EVOLUTION OF SURGICAL NAVIGATION DURING PAST DECADE

Surgical Robotics

European Summer University
Montpellier September 7-14, 2005

ISIS Y. Patoux Rev.A

Surgical Navigation - Summary

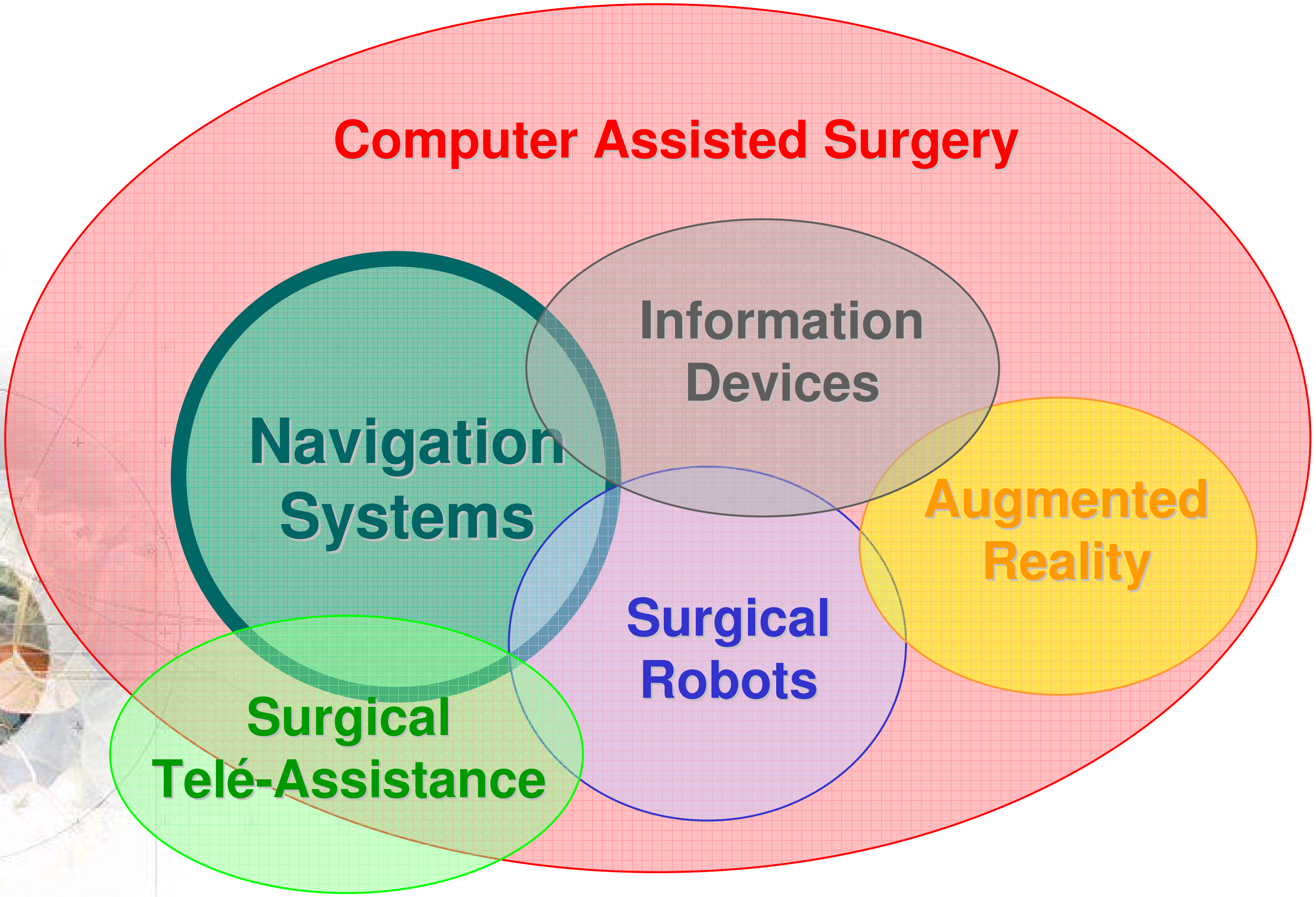
Surgical navigation has greatly evolved during the past decade, both in terms of localization technologies as well as in registration techniques, imaging modalities, patient data management, OR equipments interfacing, but also and mainly surgical applications.

The first part of this (long) presentation will overview those evolutions.

INTRODUCTION
PRINCIPLES
TECHNOLOGIES
APPLICATIONS
CONCLUSIONS

- ✓ Classification & Terminology
- ✓ Principle & Benefits
- ✓ Millestone
- ✓ Related applied technologies
- ✓ Specialties / Indications
- ✓ Systems on the market
- ✓ Conclusions and perspectives

Classification

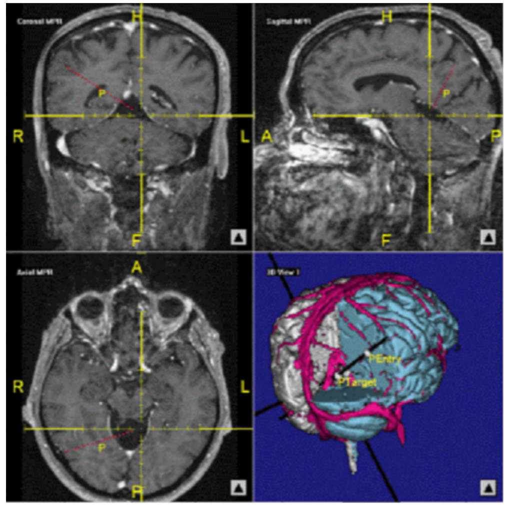


Terminology

- ✓ Navigation : Surgical derivative for the GPS, it allows the surgeon to localize on a virtual model of his patient
- ✓ Image Guided Surgery (IGS) : initial name for navigation when patient images were systematically used
- ✓ Neuronavigation : navigation applied to neurosurgery
- ✓ Computer Assisted Surgery (CAS) : appropriate for all surgical techniques with the assistance of a computer based system

✓ Similar to GPS used in cars

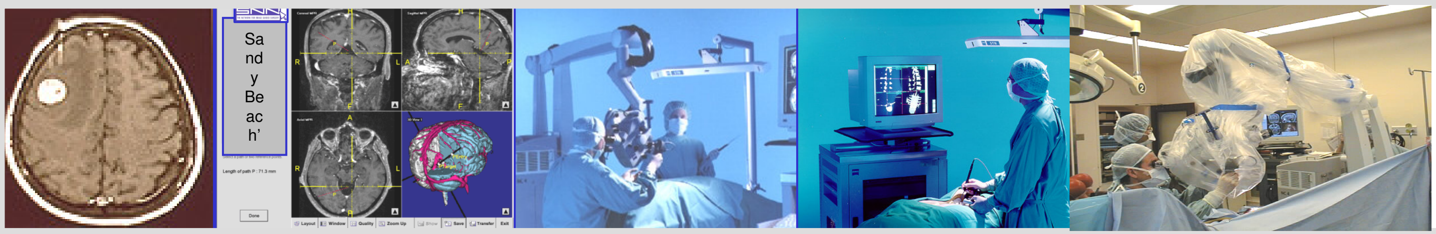
- Map = Patient's data
- Vehicle = Surgeon's tool
- Departure Point = Entry Point
- Arrival point = Target Point



Navigation is a major surgical improvement but **it is not a new surgical technique**

Navigation procedure (with images)

1. IMAGES ACQUISITION
2. SURGICAL PLANNING
3. O.R. SYSTEM INSTALLATION
4. REGISTRATION
5. IMAGE GUIDED SURGERY



Navigation procedure (without images)

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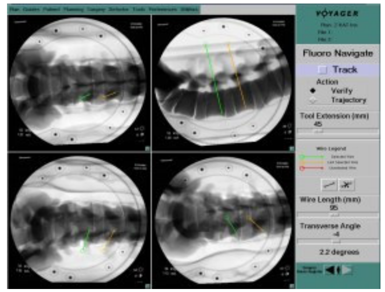
Benefits

- ✓ Navigation feeds the existing lack between high accuracy diagnosis data and operating room where those data where no more usable (negatoscope films)

- ✓ Navigation allows an easy 3D spatial interpretation



- ✓ For some surgeries, navigation replaces high constraining devices or instruments such as stereotactic frames or implants positioners

- ✓ Major benefits of navigation being increased surgical gesture accuracy, increased safety and O-R time gain

Millestone

- ✓ ~ 1990 : **<u>Original Idea</u>** : Watanabe's navigator prototype
- ✓ ~ 1993: **<u>First commercialized navigator</u>** : Viewing Wand ISG (Canada) pointer with encoded articulated arm
  Applications mostly in neurosurgery
- ✓ ~ 1994: **<u>First robotized navigator</u>** : Zeiss MKM and Elekta SurgiScope (neurosurgical applications)
- ✓ ~ 1997: **<u>First orthopaedic navigator</u>** : Medivision
- ✓ ~ 1998: **<u>First E.N.T (ded.) navigator</u>** : Medtronic / Xomed
- ✓ ~ 1999: **<u>First magnetic navigator</u>** : V.T.I (E.N.T)
- ✓ ~ 2000: **<u>First fluoro-navigator</u>** : Medtronic StealthStation (neuro-spine applications)
- ✓ ~ 2001: **<u>First image-free navigator</u>** : Praxim Surgetics

Related applied Technologies

✓ **Patient data :**

- Pre-operative patient images acquisition
- Patient images transfer & treatment
- Per-Operative data acquisition : Imagerie per-op, fluoronavigation, bone-morphing
- Image-free

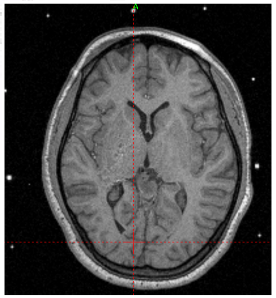
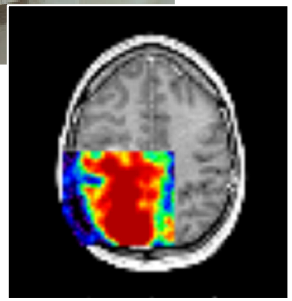
✓ **Tool and Instruments :**

- Localization technologies
- Microscope Integration
- Robotics (quick overview)

Pre-operative patient images acquisition

Radiology's CT scan, TEP scan, MRI, functionnal MRI, Angiography …

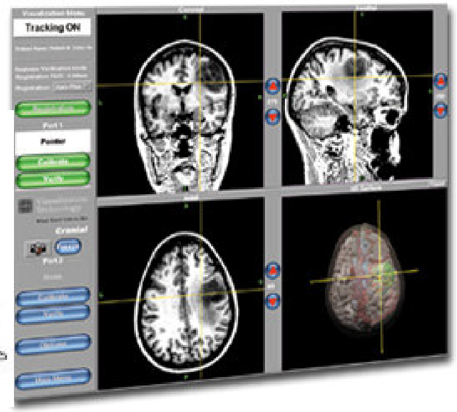


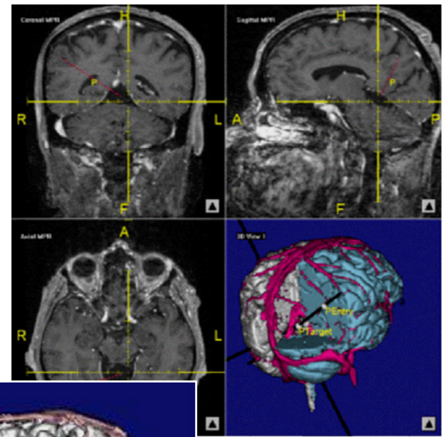
Patient image treatment

Needs workstations or powerful PCs

- ✓ Image transfer from radiology

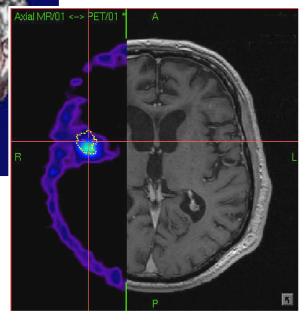


- ✓3D modelisation and perpendicular reconstructions from original sequence



- ✓Volume segmentations for targets and risk areas

- ✓ Surgery simulation :
path (entry + target points) definition and exploration (tool-view)



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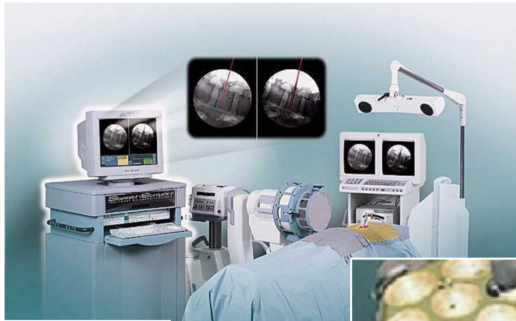
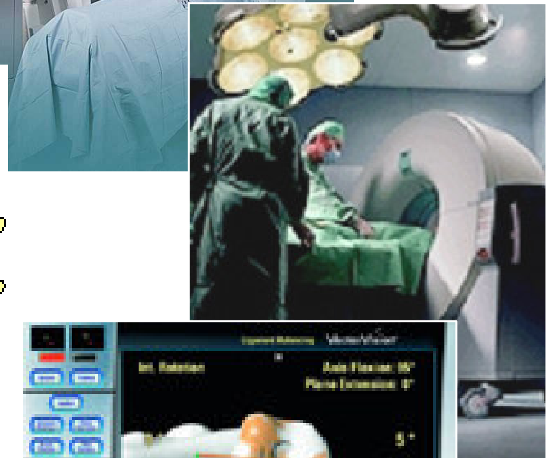
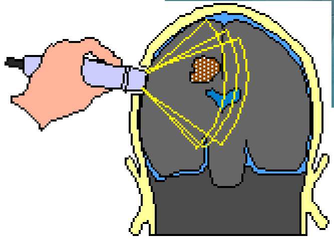
✓ **Real Images** :

- X-rays (fluoronavigation)
- Per-operative CT and MRI
- Echography

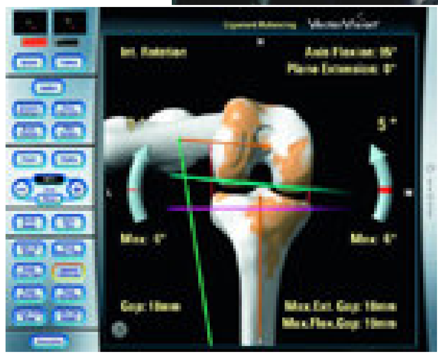






✓ **Virtual Images** :

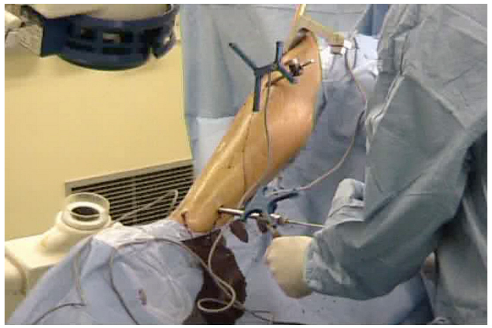
- Statistic Atlases or Databases with elastic morphing (Bone Morphing)



✓ **Image-free** :

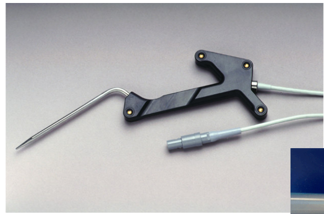
- Operative kinematic data acquisition

modelization of patient articulations movements (rotations)



Localization technologies: OPTICAL

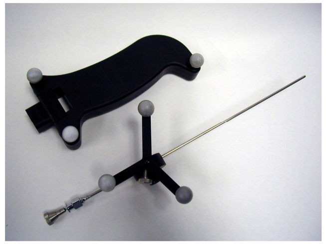
- ✓ **Active** wired or wireless IREDs based
  the infrared camera is receiving

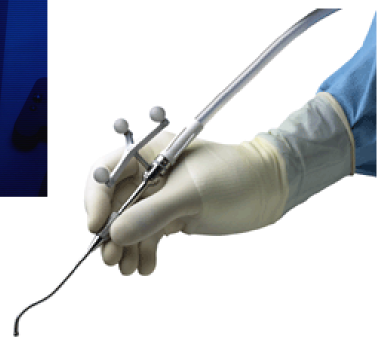


- ✓ **Passive** (wire-free), disposable sterile plastic spheres reflect the IR light
  the infrared camera is emitting-receiving

- ✓ **Mixed** of the active and passive technologies
  with/without wire
  LED and/or spheres

Zeiss STN



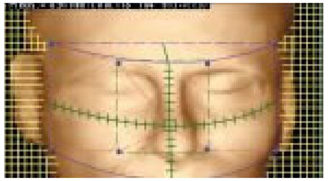


Nota : Sensible to line offsights

Localization technologies: MAGNETIC

- « coils » equipped instruments are used as pointers
- The patient « helmet » detects magnetic variations
- The processor treats the information and displays the relative positions

Nota : Sensible to important ferromagnetic volume



Collin DigiPointer

Localization technologies: ELECTRO-MECHANIC

- ✓ Generally articulated arms
- ✓ Articulations with optical encoders
- ✓ The processor treats the information and displays the relative position of the tool
- ✓ Only the «distal tool» is tracked

ISG Viewing Wand

Nota :

Limited ergonomy due to mechanical constraints

The patient reference should not move

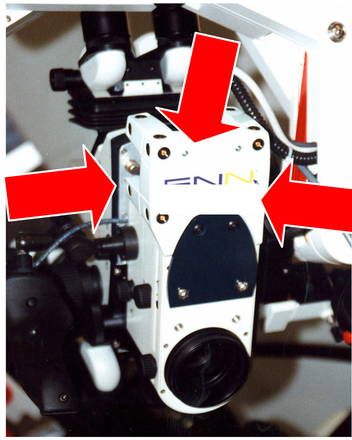
Zeiss MKM

Operating Microscope Integration

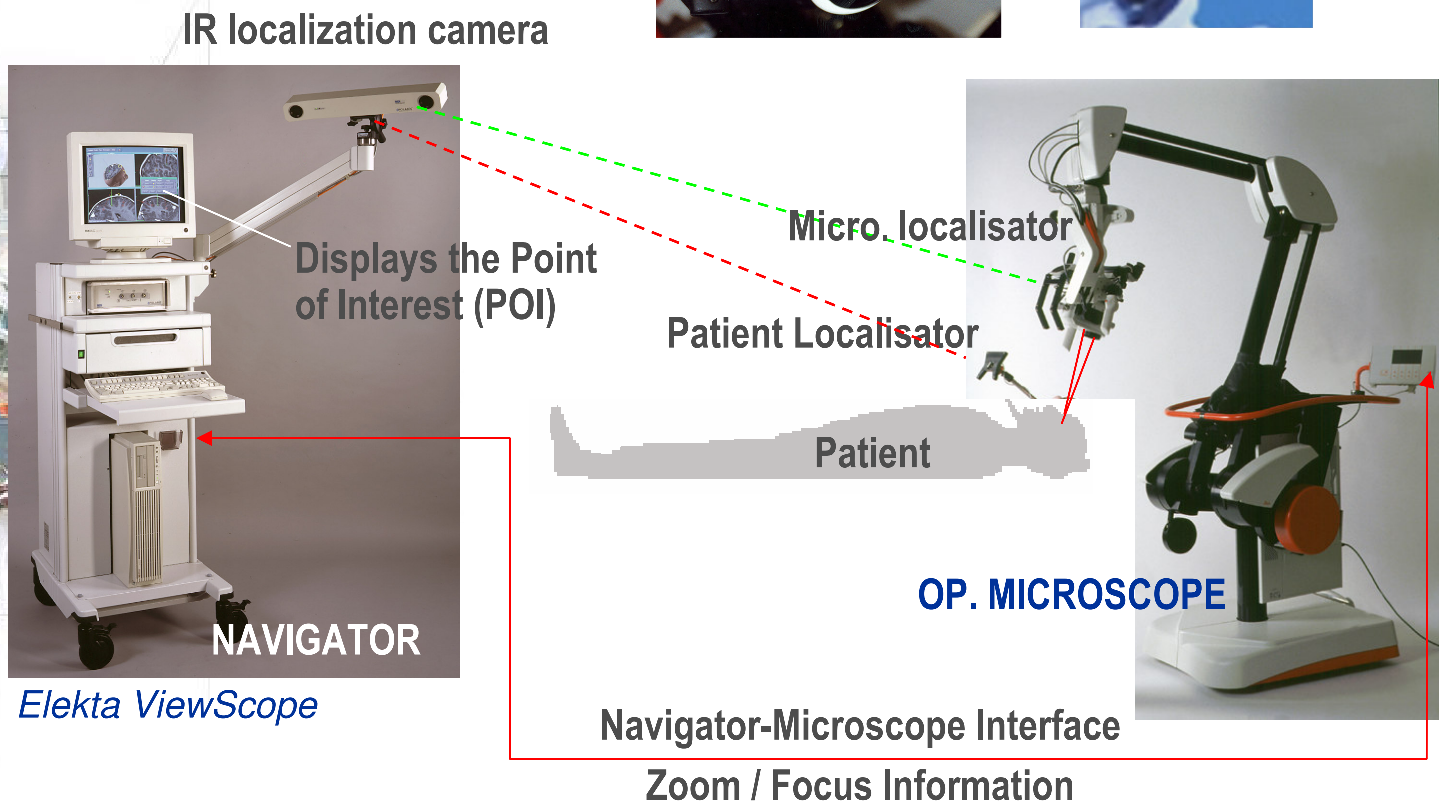
- ✓ **Neurosurgery / ENT** : 80% of surgeries use an operating microscope

- ✓ **4 problems to solve**
  - a) Interfacing the microscope to « treat » the zoom and focus data
  - b) Localize the microscope « head » in space in all operating positions
  - c) Monitor the exact focal point (point of interest) independantly from the depth of field
  - d) Superimpose the navigation data in the surgeon oculars (head-up display)

Interfacing the microscope



- Multiplanar localization devices (IREDS



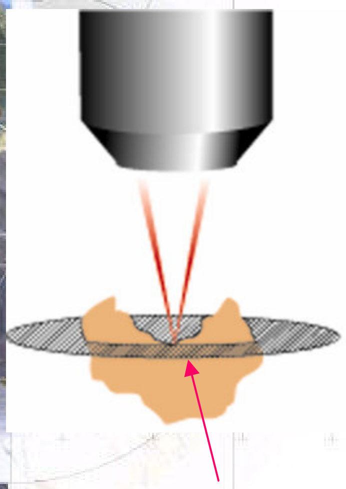
Elekta ViewScope

Monitoring of the « exact » focal point

Point of Interest : the point of interest displayed by the navigator displays is the focal point of the microscope

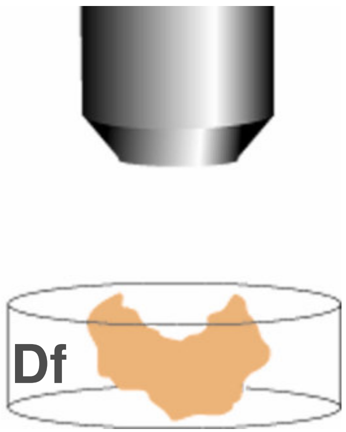
Depth of field : distance (z) on which the operator has a clear image (related to variable parameters)

With Autofocus or convergent laser beams



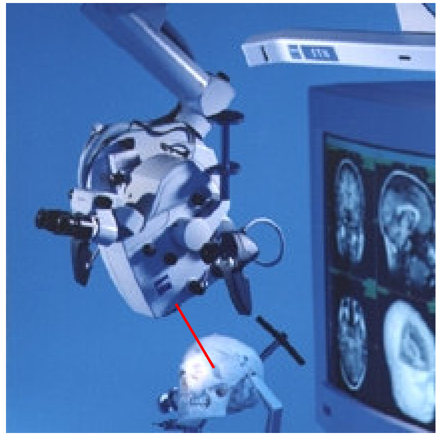
Focal point is identified

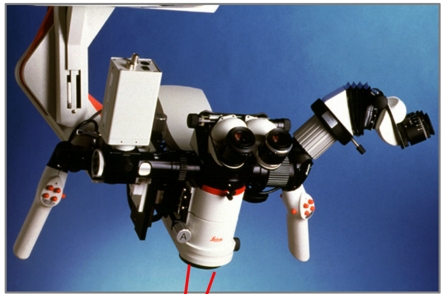
“Other” Systems



Focal point is “lost” in microscope DEPTH of FIELD (x,y,z?)

Zeiss SMN



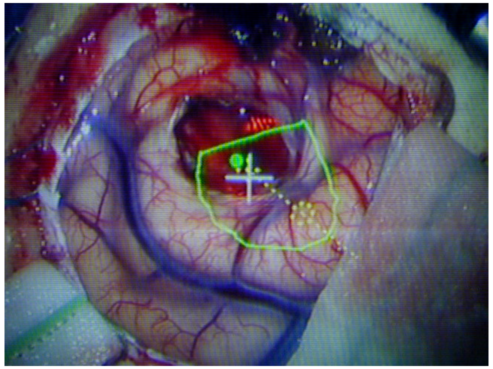


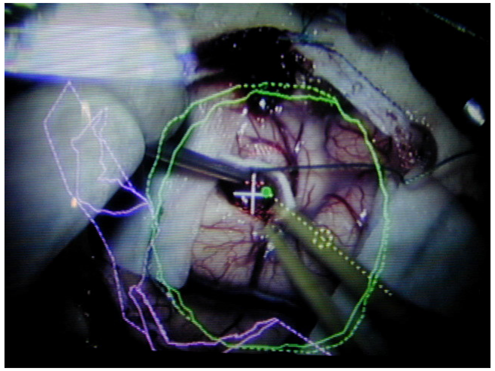
Elekta ViewScope

Integration of navigator's data in the microscope oculars

- ✓ H.U.D (Head-Up Display) analogy to aviators high technology helmets
- ✓ Correlated information of focus and zoom
- ✓ Superimposition of planned data : path, entry point targets
- ✓ Superimposition of contours of critical volumes : lesions, risk areas

…





ISIS SurgiScope

Benefits

- No physical contact between tool and structures
- Data displayed on the navigator's monitor AND in the microscope oculars
- Safety ergonomy : real time operation without leaving the operating field
- Active localization and guidance = the navigator really guides the surgery
- No additional pointer

Zeiss SMN

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Neurosurgery - Cranial

- ✓ Active bidirectionnal Link
- ✓ Multicoordinate
- ✓ 6 D.O.F (degrees of freedom)
- ✓ High accuracy (~ 1mm)
- ✓ **Automatic** positionning on planned trajectory
- ✓ Stereotactic indications

ISIS SurgiScope

Zeiss MKM

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Neurosurgery - Spine

- ✓ **Automatic** positionning on planned trajectory

MAZOR SpineAssist

P.I Galileo

Orthopaedy – Knee

- ✓ **Automatic** positionning of cutting plates
- ✓ **Automatic** drilling of the bone surfaces

MAQUET (URS) Caspar

ISS Robodoc

Concerned Surgical specialties

- ✓ Neurosurgery : cranial and spinal surgeries
- ✓ E.N.T : sinus and skull-base surgeries
- ✓ Orthopedy : hip and knee surgeries (THA, TKA), traumatologic surgery (fractures)

- ✓ *Maxillo-Facial Surgery: osteo-synthesis implantation*
- ✓ *Dental surgery : implants*

Neurosurgery – The needs

- ✓ Software modules and instruments for cranial : multimodalities image fusion, stereotactic module
- ✓ Software modules and instruments for spine : fluoronavigation
- ✓ Operating microscope integration
- ✓ Devices and software for biopsies
- ✓ Compatibility with existing systems (radiotherapy, stereotactic frames…)

Neuro-Cranial - Systems on the market

1996

Elekta
Insight
ViewScope
SurgiScope

Radionics
OTS

Aesculap
SPOC

Philips
EasyGuide Neuro

Sofamor Danek
StealthStation

BrainLab
VectorVision

Zeiss
STN
SMN
MKM

Radionics
OTS

ISIS
SurgiScope

Medtronic
StealthStation

BrainLab
VectorVision 2

Stryker
Navigation

Radionics
OmniSight

G.E.M.S
InstaTrack

2005

Neuro-Spine - Systems on the market

1997

Sulzer Medica *Navitrack* → **CenterPulse** *Navitrack*

OrthoSoft *Navitrack*

Aesculap *SPOC*

Sofamor Danek *StealthStation* → **Medtronic SNT** *StealthStation* *+ fluoronavigation*

BrainLab *VectorVision* → **BrainLab** *VectorVision 2*

Zeiss *STN* → **Stryker** *Navigation*

Radionics *OTS* → **Radionics** *OmniSight*

G.E.M.S *InstaTrack*

MAZOR ST *Station* *** Robotique***

2005

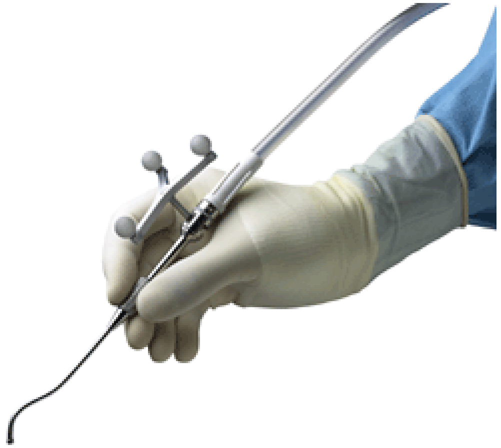
E.N.T Surgery – The needs

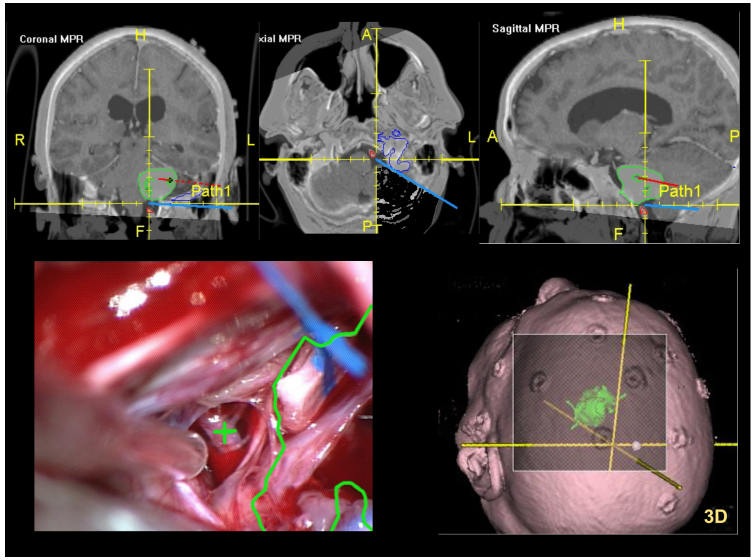
- Skull base surgery : software modules (CT-MRI image fusion) and skull base instruments

  Operating microscope intégration

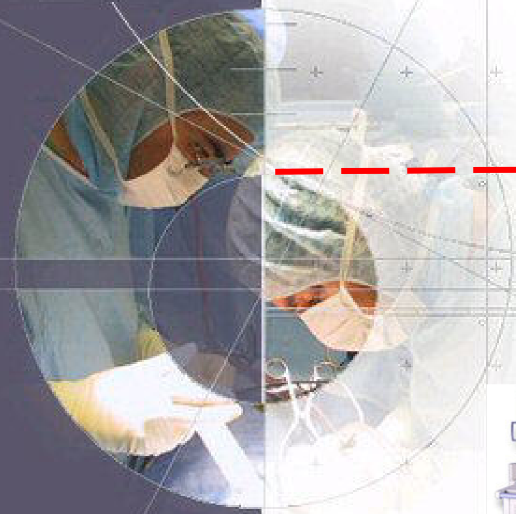
  Sinus surgery : software modules and sinus specific instruments (universal tracker)

  Integration and display of the endoscope image





E.N.T - Systems on the market



Medtronic / Xomed
StealthStation - Landmark

Stryker
Navigation System

BrainLab
Kolibri

Radionics
SinusSight

Praxim
Surgetics ENTact

OPTICAL LOCALIZATION

MAGNETIC LOCALIZATION

G.E.M.S
InstaTrack

Collin ORL
DigiPointer

Orthopaedic surgery– The needs

- ✓ Software Module and instruments for hip (Total Hip Arthroplasty)
- ✓ Software Module and instruments for knee (with ligaments balancing)
- ✓ Compatibility with prothesis and implants (open softwares)
- ✓ Software Module and instruments for trauma (fractures reduction)

BrainLab

Orthopaedy - Systems on the market

OrthoSoft
Navitrack

PRE-OPERATIVE CT SCAN

ZCat

Kinamed
NaviPro

G.E.M.S
InstaTrack

Medivision
SurgiGate

Medtronic
Treon-Ion

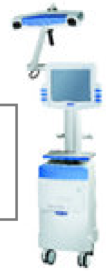
Stryker
Navigation System

KINEMATIC ANALYSIS

P.I Systems
*Galiléo**

** Semi-robotic*

Praxim
Surgetics



BrainLab
VectorVision

«BONE MORPHING»

Aesculap
OrthoPilot

Conclusions

- ✓ Wide panel of configurations and technologies available
- ✓ The choice of a system should be orientated by the real needs of the surgeons (instruments and softwares)
- ✓ Choice could be different if dedicated to one specialty/indication or multi-specialties
- ✓ System should be evolutive but beware of incompatibilities (operating microscope, X-rays, implants …)

Potential for navigation

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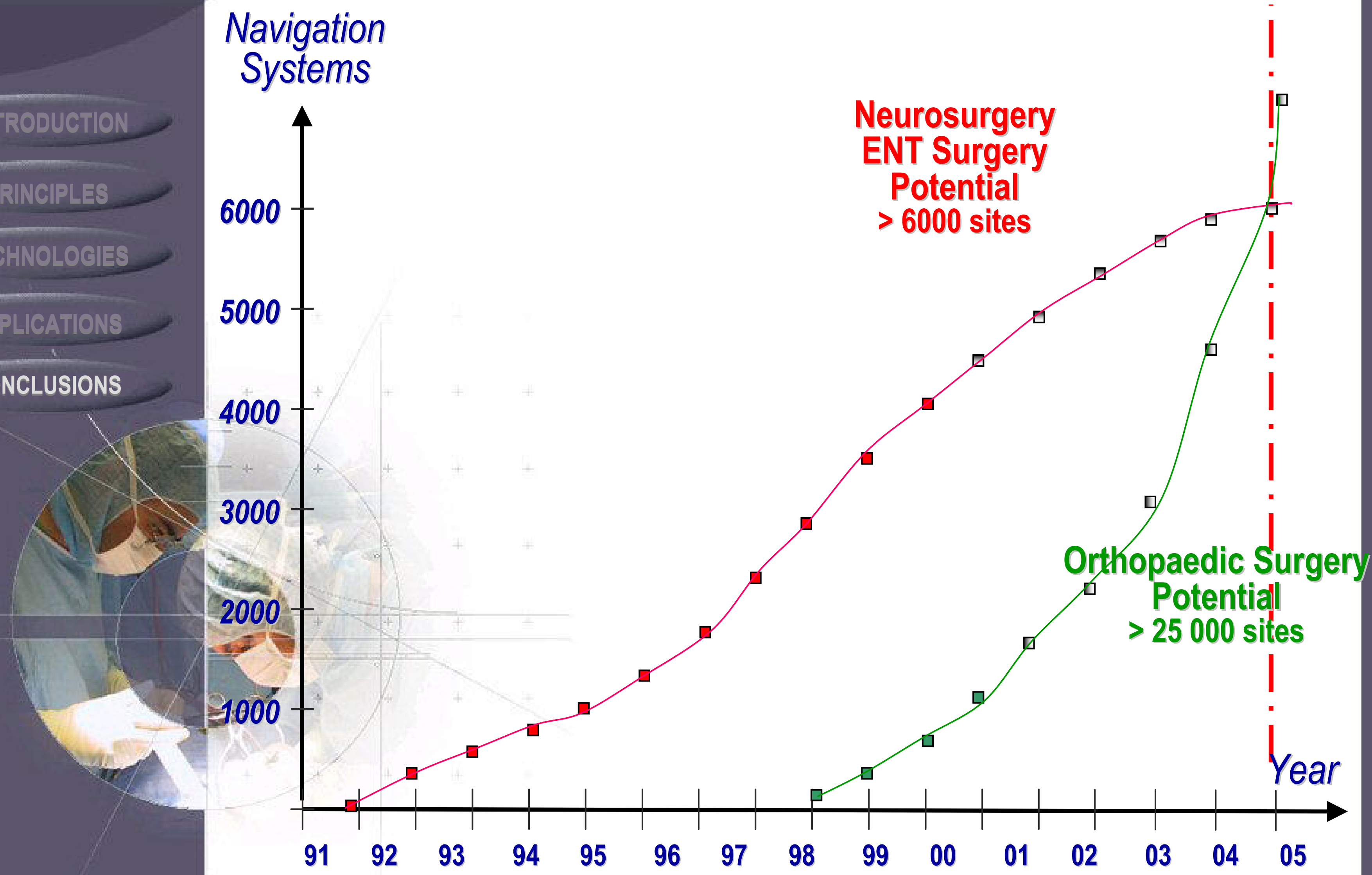
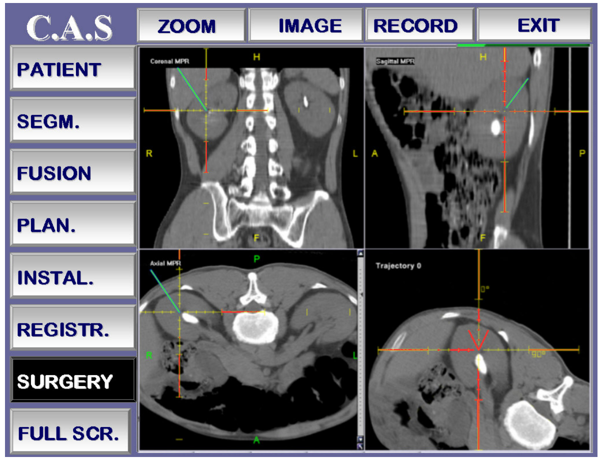


Perspectives

- ✓ New specialties : Dental, Cranio Maxillo-Facial,
- ✓ Surgery of soft and mobile tissues: cardiac, visceral, urological, gynaecological surgeries ...



- ✓ New applications : remote training, surgical tele-assistance, virtual surgery ...

Surgical Navigation

Credit Video : Val de Grâce Hospital Neurosurgical Department
Special thanks to Pr Michel Desgeorges

EVOLUTION OF SURGICAL ROBOTICS DURING PAST DECADE

Surgical Robotics

European Summer University

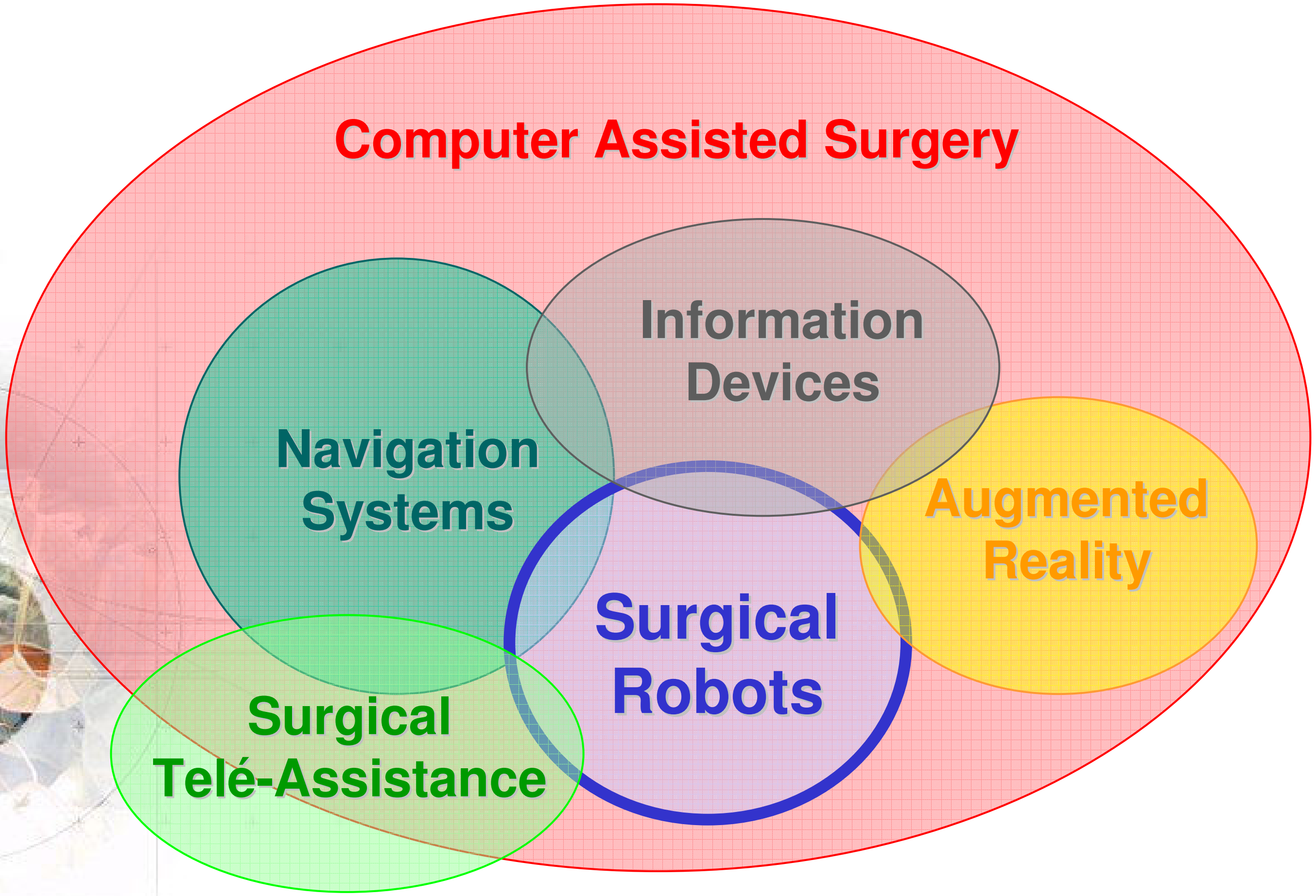
Montpellier September 7-14, 2005

ISIS Y. Patoux Rev.A

Initially based on navigation principle, Surgical Robotics also entried the O.R 10 years ago (~). During this decade, two major orientations were taken: Automatic tool positioners and
Remote Instruments manipulators.

As for navigation, number of specialties now uses or intends to use robots as additional accurate surgical tool in the O.R. environment

The second part of the presentation will briefly overview the different systems and their applications.


Computer Assisted Surgery
Information Devices
Navigation Systems
Augmented Reality
Surgical Robots
Surgical Telé-Assistance

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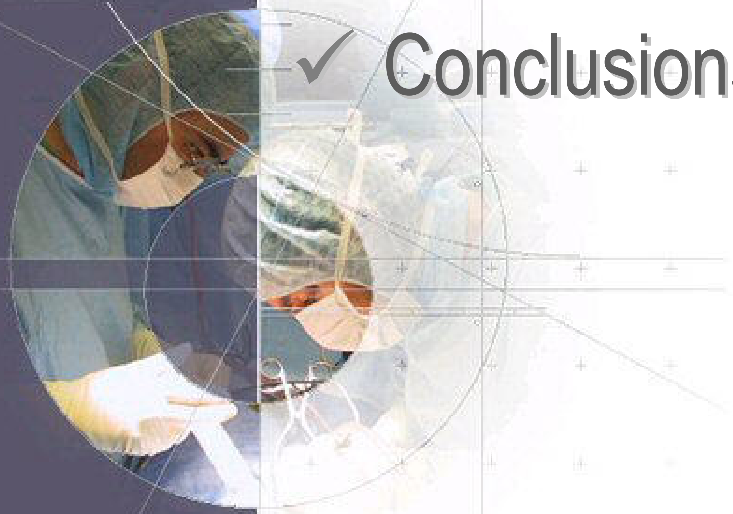
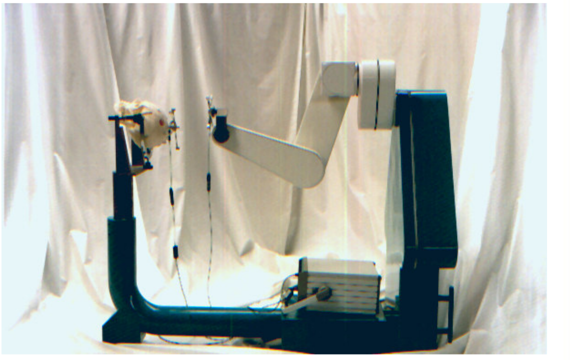
- ✓ Millestone
- ✓ Tool positioners
- ✓ Remote tele-manipulators
- ✓ Robotic Surgical Tele-Assistance
- ✓ Conclusions and perspectives

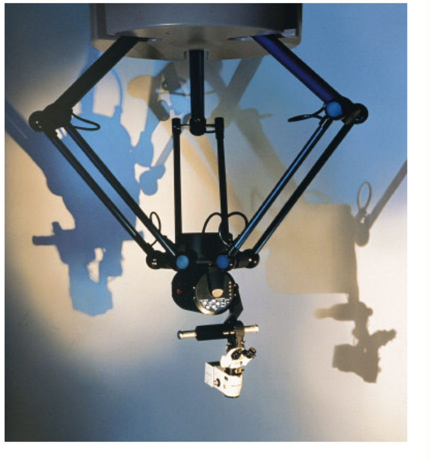


Millestone

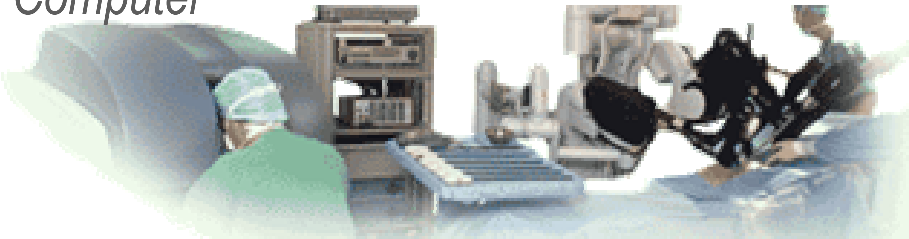
- ✓ 1986 : Introduction of robotized positioners in stereotactic surgery
  Ex: Robot GT6A adapted to Stereotaxy collaboration with Pr A-L BENABID



- ✓ 1994 : Introduction of bi-directionnal robotized navigation in neurosurgical OR. First Microscope integrated pointers
  Ex: Carl Zeiss MKM and ELEKTA SurgiScope



- ✓ 1998 : Introduction of « robotic assistance » in other specialties (cardiac, visceral and urology) with Tele-Manipulators (remote control with visual feedback) :
  Ex: Intuitive Surgical DaVinci, Computer Motion Zeus, Computer Motion Aesop



- ✓ 1998 : Introduction of « total robotic act » in Orthopedic surgeries with robotic tool holders
- ✓ *Ex: Caspar MAQUET (then URS) and ISS Robodoc*

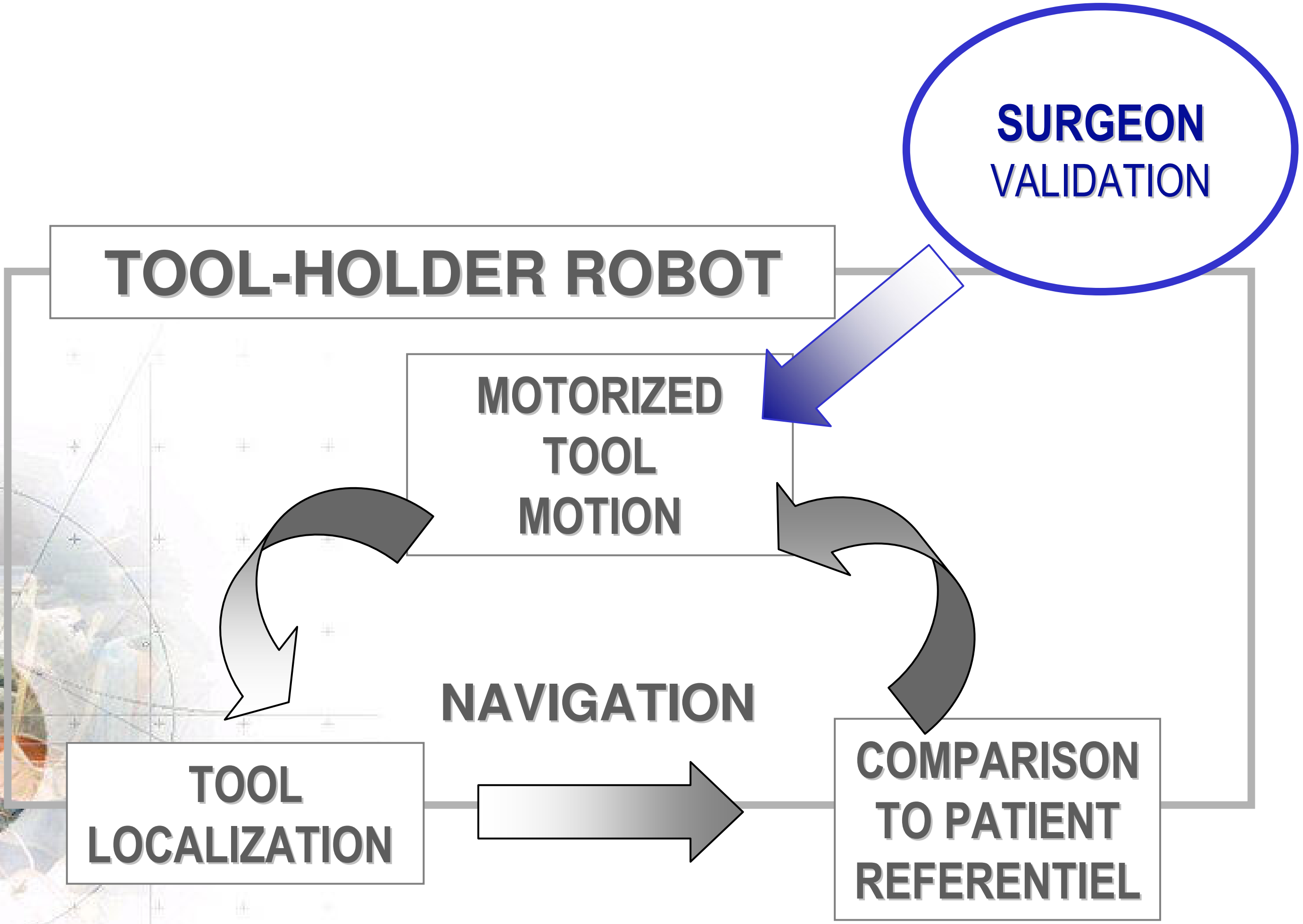
The robot controls the tool motion (trajectories, speed…) when the surgeon valids or stops the movement.

There is a loop feedback on predefined positions or trajectories.

Several robots of this kind are used since more than 10 years *

*Based on navigation principle, these robots are appropriate to surgeries linked to solid/rigid organs (Neurosurgery, ENT, Orthopedic surgery)

Principle


SURGEON
VALIDATION
TOOL-HOLDER ROBOT
MOTORIZED
TOOL
MOTION
NAVIGATION
TOOL
LOCALIZATION
COMPARISON
TO PATIENT
REFERENTIEL

ZEISS MKM system

- ✓ Zeiss MKM (Multi Koordinates Micromanipulator) is a 6 DOF (degrees of freedom) anthropomorphic robot .
- ✓ Accurate positioning of the « distal lead » imposed consequent motorized axis and a heavy counterweight (~900 Kg)

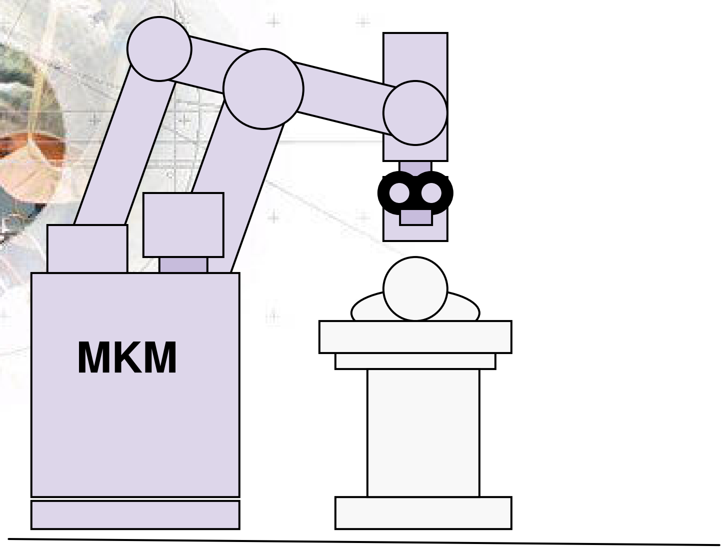
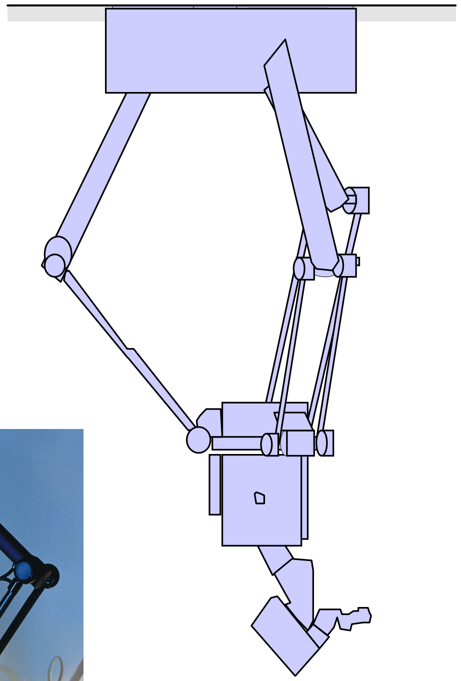
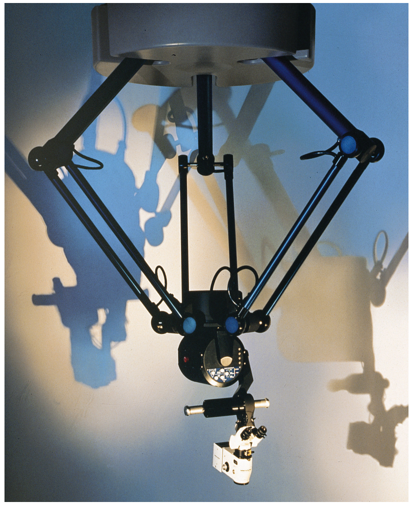


Photo HIA Val de Grace

Elekta SurgiScope

- ✓ SurgiScope system was initially developed by Elekta, The ISIS team took back R&D and sales in 2001
- ✓ It's a parallel robot (delta structure) with 6 DOF
- ✓ Accurate positioning of the « distal lead » is separated on the 3 articulated arms that allows a lower volume but imposed a ceiling mounted structure





6 DOF robotics allows a very flexibility of movement and tool positioning :

- ✓ **cartesian** (translations)
- ✓ **spherical** (rotations)
- ✓ « **Key-hole** » (translations-rotations combination)

Combination of those movements allows a wide panel of possibilities mostly in deep-seated lesions with difficult access.

It also allows very small openings for MIS (Minimal Invasive Surgery)

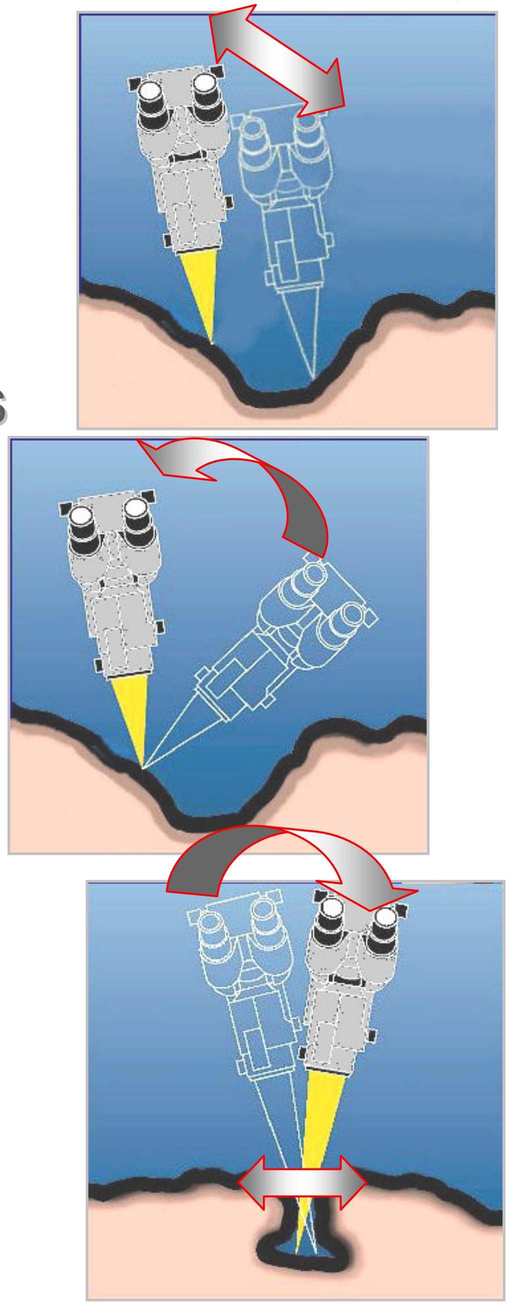


Image Guided Tool Positioners

- ✓ Not only the Microscope
- ✓ Even if not so accurate as stereotactic devices, the precision is sufficient to position rigid instruments such as : biopsy needles, hematomas evacuators, neuro- endoscopes…
- ✓ Main technical modification being the reference axis

  (microscope axis ≠ tool axis)

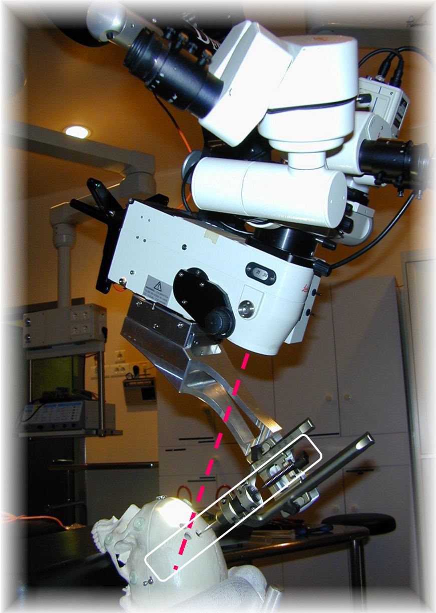


Photo ISIS

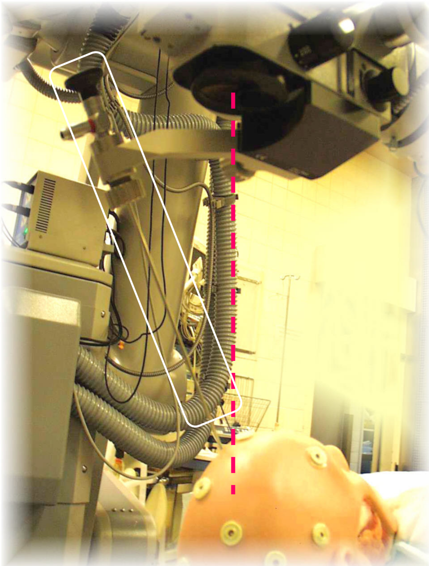


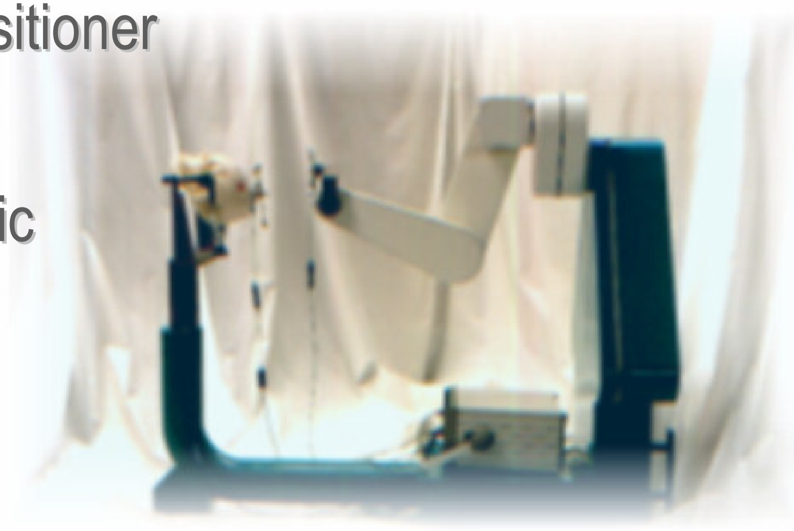
Photo HA Val de Grâce

Image Guided Tool Positioners

- ✓ Brain Stereotactic Positioner

  ISS Neuromate

  6 DOF Antropomorphic



- ✓ SPINE tool positioner

  MAZOR SpineAssist

Remote Tele-Manipulators

✓The surgeon controls the motion of remote instruments holders. The feedback is mostly visual (video from the endoscopic view). The tele-manipulator reproduces, amplify or filter the surgeon's movements (it's a Master-Slave system)

✓There is no "robotic looped feedback" but "human" feedback

Several robots of this kind are used since several years * (ex: *Computer Motion Zeus*, *Intuitive Surgical DaVinci …)*

✓Based on laparoscopic surgical techniques, these robots are appropriate to surgeries linked to mobile and soft organs (cardiac, urological, gynecological surgeries etc…)

Principle

TELE-MANIPULATOR ROBOT

TOOL MOTORIZED MOTION

SURGEON TOOL LOCALIZATION

→

SURGEON COMPARISON TO PATIENT REFERENTIAL

INTRODUCTION
TOOL POSIT.
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CONCLUSIONS

Camera holders

✓The surgeon voice controls the motion of a robotic camera holder device (laparosocpic procedures).

✓Movement are basic: up, down, left, right, backward, forward

✓There is no automatic feedback but a visual check, by the operator, of the position of the camera related to the patient.

✓Several robots of this kind are used since several years (ex: *Computer Motion Aesop*, *Armstrong Healthcare EndoAssist …)*

✓Based on laparoscopic surgical techniques and similar to tele-manipulators, these robots are appropriate to surgeries linked to mobile and soft organs (cardiac, urological, gynaecological surgeries etc…)

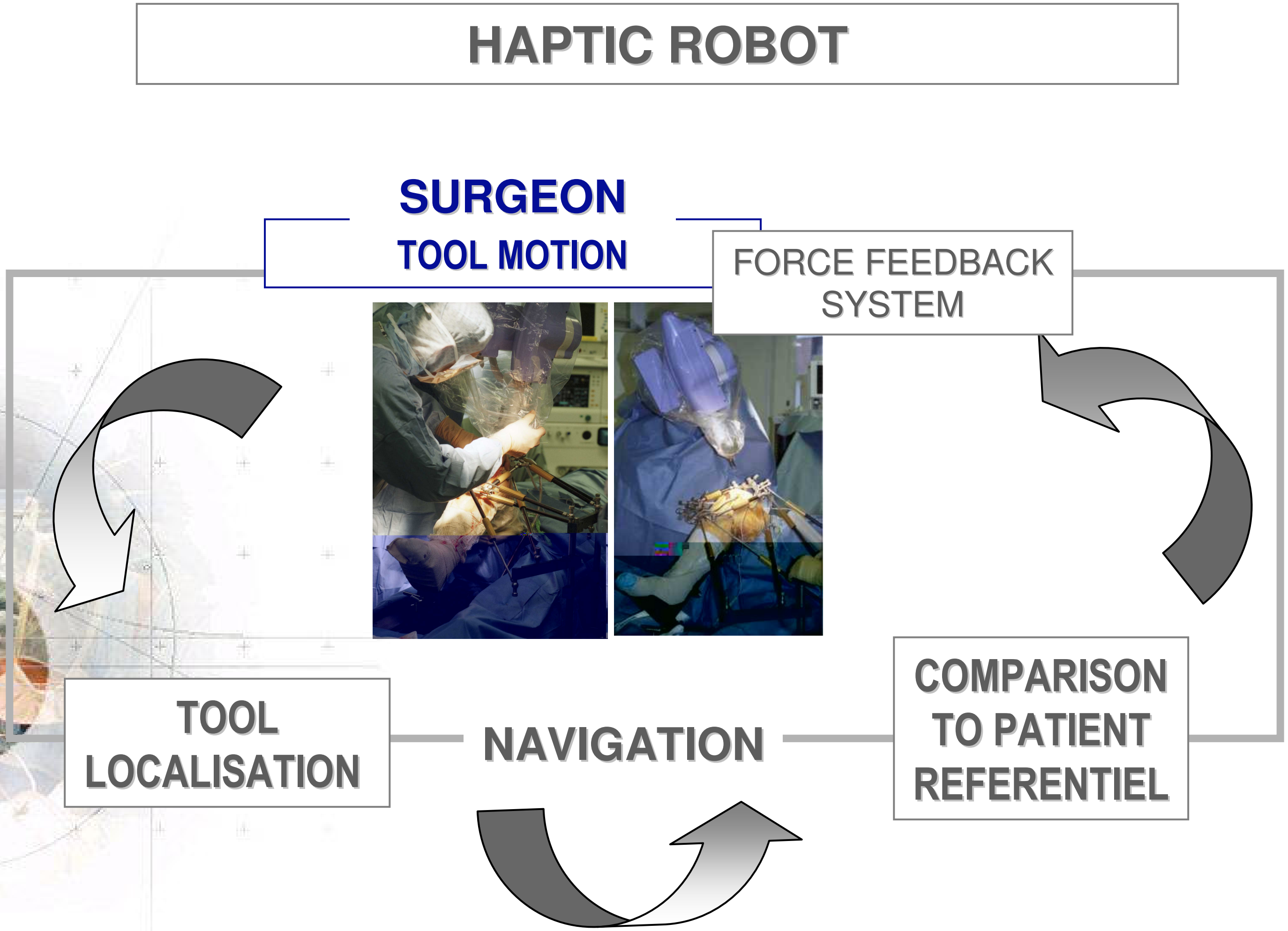
Haptic robots

✓The surgeon controls the motion of his instrument, the robot guides the surgeon with an «intuitive force feedback» It's also called a «cooperative robot»

✓In a predefined working volume, there is a progressive feedback (constraint) from totally free to blocked..

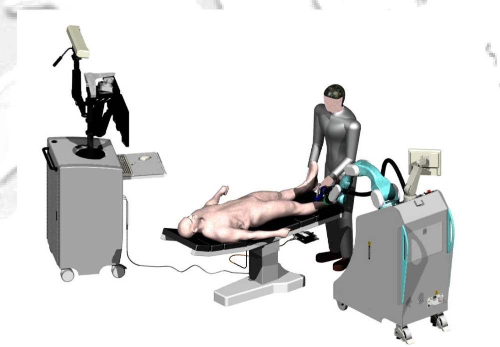
✓The interest being that risked areas can be pre-defined and preserved during surgery

✓This kind of robot is not used in day to day surgery, but some prototypes are under trials (Acrobot)


HAPTIC ROBOT
SURGEON
TOOL MOTION
FORCE FEEDBACK SYSTEM
TOOL LOCALISATION
NAVIGATION
COMPARISON TO PATIENT REFERENTIEL

Robotics Surgical Tele-Assistance is a dynamic combination of tool-positioning and remote tele-manipulation .

It allows the active participation of a remote expert and a real time control of the tool positioning thanks to transmitted patient and O.R.data.



3 Years military program to develop a prototype of Robotized Surgical Tele-Assistance Device for the External Operations (OPEX).

Medico-legal constraints
Same level of care as delivered in Metropole

VISCERAL SURGEON

ORTOPAEDIC SURGEON

SURGICAL EMERGENCY (wound gravity)

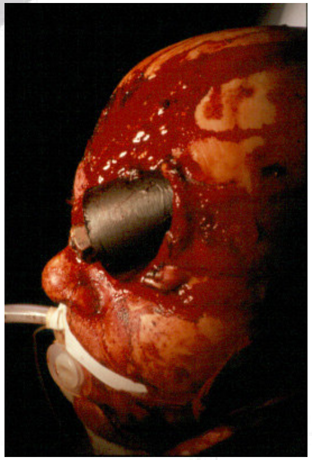
PATIENT
Wounded soldier

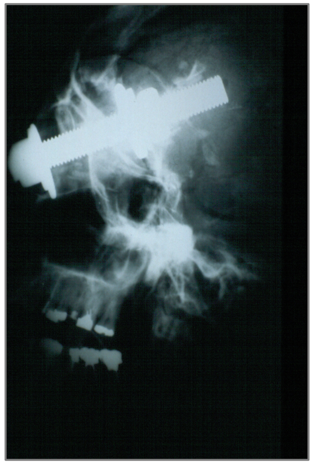
CRISIS SITUATION (conflict)

Clinical and Technical safety
Real time assistance
Quickness, fiability and accuracy
(Navigator et Robot)

Capital protection
Human life value
Technical Investment
(specialist training)

FIELD CONSTRAINTS (light Infrastructure …)





PATIENT ARRIVAL

IMAGING

Local site diagnosis

Expert advice request

Combined
(local and expert)
Diagnosis and decision

Combined
(local and expert)
Planning

EVASAN
(sanitary evacuation)

Robotized Assisted Surgery

Principle

INTRODUCTION
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SURGICAL TELE-ASSISTANCE

TOOL MOVEMENT

NAVIGATION

OPEX SURGEON
TOOL
LOCALISATION

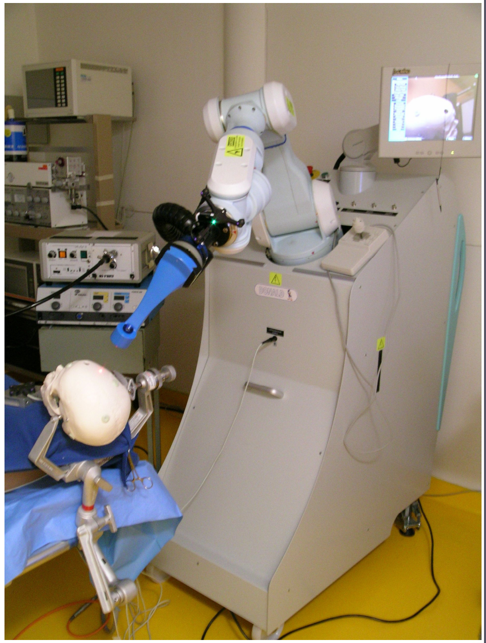
EXPERT
TOOL
LOCALISATION

OPEX SURGEON
COMPARISON
TO PATIENT
REFERENTIEL
+ VALIDATION

EXPERT
COMPARISON
TO PATIENT
REFERENTIEL

Navigator and data communication

OPEX SYSTEM



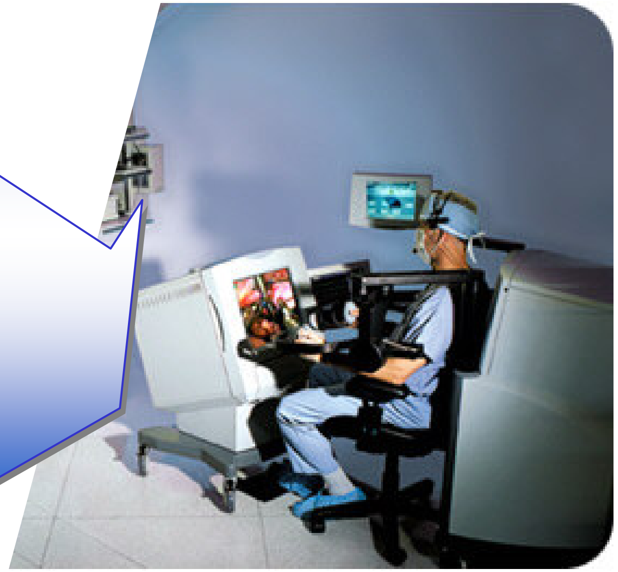
Robotic Tool Positioner

EXPERT CONSOLE

Tele-assistance

Tele-Surgery

The surgical gesture is performed with a tele-manipulation console under video-control by a remote surgeon



** Worlwide « Première » of a telesurgery between Strasbourg and New-York performed by Pr J. Marescaux on septembre 7, 2001*

CIVILIAN APPLICATIONS

Oil Platforms

Spatial stations

« long runs » ships

MILITARY APPLICATIONS

Mobile Surgical Antennas

Military Ships

Submarines

TOOL POSITIONERS

NeuroSurgery
ENT Surgery

« FIXED » ORGANS SURGERY

Orthopedic Surgery

TELE-MANIPULATORS

« MOBILES » ORGANS SURGERY

cardiac,
visceral,
thoracic,
urological,
gynecological
surgeries

SURGICAL TELE-ASSISTANCE

- **IS SURGICAL ROBOTICS A MATURE TECHNOLOGY ?**

  Probably yes but not for all applications !

  Easy of use should be optimized for a day to day utilization without being a specialist.

- **WHAT ARE THE EVOLUTION TRENDS FOR THE FUTURE ?**

  Use simplification, OR ergonomy, Market Price

- **IS IT A REAL ADDED VALUE ?**

  Industrial field already demonstrated it

  Benefits for the operator, then for the patient.

INTRODUCTION
TOOL POSIT.
TELE-MANIP.
Tele-ASSISTANCE
CONCLUSIONS

- **FUTURE ?**

Active « **macrorobots** » which will performed an automatic task (drilling, cutting …) under the surgeon's control

Passive or **haptic** robots that will mechanically limit the surgeon's gesture (with or without force feedback)

Miniaturized «**microrobots**» tele-piloted which will be able to reach very « inaccessible » organs

- **« macro-micro-active-passive » combination ???**

Maybe the answer in the coming

Surgical Robotics
European Summer Universities

Thanks for your attention !

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