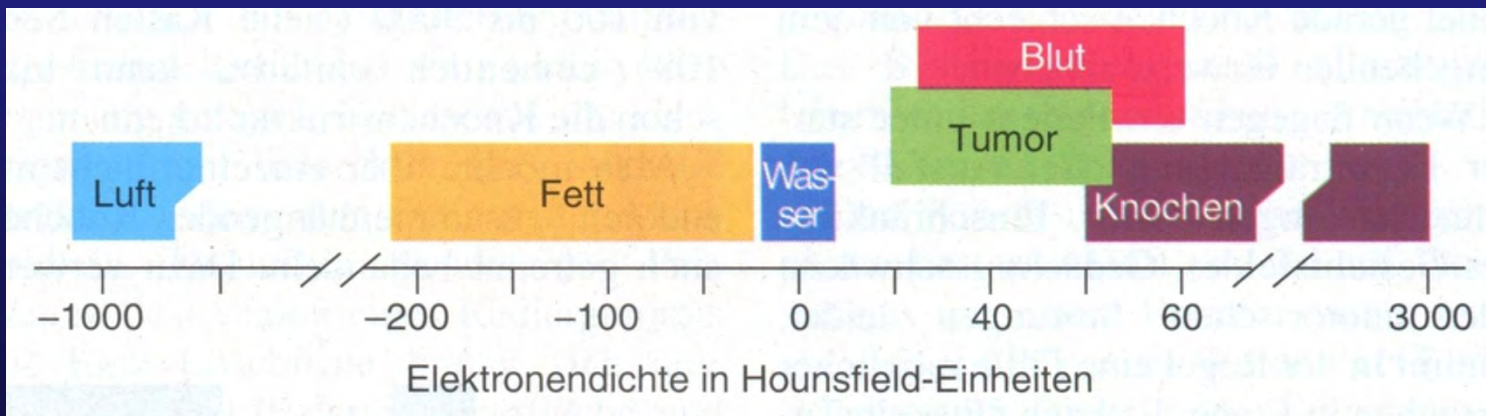
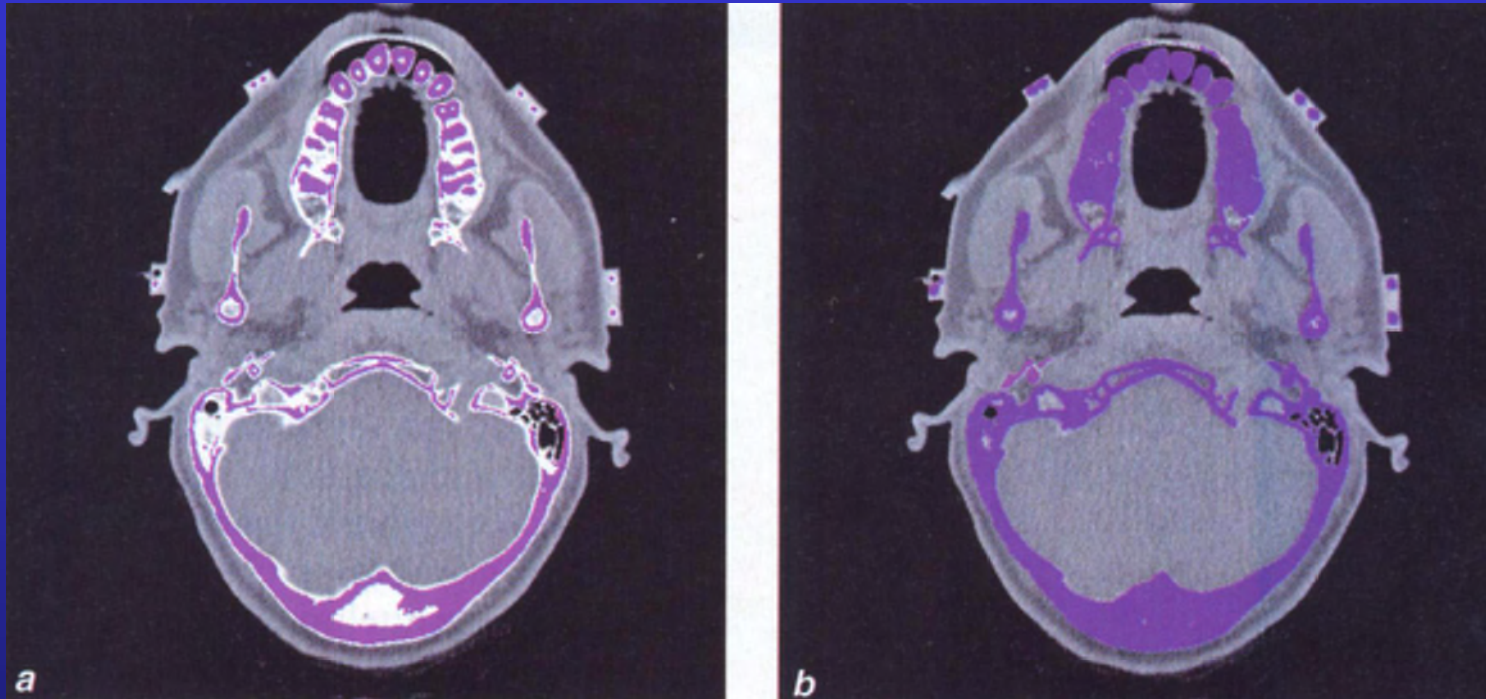
- No „Imaging“
- C-Arm based Navigation
- C-Arm and CT/MRI based
- CT based Navigation
- MRI based Navigation
- Multimodal (...+ PET, MRA etc.) Navigation

Computer Assisted Surgery



CT based Navigation





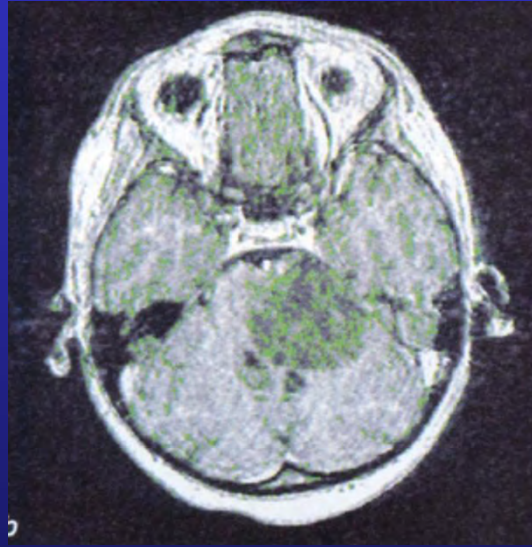
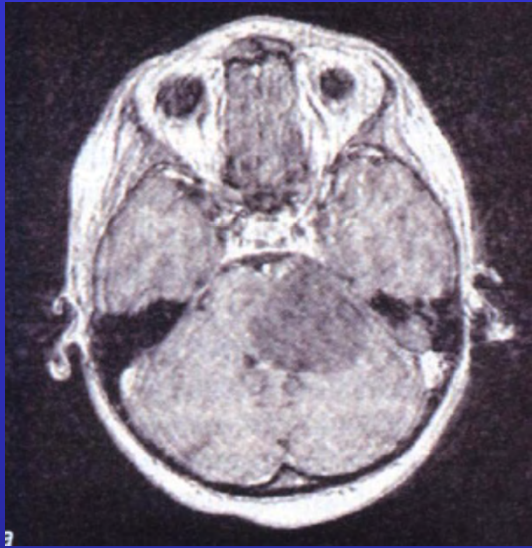
Substance	HU
Air	-1000
Fat	-120
Water	0
Muscle	+40
Contrast	+130
Bone	+400 or more

MRI based Navigation

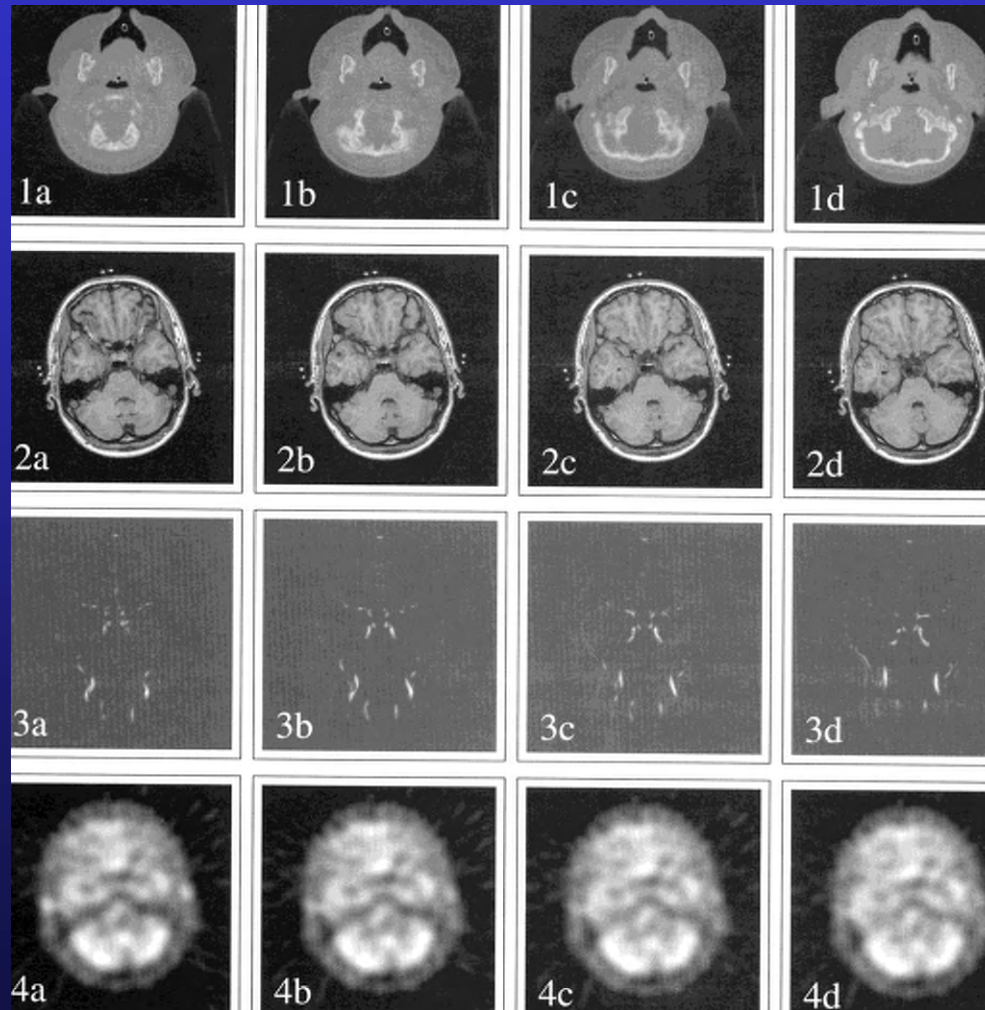
Problems:

- Segmentation
- Matching
- Modality based distortion

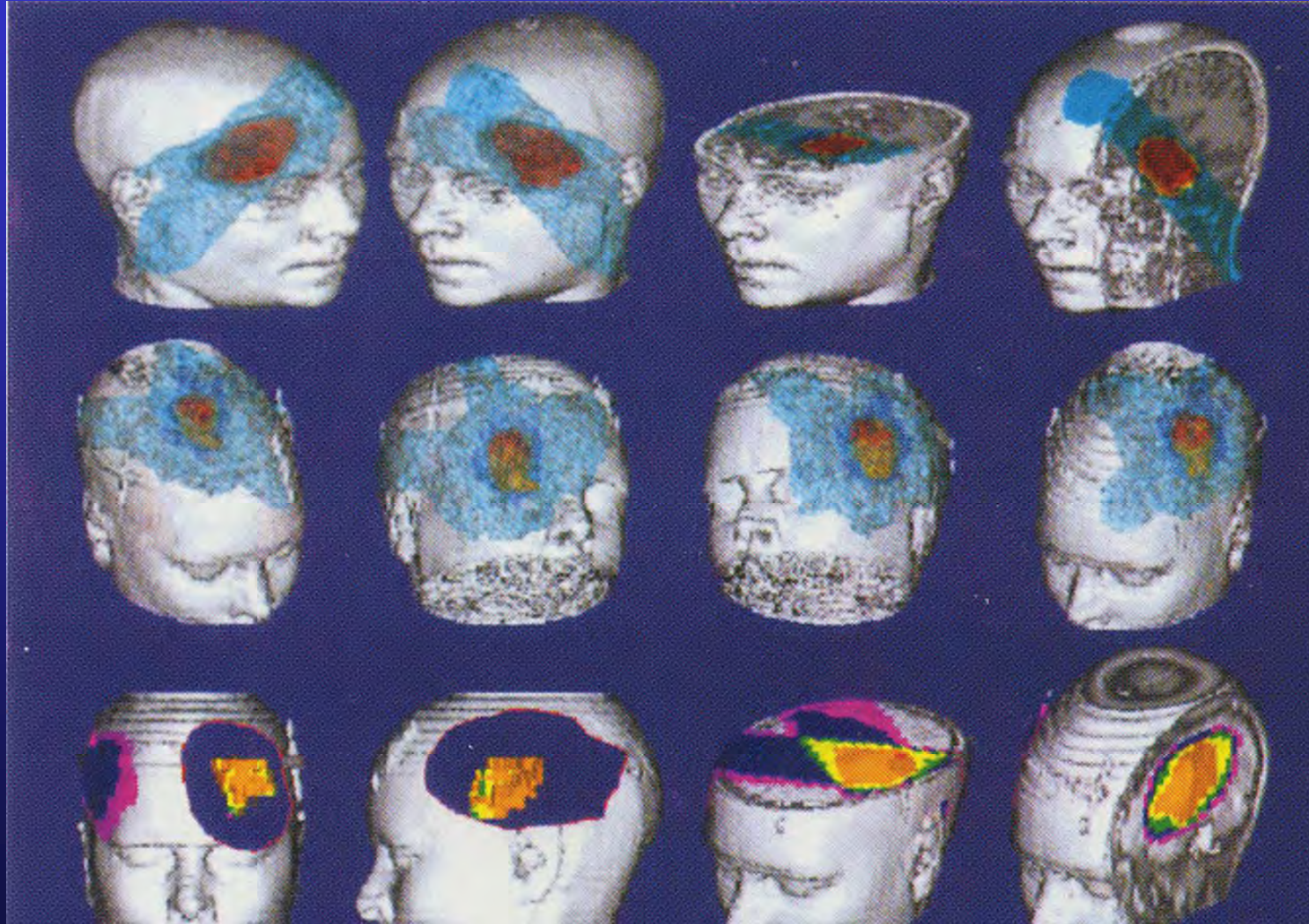




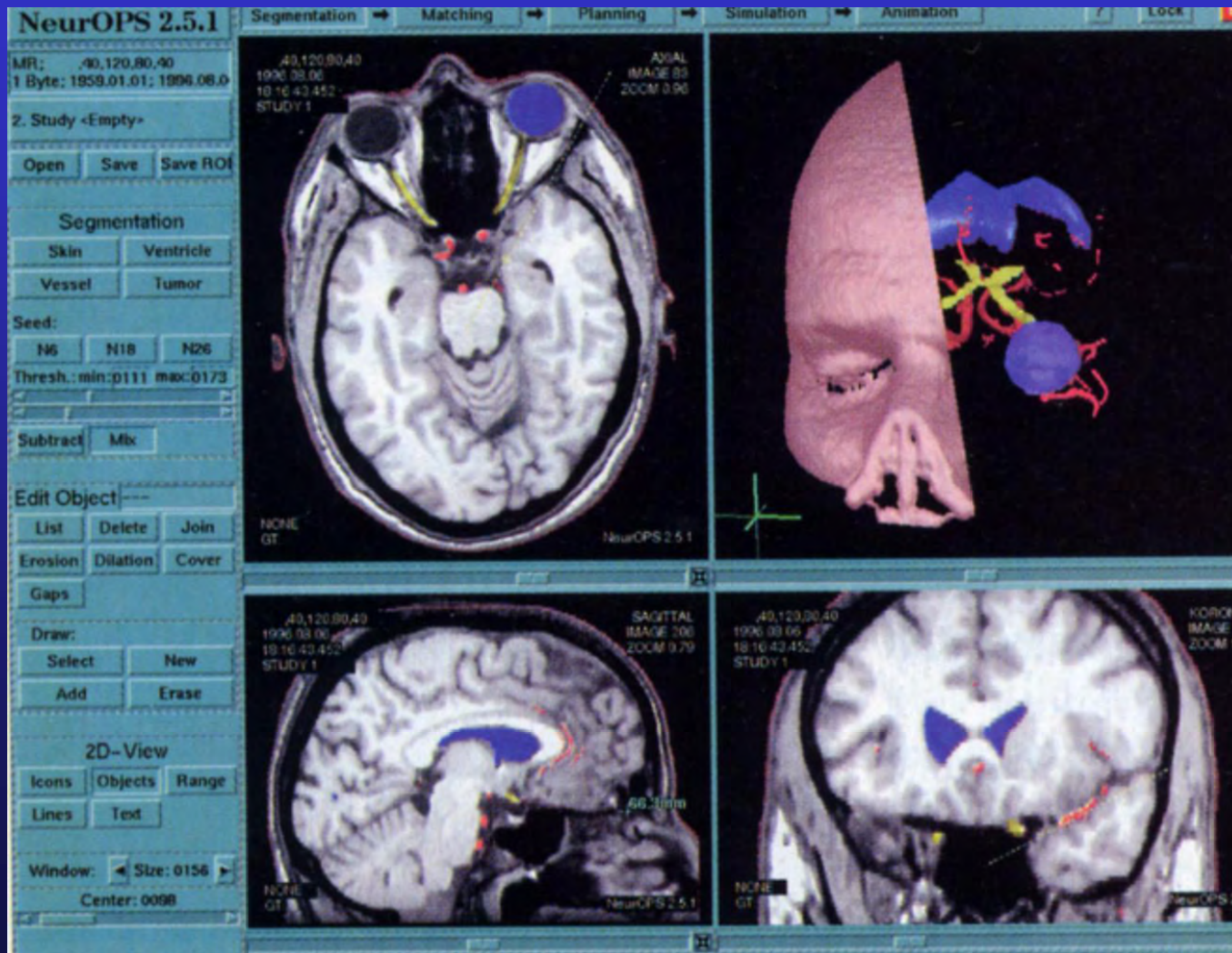
Multimodal Navigation



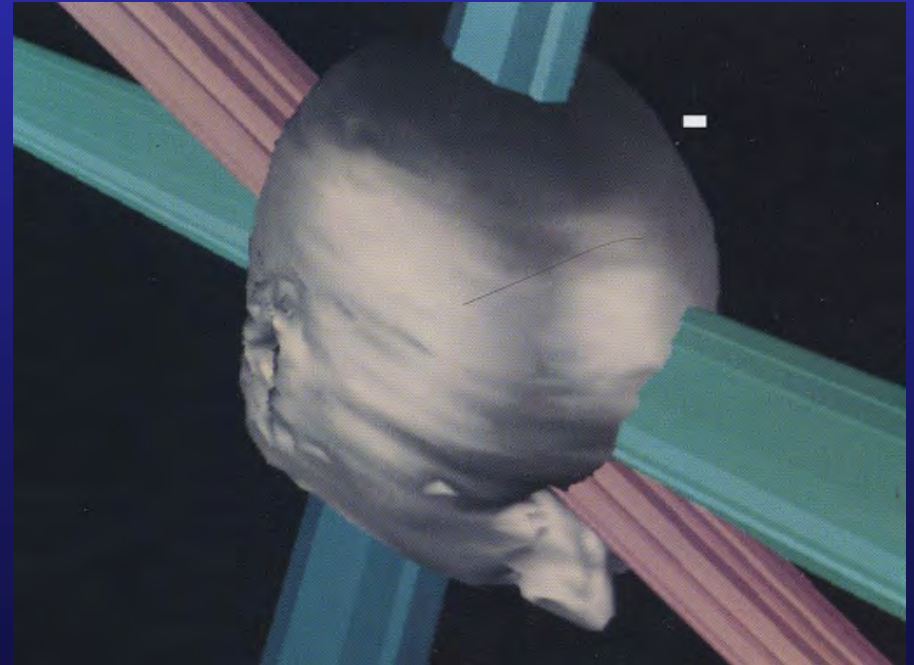
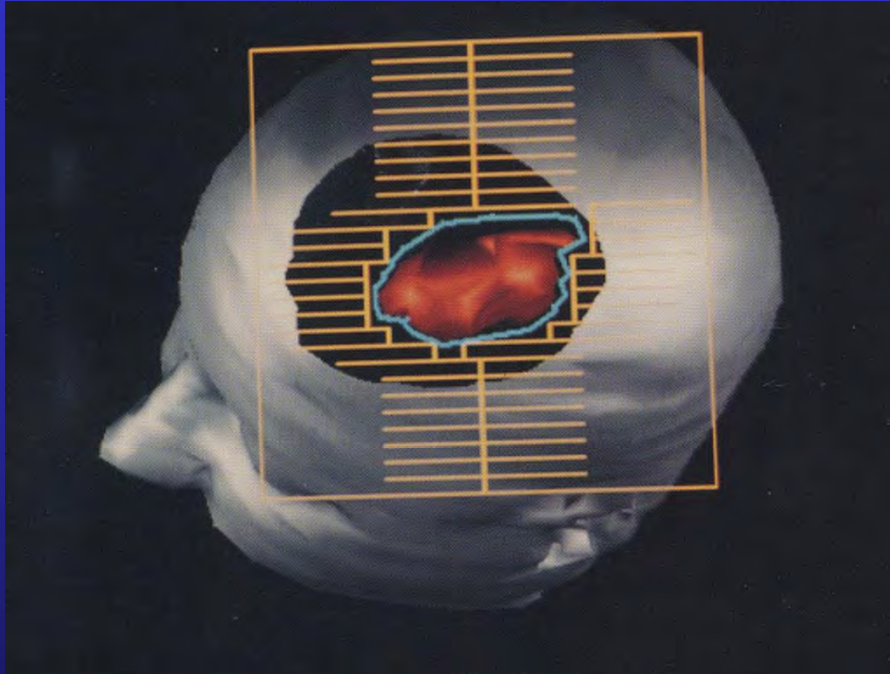
Multimodal Navigation



Multimodal Navigation



Multimodal Navigation



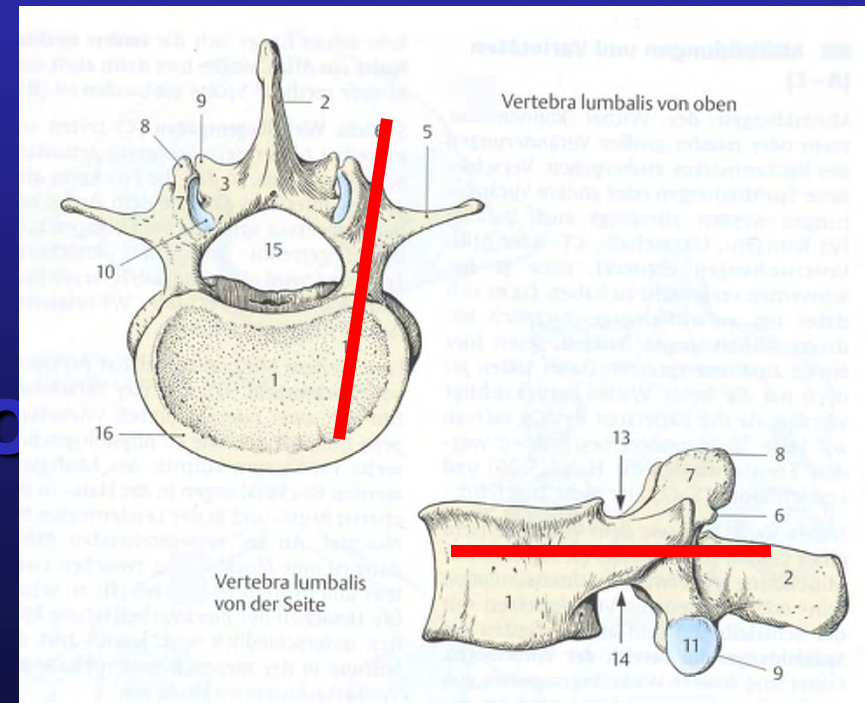
Pre-/Intraoperative Planning

- **Pedicle screw**
- **K-wire fixation**
- **Specimen biopsy**
- **KTEP**
- **Pfannendachosteotomie**

Pre-/Intraoperative Planning

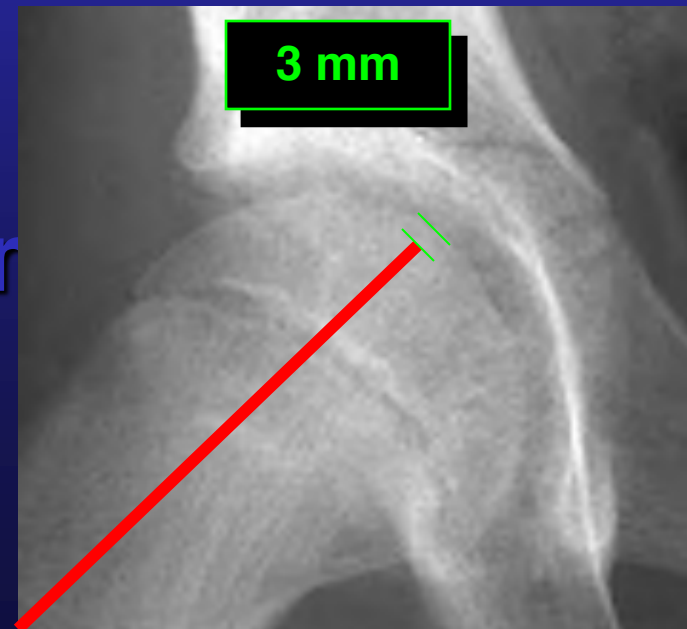
- Pedicel screw
- K-wire fixation
- Specimen biopsy
- KTEP
- Pfannendachosteotomie

- Direction
- Screw length



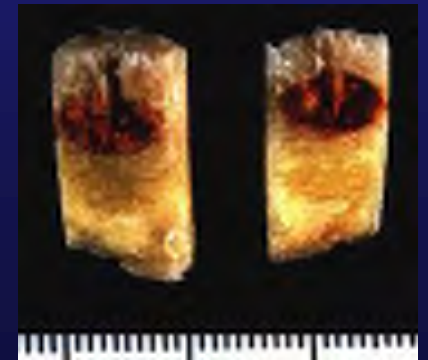
Pre-/Intraoperative Planning

- Pedicel screw
 - **K-wire fixation**
 - Specimen biopsy
 - KTEP
 - Pfannendachosteotomie
- Direction
 - Minimal distance to joint



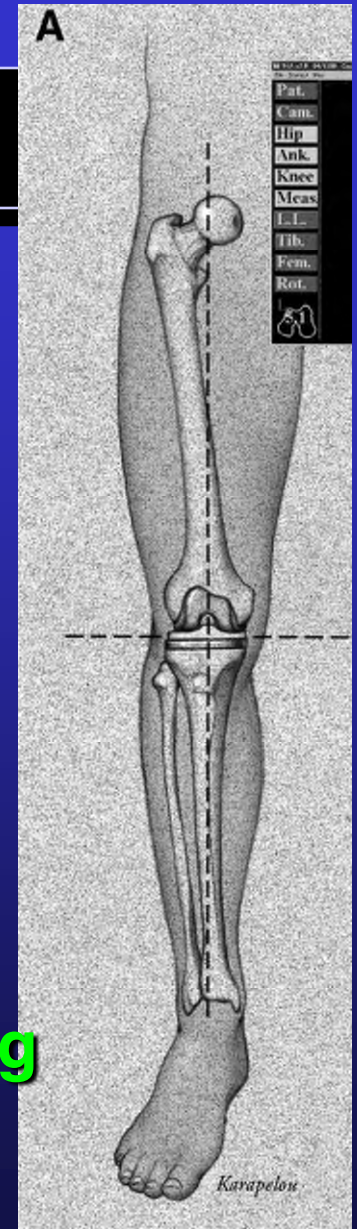
Pre-/Intraoperative Planning

- Pedicel screw
- K-wire fixation
- **Specimen biopsy** - Direction
- Target
- KTEP
- Pfannendachosteotomie



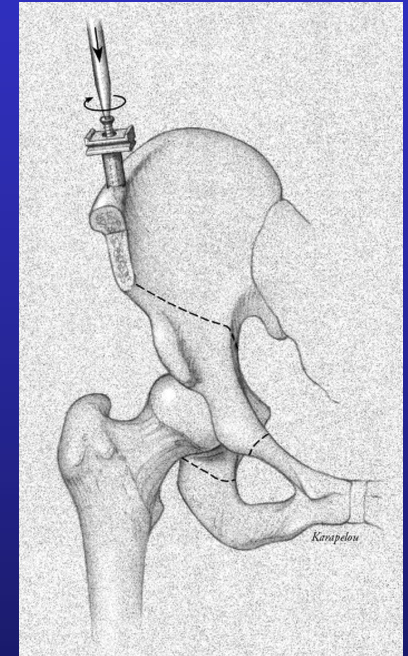
Pre-/Intraoperative Planning

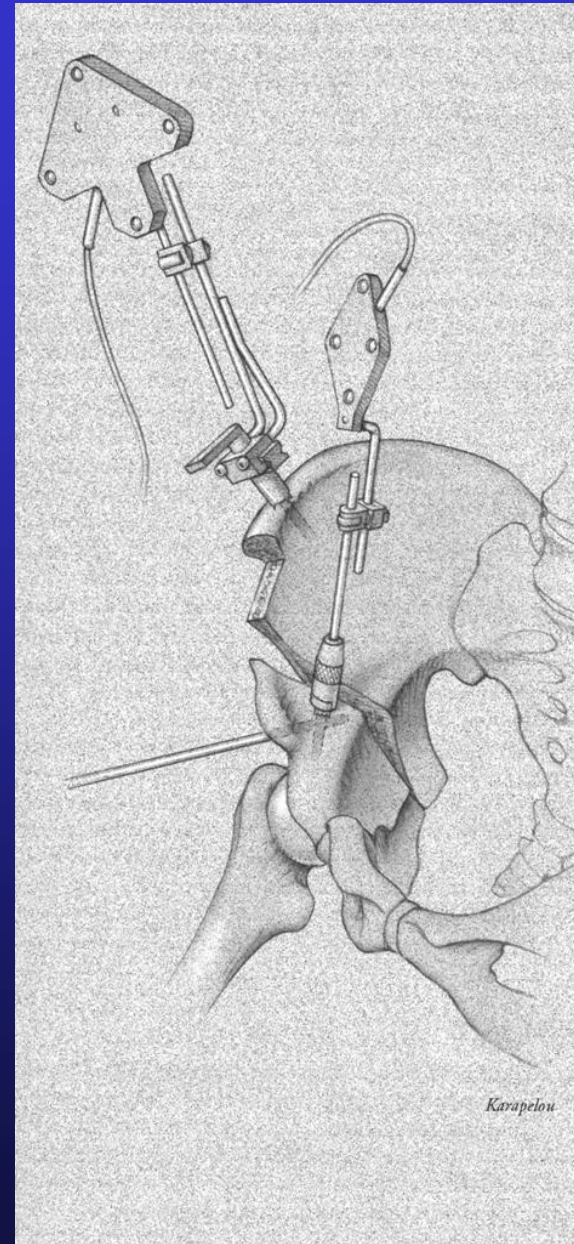
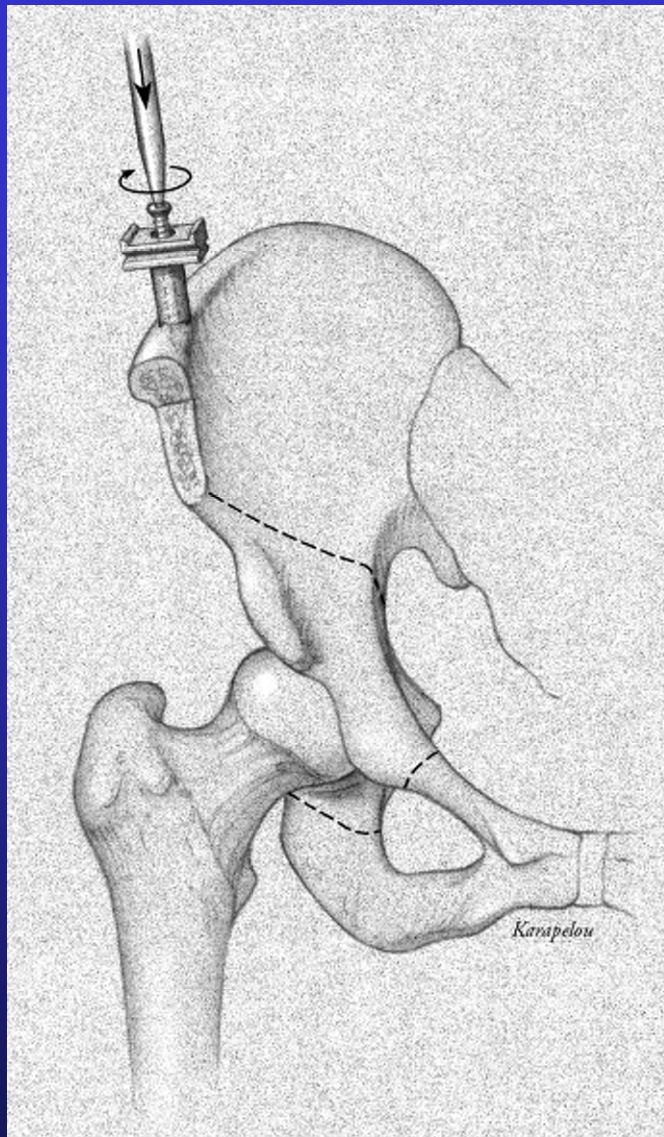
- Pedicel screw
 - K-wire fixation
 - Specimen biopsy
 - **KTEP**
 - Pfannendachosteotomie
- Cut height
 - Cut planes
 - Implant size
 - Implant positioning

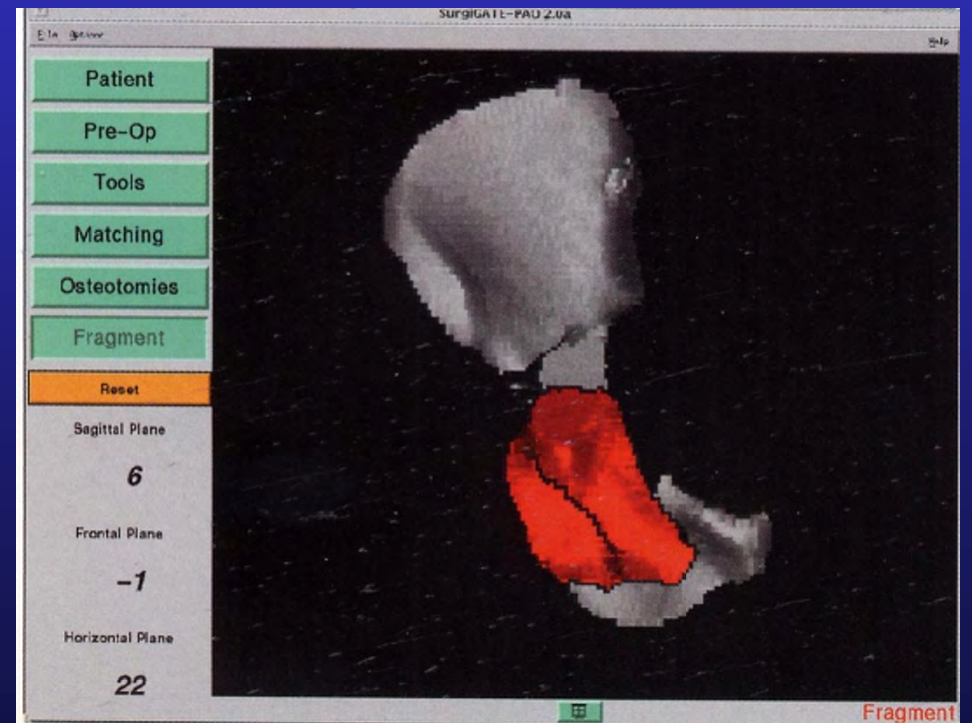


Pre-/Intraoperative Planning

- Pedicel screw
- K-wire fixation
- Specimen biopsy
- KTEP
- **Pfannendachosteotomie**
 - Cut heights
 - Cut planes
 - Fragment slewability
 - Fragment positioning
 - Osteosynthesis









Visualization



Visualization

- virtual

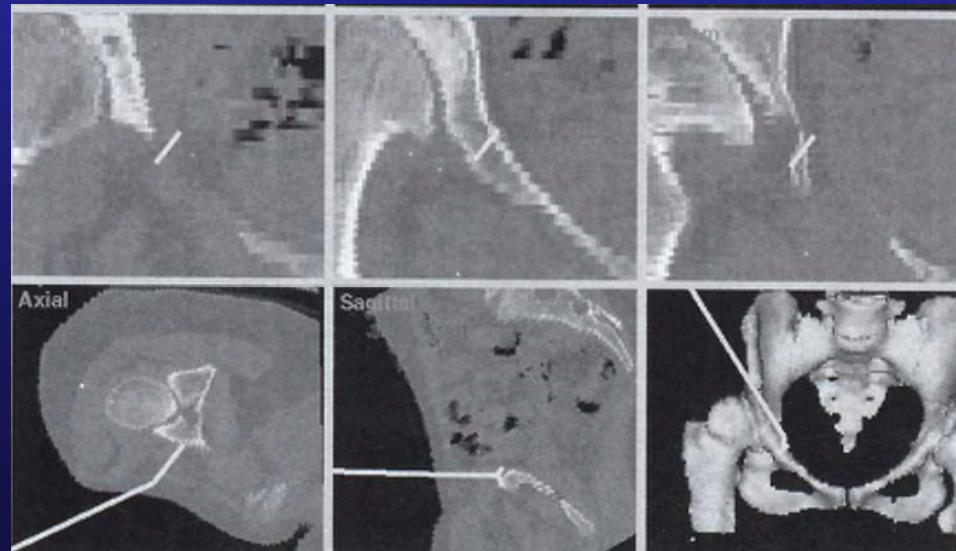
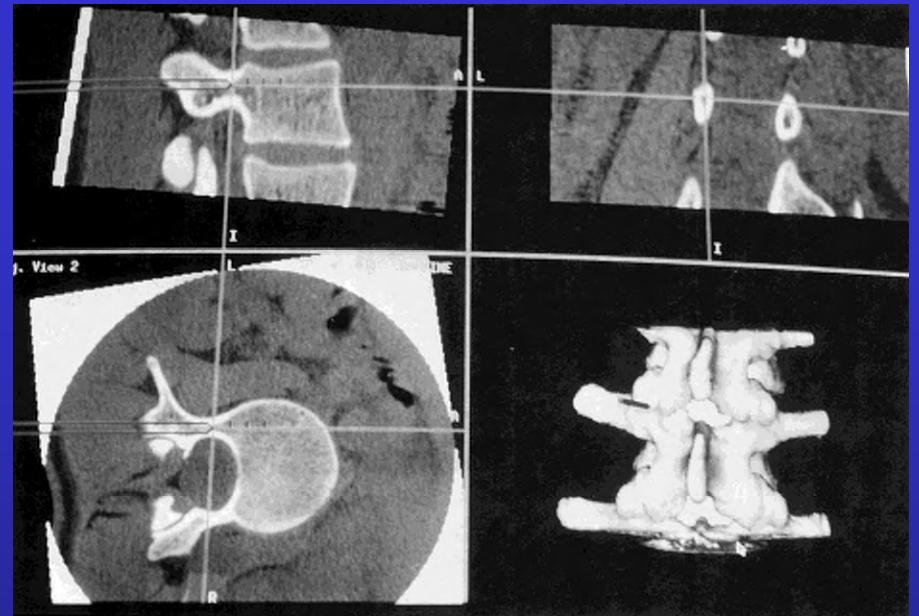
- 2D
 - orthogonal
 - consecutive
 - multiplanar
- Pseudo 3D
- 3D

- Monitor
- Head Mounted Display
- AR

- unsegmented
- point/line reduction
- geometric bodies
- segmented

- „rapid prototyping“

- 2D
orthogonal
consecutive
multiplanar
- Pseudo 3D
- 3D

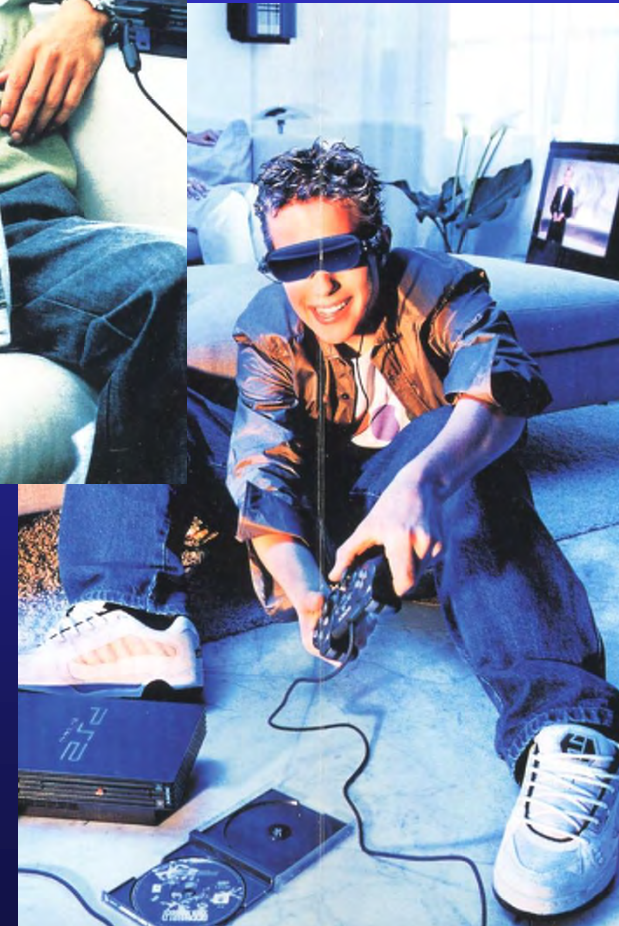
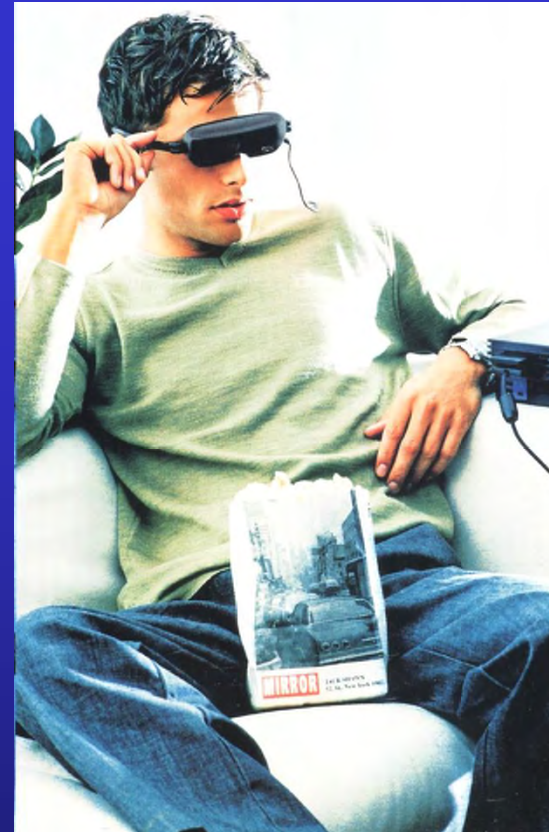


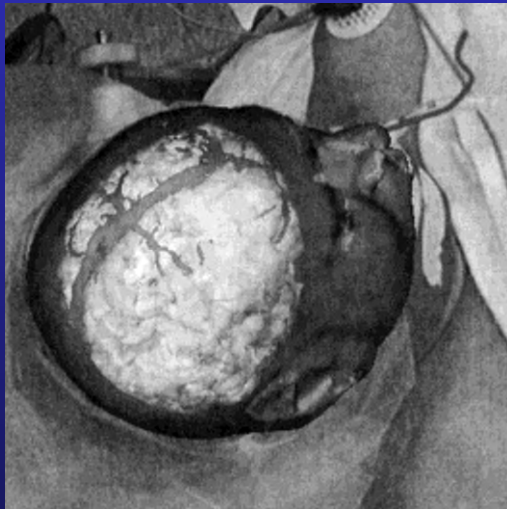
- 2D

orthogonal
consecutive
multiplanar

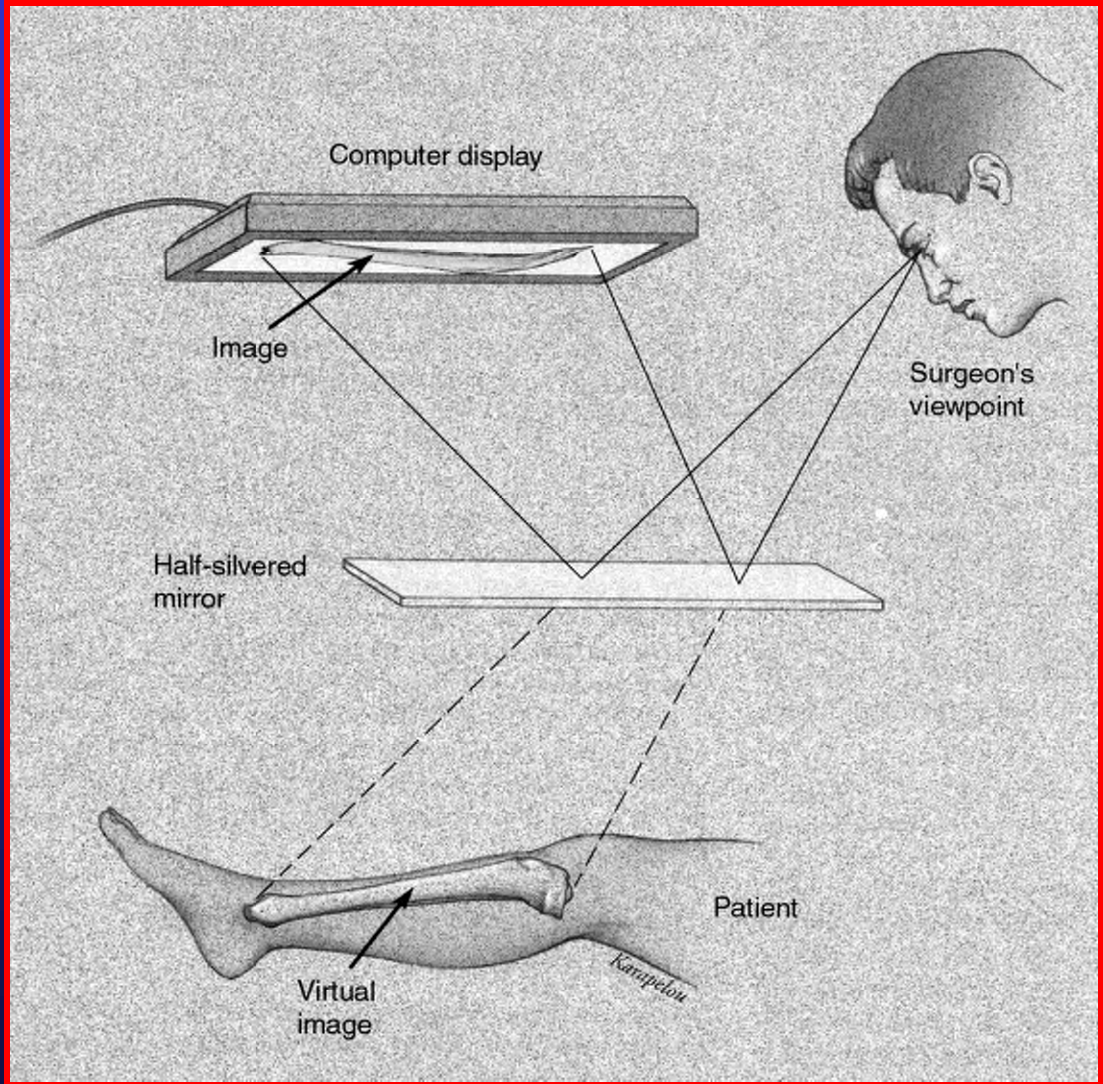
- Pseudo 3D

- 3D

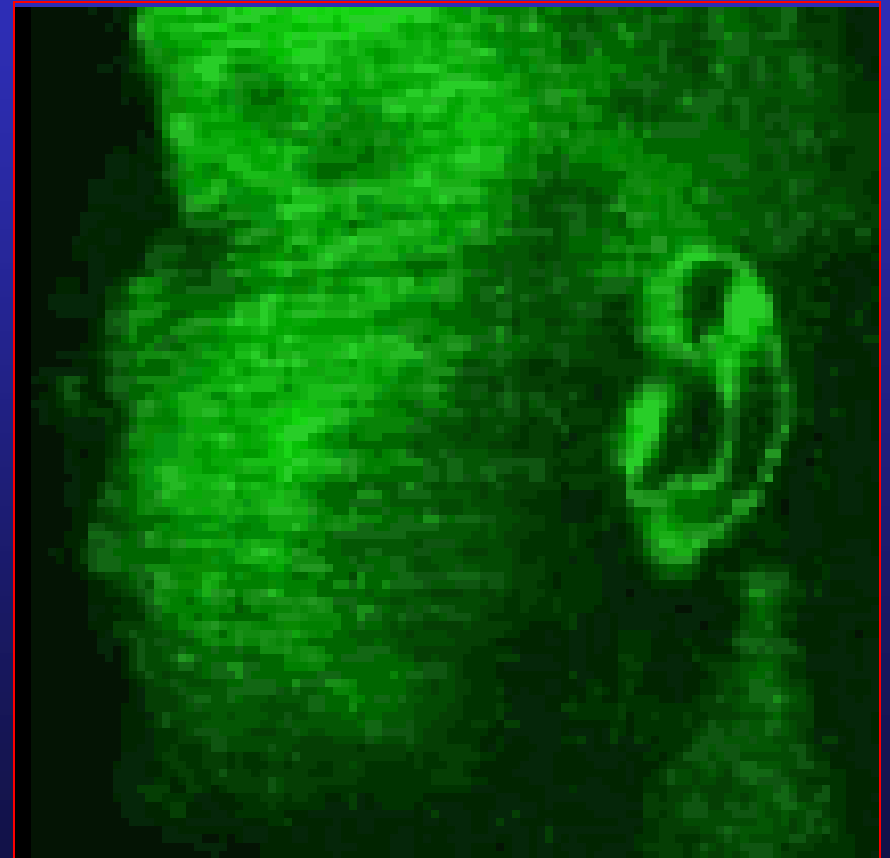
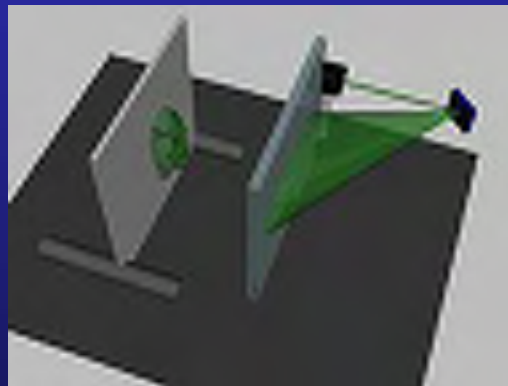
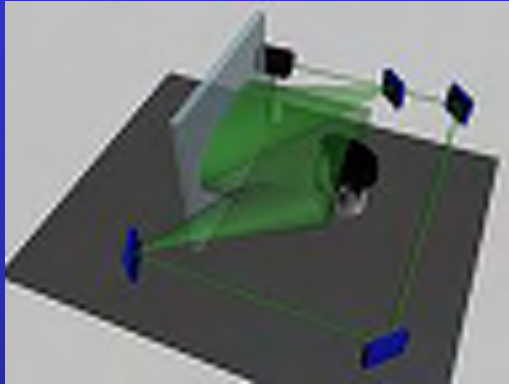




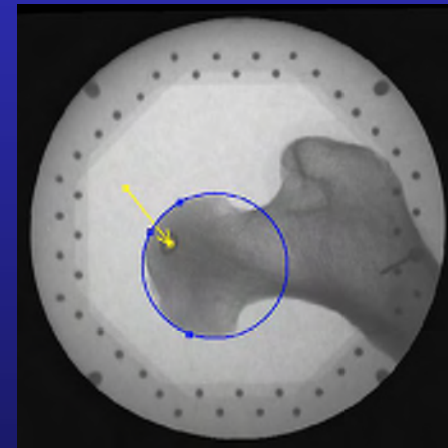
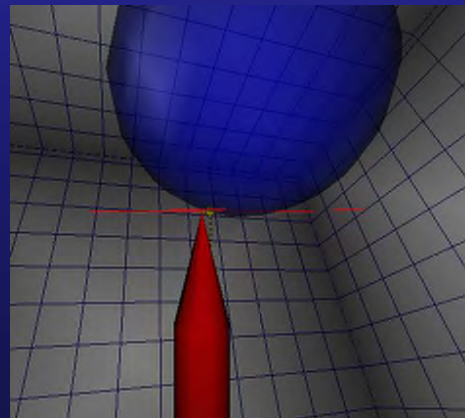
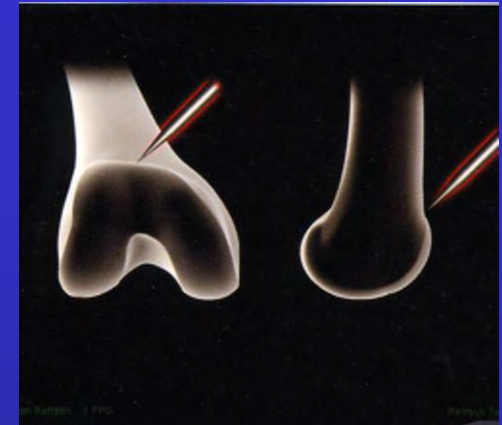
augmented reality

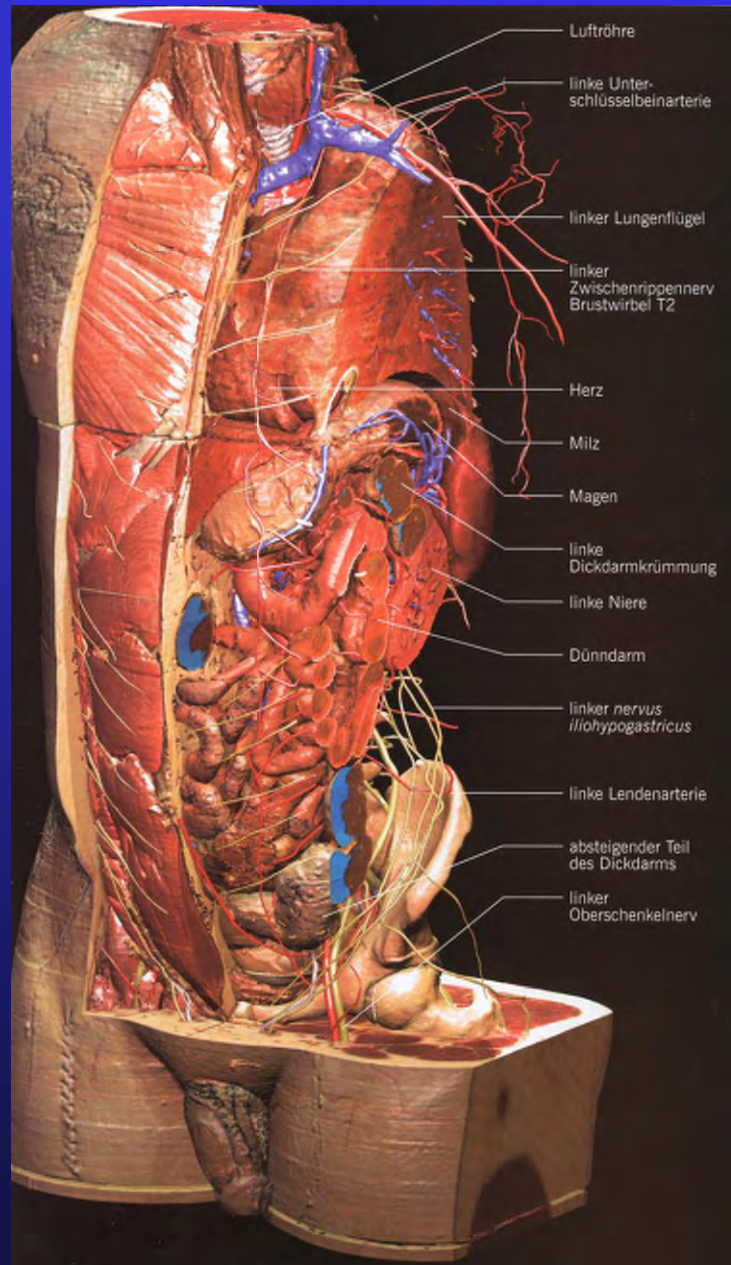


Holography

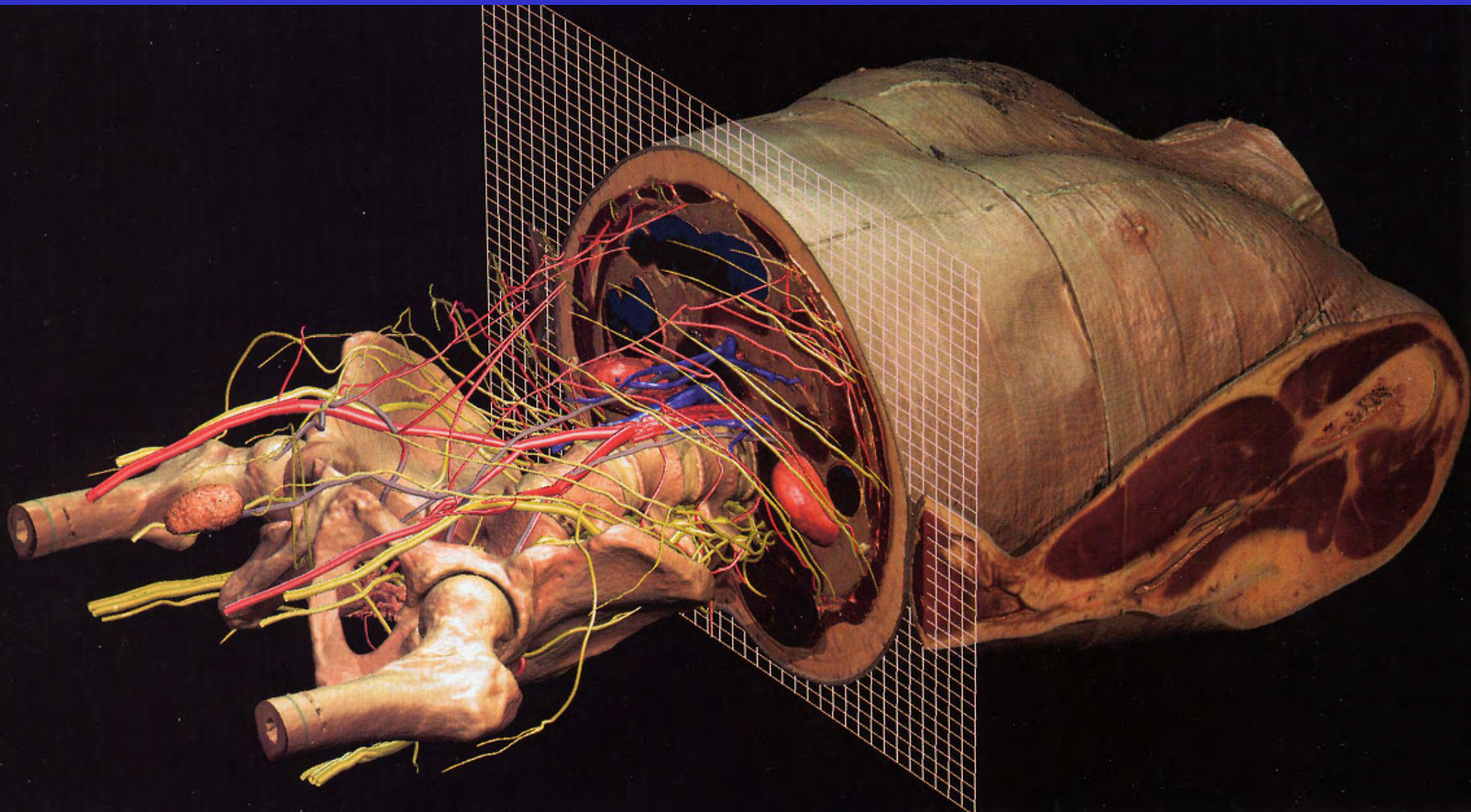


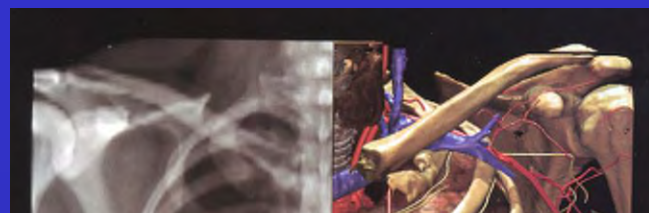
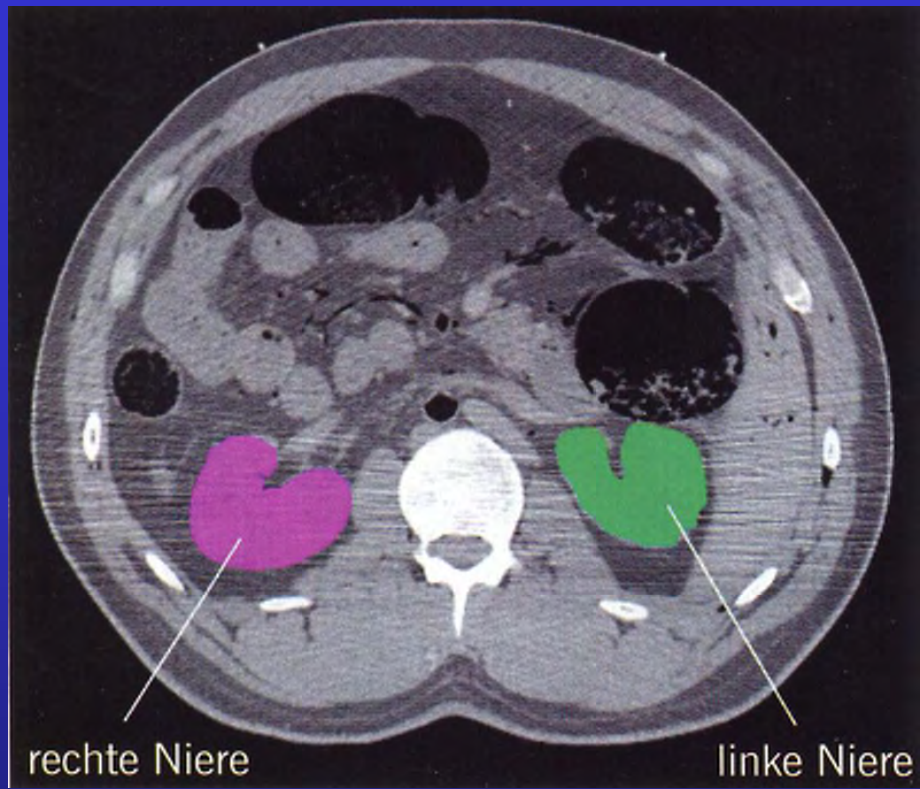
- unsegmented
- Point/Line reduction
- Geometric bodies
- segmented





Project VOXEL-MAN based
on data from „visible human“

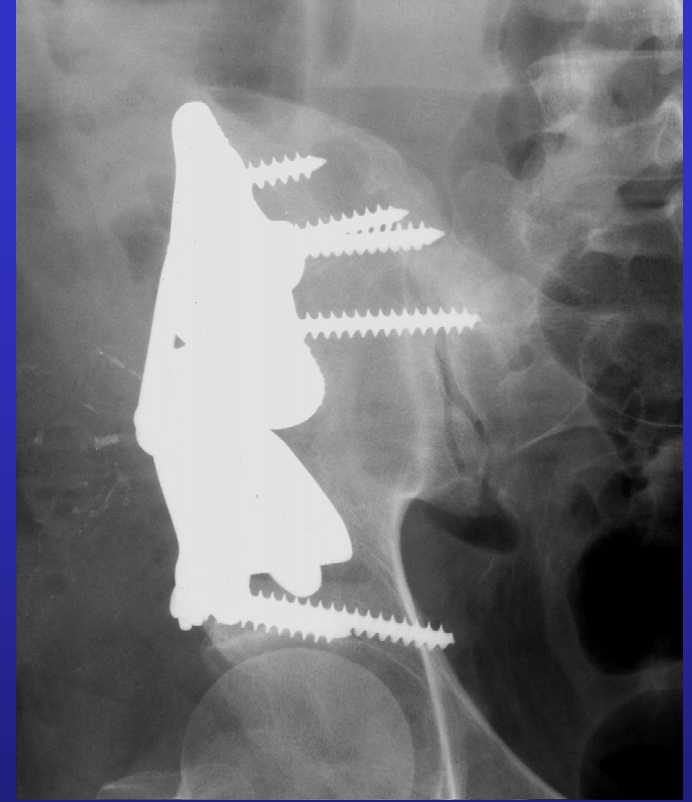






rapid prototyping



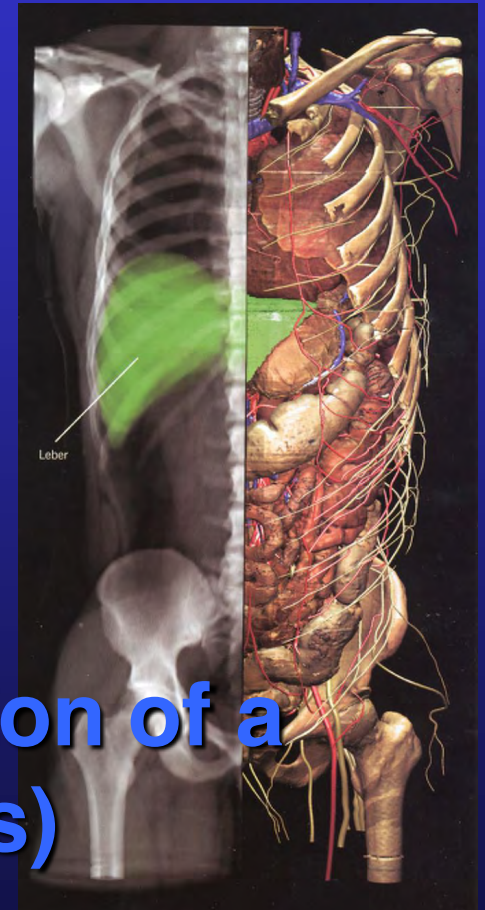


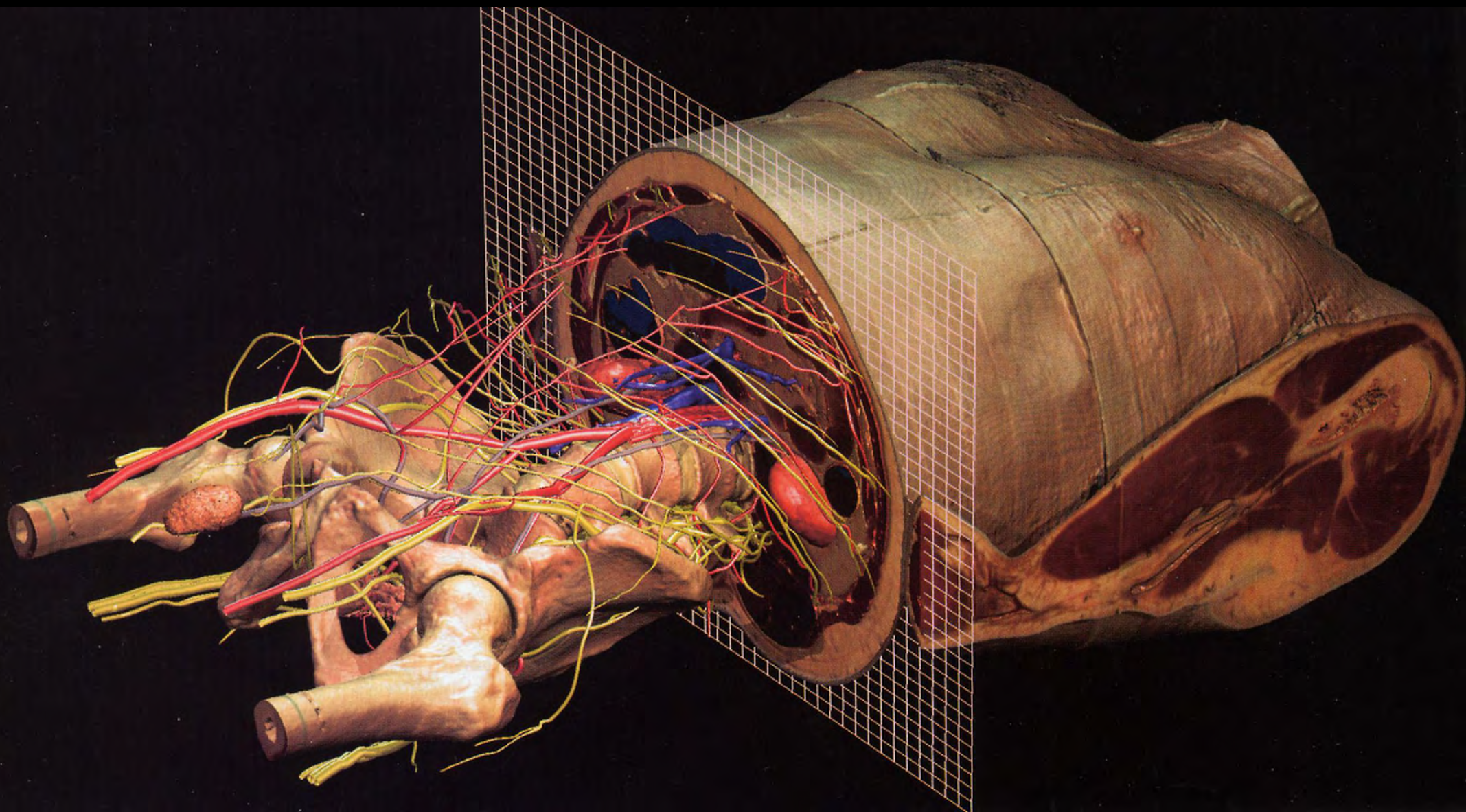
Pros & Cons

Pros

Visualization

- **multiplanar**
- **flexible directions of view**
(e.g. operative view)
- **Improved clarity**
(e.g. after colorful segmentation of a tumor including vessels/nervs)





Pros

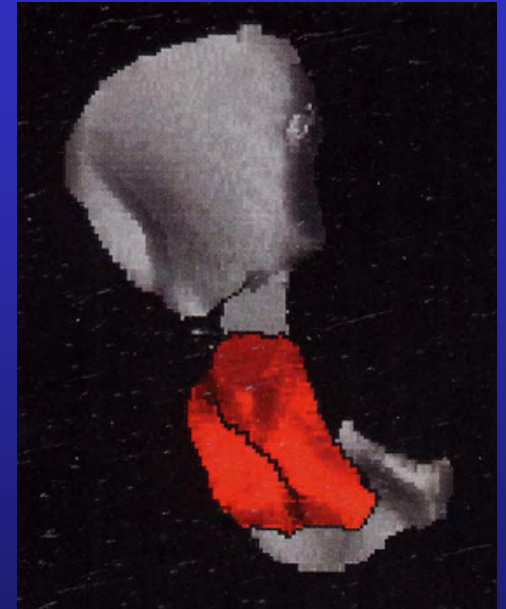
Data Fusion

- **information increase due to multimodal imaging**
- **integration of functional findings (statements)**

Pros

Virtual 3D Modeling

- optimal spatial representation
- biomechanical evaluation
- optimized 3D planning
- check of contact, osteosynthesis planning etc. ...



Pros

Planning

- preop feasibility check
- virtual positioning of the implant
- optimized choose of implant

Pros

Accuracy

- exact intraoperative realization
- reproducibility (scientific studies)
- complication reduction
- biomech. optimization of implantat position
- influence on long-term results?!

Pros

Minimal Invasive

- small incisions
- transdermal methods
- minimal WT-mobilization
- minimal wound surface
- complication reduction

Pros

Documentation

- Preoperative planning documents
- intra- & postoperative documents (e.g. screen shots of operation steps)
- quality management

Pros

Radiation Reduction

- for OR staff
- for patients

Pros

Tool for Education

- improved training through virtual simulations (e.g. pedicular screw positioning, planning, in vitro OR etc.)
- extended intraoperative examination

Future Pros

- **biomechanical modeling**
- **collision animation**
- **telemedicine**

Cons

Training Curve

- new „tools“
- „2 level“ surgery (virtual - real)
- conventional OR-equipment
essential (malfunction, plausibility)

Cons

Extra OR Time

- increased blood loss
- increased inflammation risk
- Increased thrombosis rate

Cons

No Haptic Feedback

- tissue properties not taken into account with active robotics
- bone quality by nail implant
- pedicular drilling



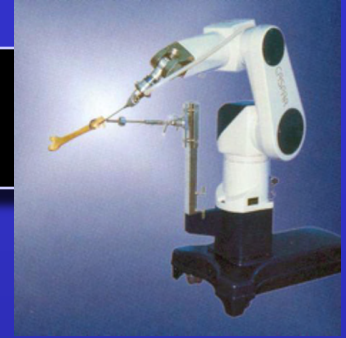
Cons

Tool Limitations

- minimal milling head diameter for HTEP with active robots
- limited prosthesis design



Cons



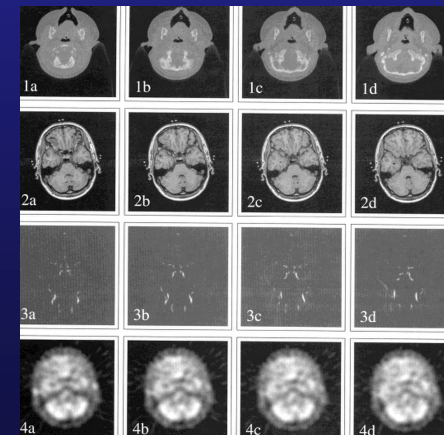
Bigger Incisions

- e.g. robot need linearer access to femur diaphysis
- increased muscle debonding/ablation
- higher incidence of muscle insufficiencies

Cons

Increased Radiation Exposure

- for patients: often preoperative CT necessary
- additional examinations: PET, SPECT



Cons

Second Operations (Zweit-Op´ s)

- e.g. pin - method



Cons

Psychology

- uncritical/blind trust
- „operating virtual image“



Cons

- required space in OR
- Sterility
- Security
- Costs

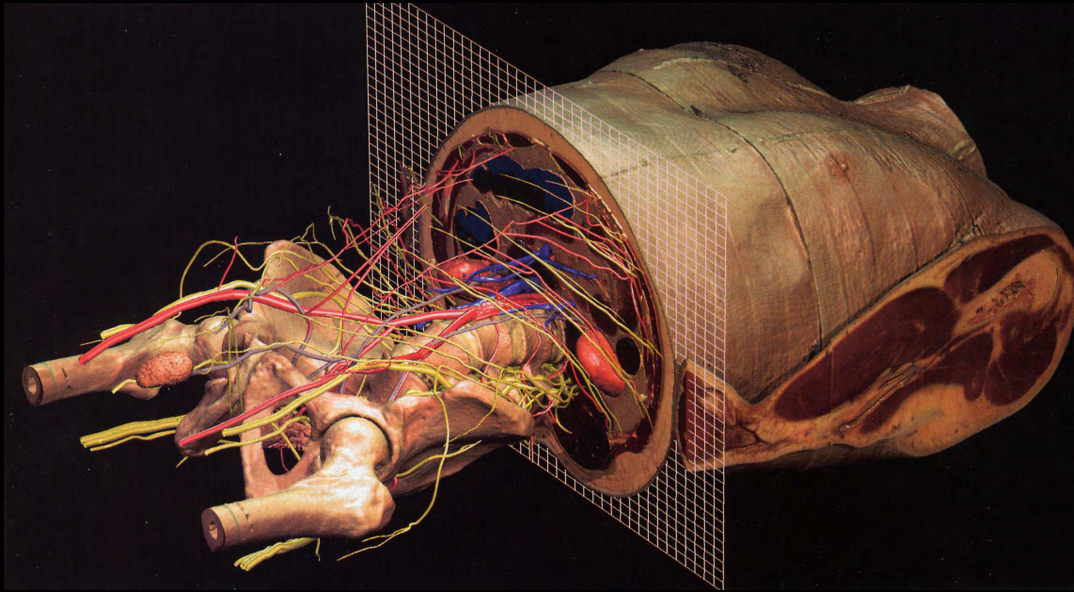


Conclusions

- meaningful innovation on many levels
- main pros: optimized visualization, precision, reproducibility

Conclusions

- **conscious handling necessary together with consequent improvement**
- **for benefit analysis: targeted prospective studies in selected scientific centers**



Thank you

Technical University Munich /Germany

