Trends in Computer-Assisted Surgery: Past, Present and Future

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Themes of Today's Talk

- Computer-assisted Surgery Today
  - brief case studies of Intuitive Surgical and ISS
- From orthopedics to soft tissue
  - intra-operative image guidance methods
  - improved interventional devices
- Toward true surgical assistance
  - better eyes through intra-operative information presentation
  - better hands through enhanced end-effectors

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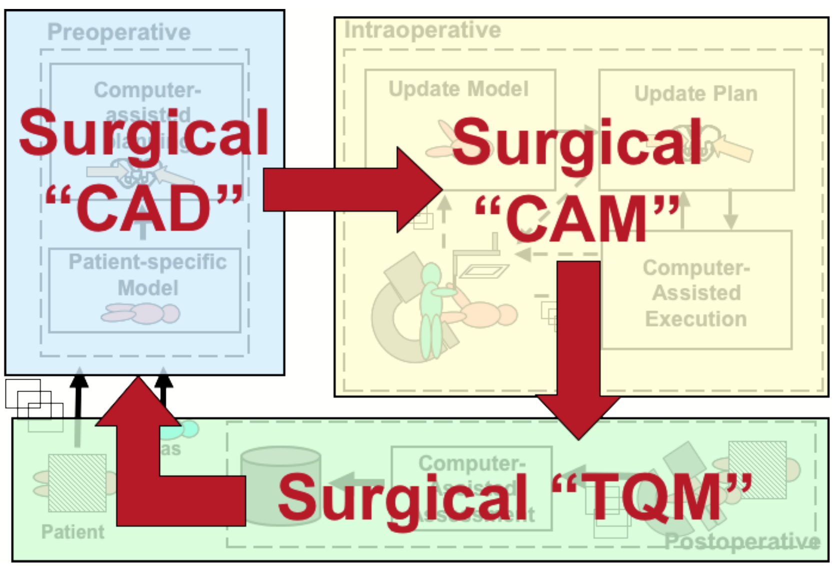
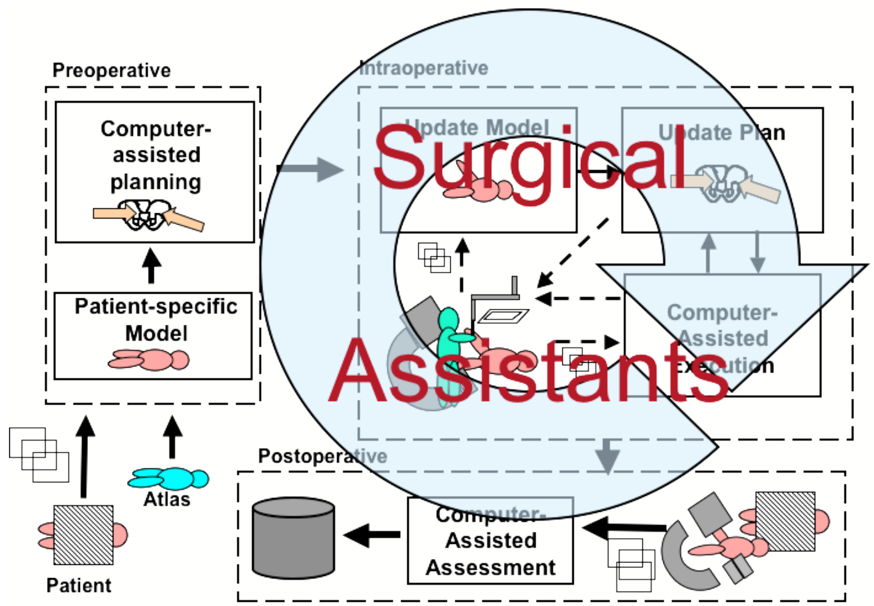
What is CIS?

The integration of information processing with sensing and robotics to produce a **“super-human”** man-machine team



Surgical CAD-CAM



Surgical Assistance

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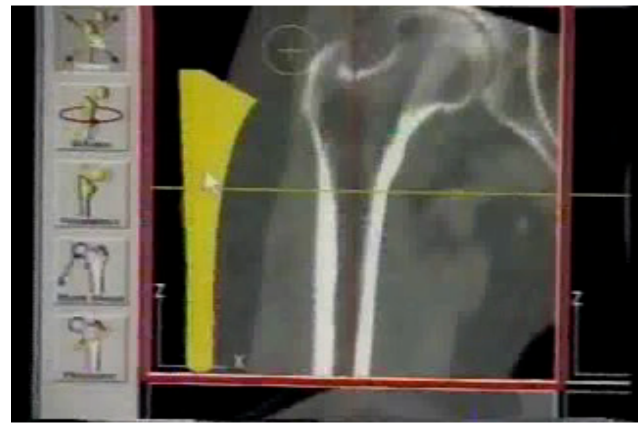
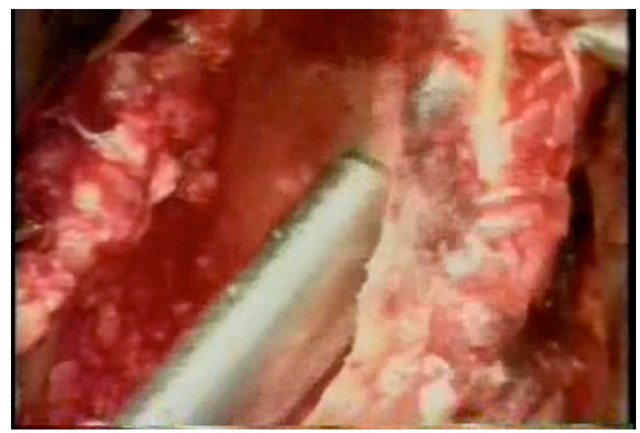
ROBODOC® System

- Initially developed to assist with Total Hip Replacement (THR) surgery
  - machine femur for cementless prosthesis (femoral stem)

Traditional mallet and broach <===

Computer-assisted planning and execution =====>





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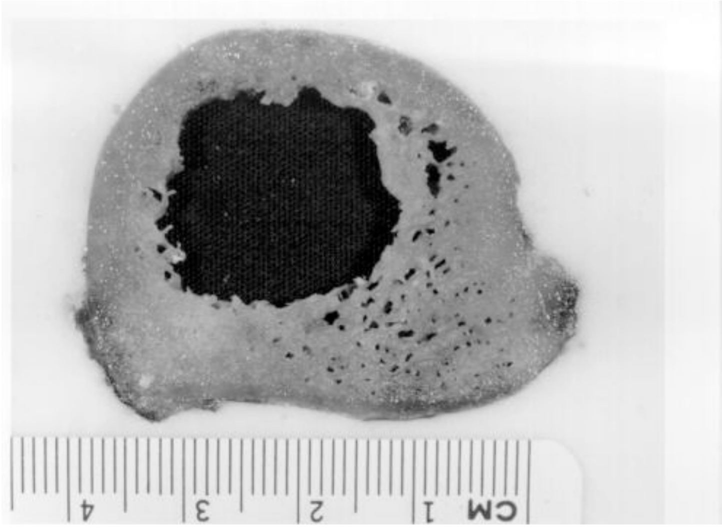
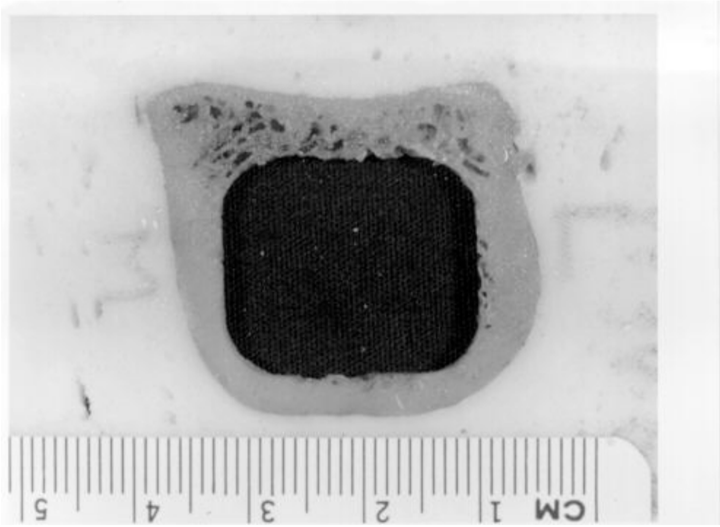
ROBODOC Benefits

- Intended benefits:
  - Increased dimensional accuracy
  - Increased placement accuracy
  - More consistent outcome



Broach



Robot

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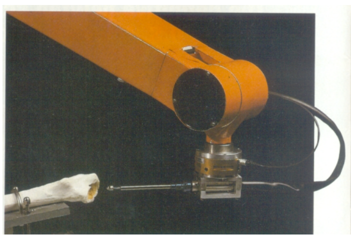
ROBODOC History

1986-1988 Feasibility study and proof of concept at U.C. Davis and IBM



1988-1990 Development of canine system

May 2, 1990 First canine surgery

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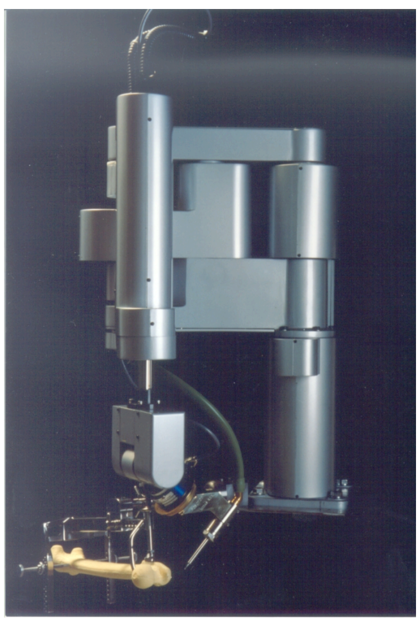
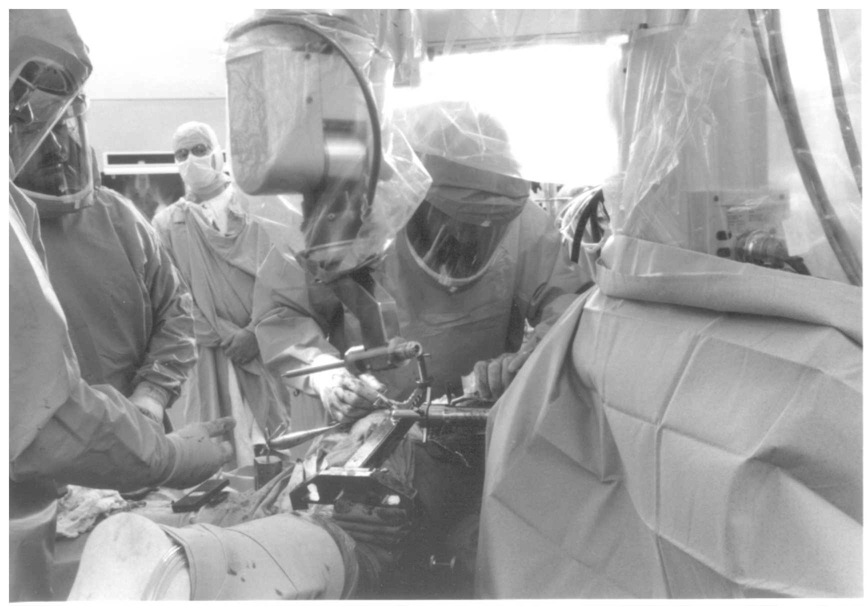
ROBODOC History

1990-1995	Human clinical prototype
Nov 1, 1990	Formation of ISS
Nov 7, 1992	First human surgery, Sutter General Hospital
Aug 1994	First European surgery, BGU Frankfurt





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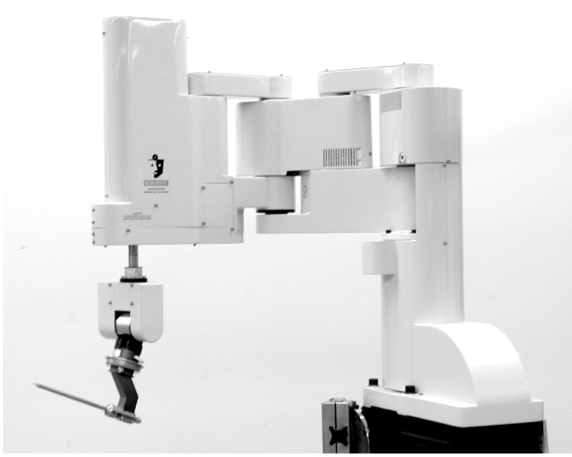
ROBODOC History

1995- ROBODOC as a Medical Product

March 1996	CE Mark (C System)
April 1996	First 2 installations (Germany)
Nov 1996	ISS initial public offering (NASDAQ)
Sept 1997	IMMI acquisition (Neuromate)
March 1998	First pinless hip surgery
Feb 2000	First knee replacement surgery



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ROBODOC Status

- Approximately 50 systems installed worldwide
  - Europe (Germany, Austria, Switz., France, Spain)
  - Asia (Japan, Korea, India)
  - U.S. (Clinical trial for FDA approval)
- Over 10,000 hip replacement surgeries
- Several hundred knee replacement surgeries
- Public response in Europe (esp. Germany) initially positive, but became negative, ending use of the system
- ISS “ceased operations” on June 2, 2005
- ISS resumed operations in Sept. 2006 (Novatrix Biomedical)

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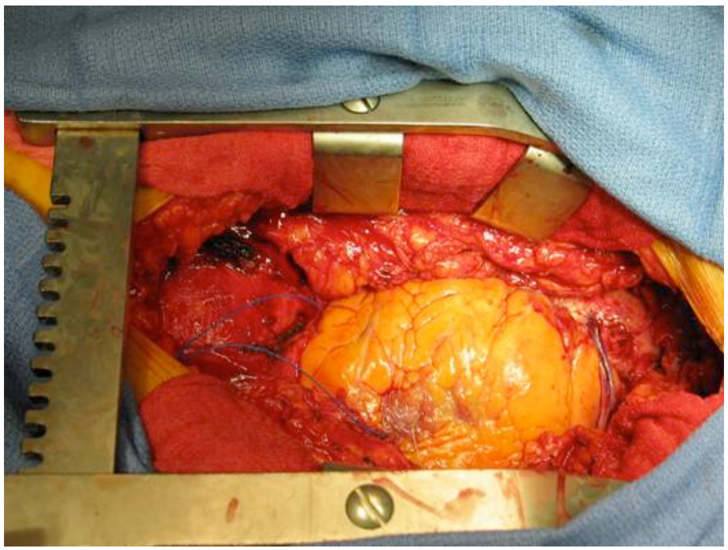
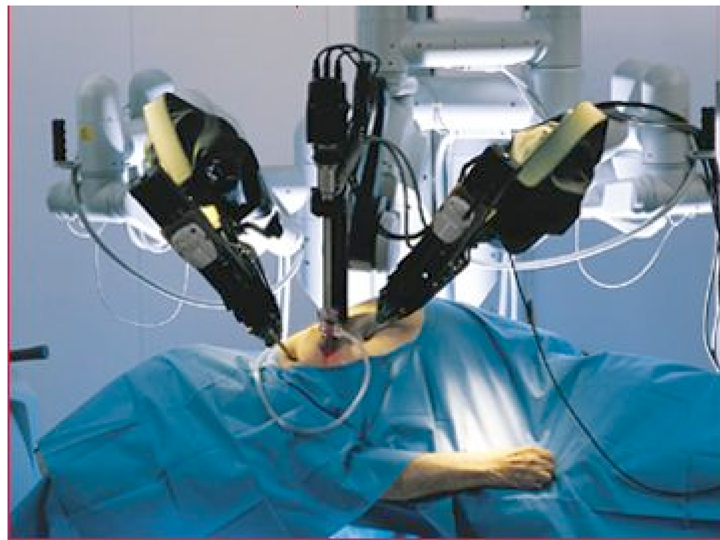
da Vinci® System

- Initially developed for battlefield telesurgery
  - commercialized for minimally invasive cardiac bypass procedures



Traditional bypass with full chest exposure



da Vinci minimally invasive approach

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da Vinci Benefits

- Intended benefits:
  - Decreased patient trauma
  - Enhanced surgical precision
  - Shorter patient recovery

Traditional approach

Robot-assisted

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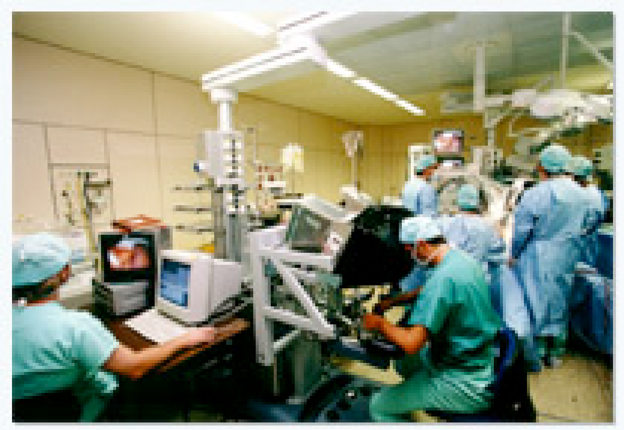
Intuitive Surgical History

1985-1995 Feasibility study and proof of concept at SRI for army telesurgery

1995 Intuitive Surgical founded

1995-97 The "Mona" system developed and tested

March 1997 First test of Mona in Belgium



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Intuitive Surgical History

1999	da Vinci system offered for sale
2000	Intuitive IPO FDA approval (5-10 K)
2003	Computer Motion acquired
2006	Second generation "S" model introduced

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da Vinci Status

- Over 500 systems installed worldwide
- Principle application prostatectomy
  - Projected: in 2007, over 50% of prostatectomies in US will be performed by a da Vinci
- Financial success
  - 2005 revenue 227 M
  - 2006 revenue 372 M
  - Intuitive surgical market cap. of >9 B

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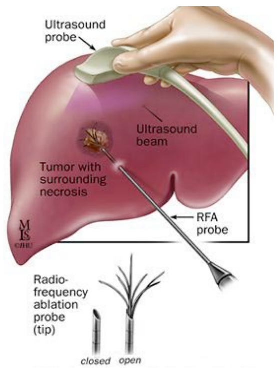
A New Challenge: Surgical CAD-CAM for Soft Tissue

- Minimally invasive cancer treatment involves accurate image guidance in deformable tissues:
  - liver or kidney tumor ablation
  - prostate brachytherapy
  - external beam radiation therapy
- Ultrasound is key technology
  - safe, cheap, easy to use
- Two approaches to image guidance:
  - external tracking with registration
  - direct observation



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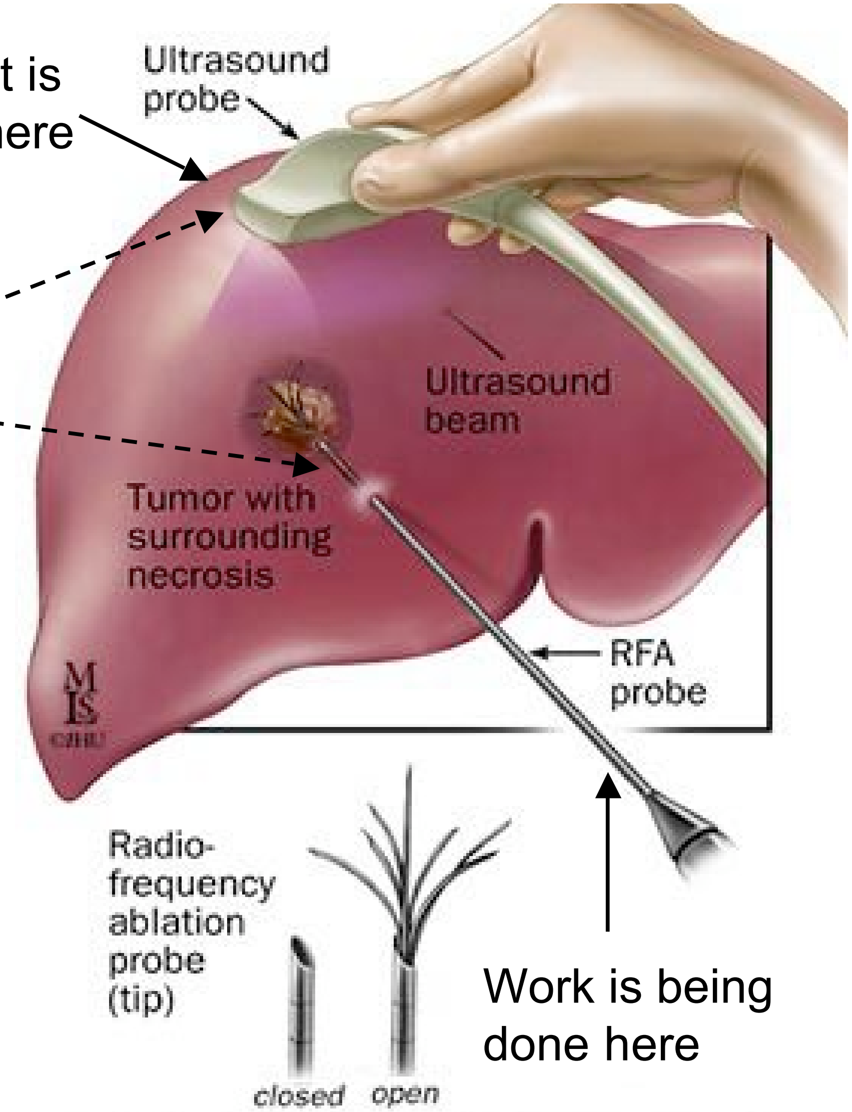
Methods of Registration for Guidance

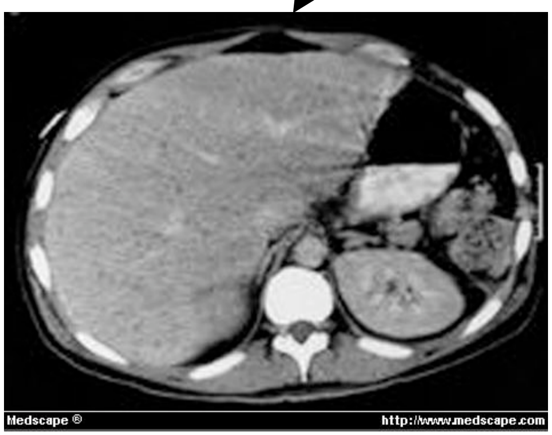
Traditional approach uses a tracking device to determine where probe and/or imager are located relative to pre-operative plan

Tracking Device

Treatment is visible here



Work is being done here



Pathology is visible here

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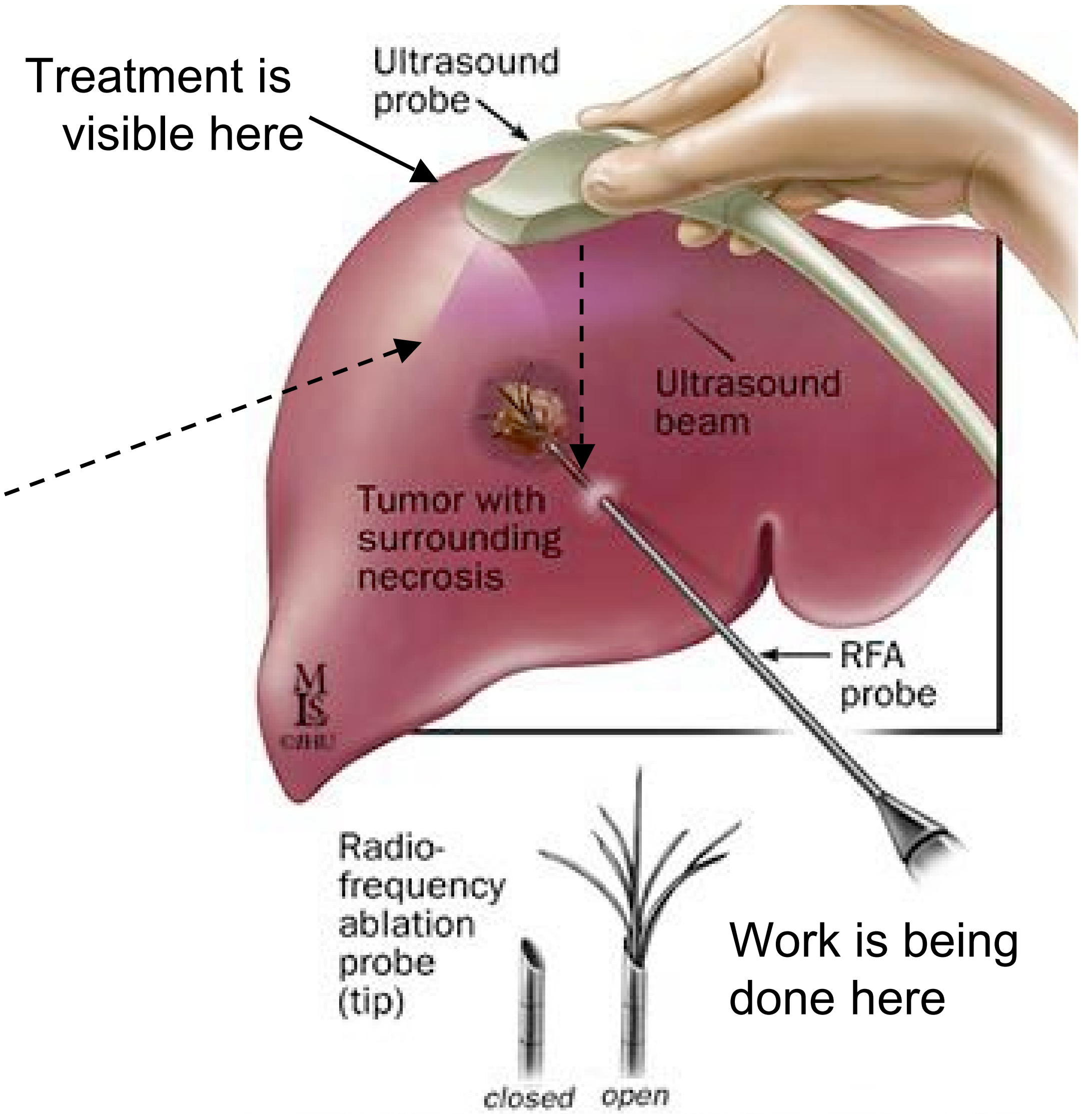
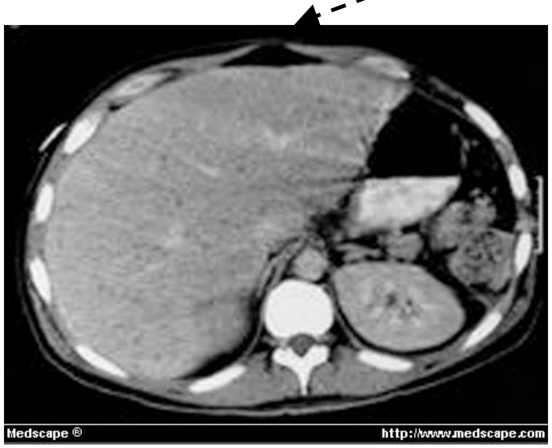
Methods of Registration for Guidance

Other approaches directly register images and directly observe intervention





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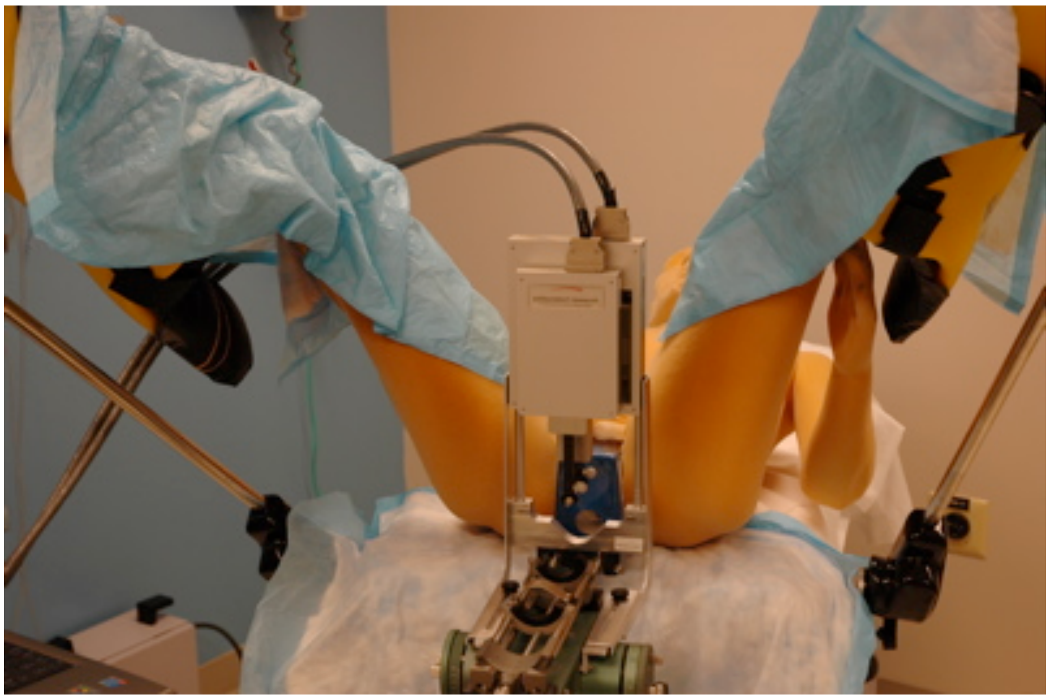
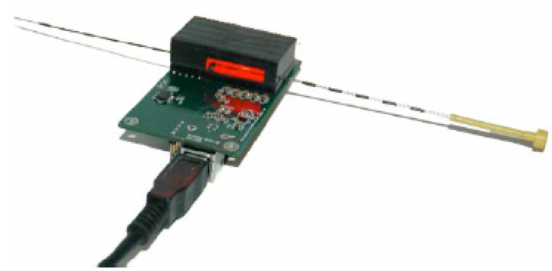
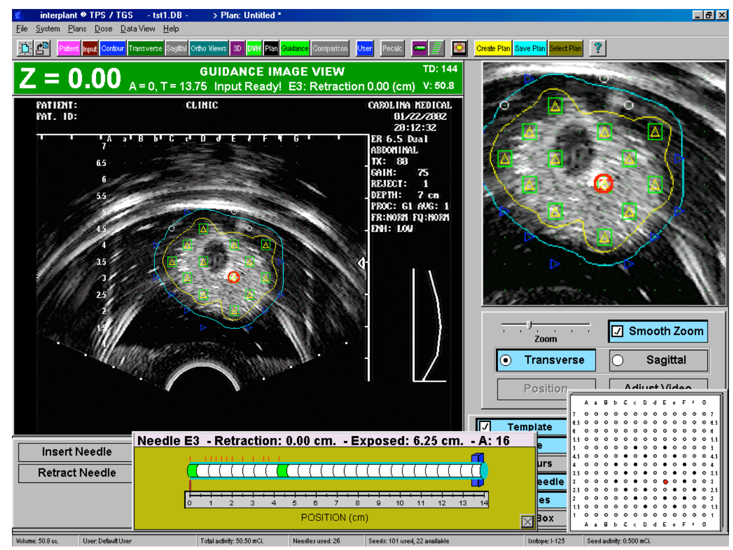
TRUS Guided Prostate Seed Placement







JHU RadOnc: Song, DeWeese
JHU Engineering: Kazanzides
Queen's : Fichtinger, Abolmaesumi
Industry: Burdette / Acoustic Medsystems

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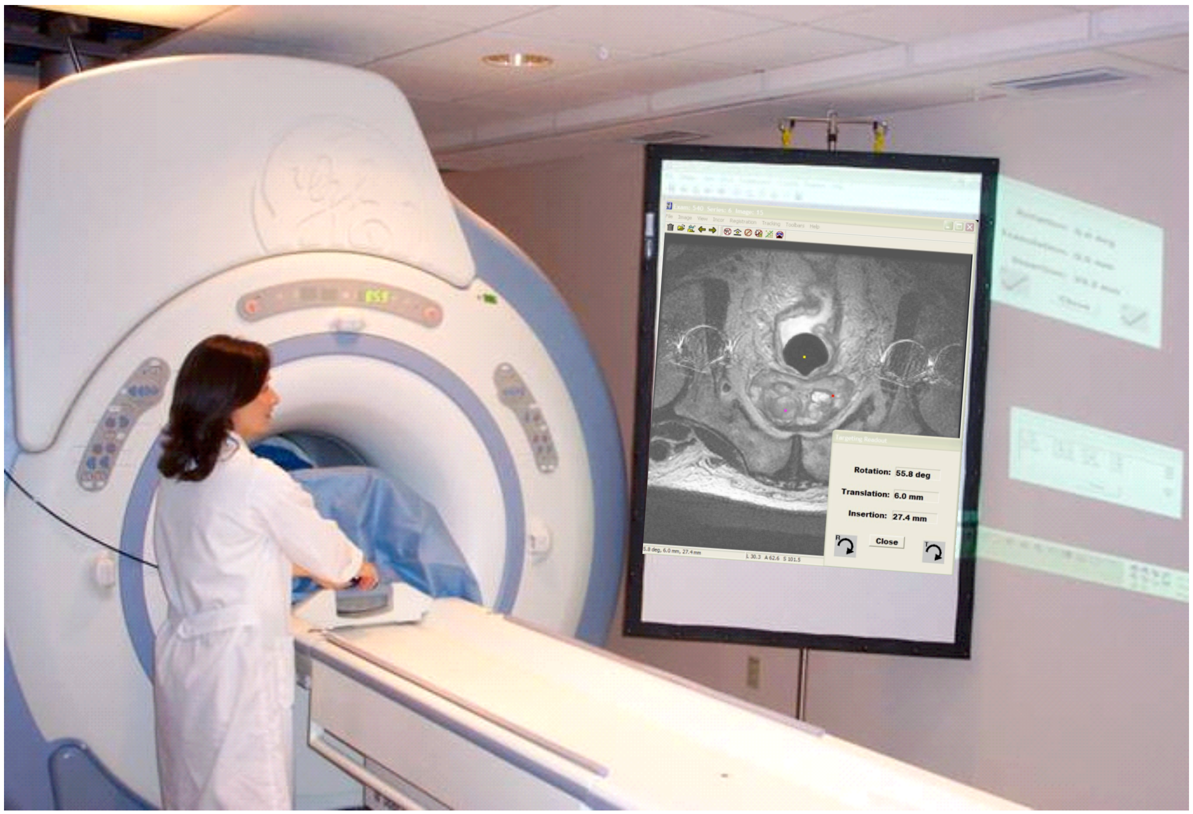
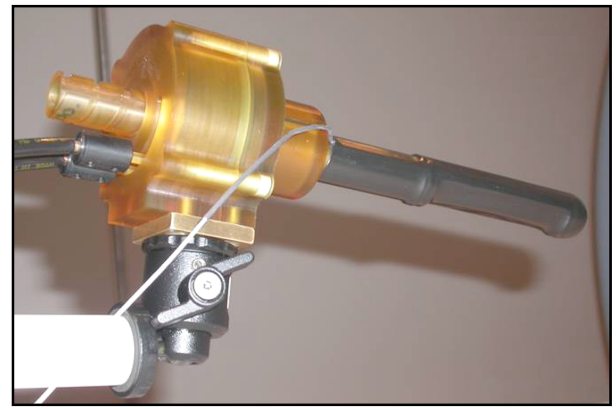
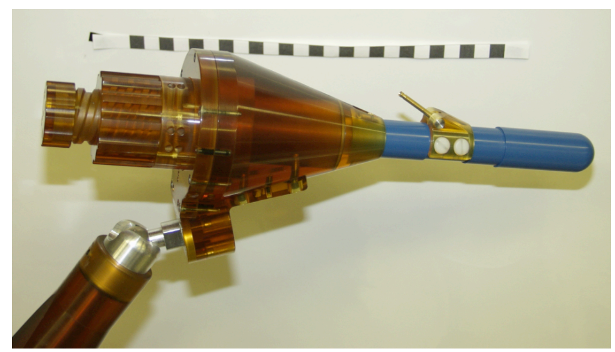
In-Scanner Prostate Biopsy

A “manual” robot combined with real-time US imaging
and MR-US registration through device







Krieger et al, IEEE TMBE, 2005
Susil et al. J Urol,, 2006
Krieger et al, MICCAI 2007

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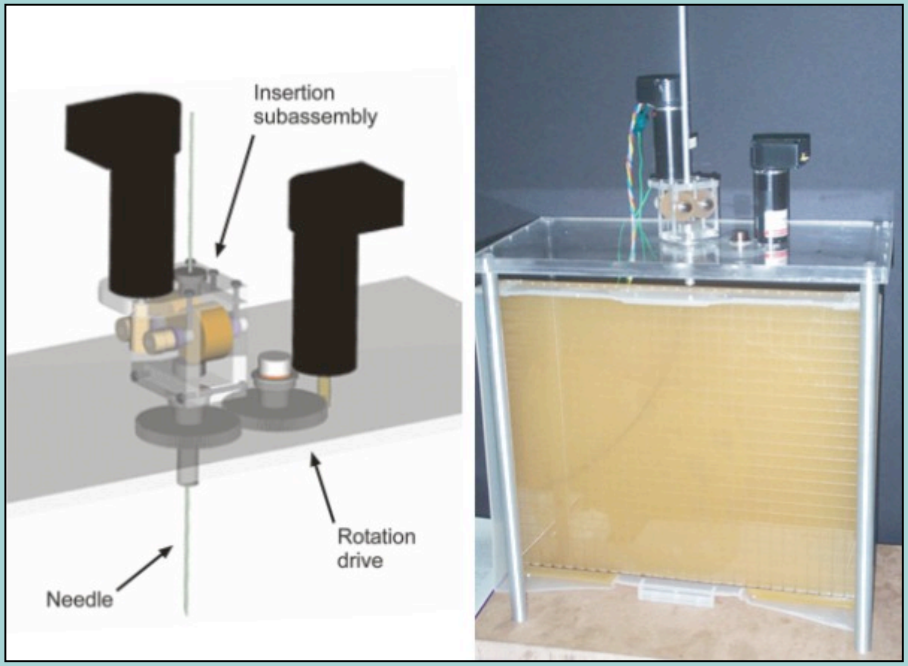
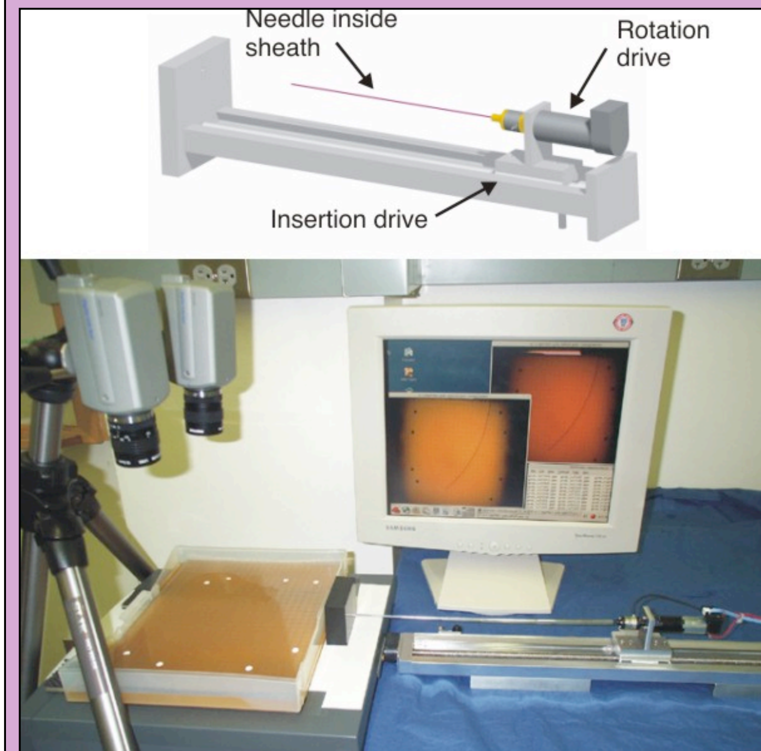
Steerable Needles

A way to get devices into spaces currently hard to access

Friction Drive Device



Telescoping Device



JHU Engineering: Okamura, Cowan, Chirikjian
Berkeley: Goldberg
Queen's : Fichtinger, Abolmaesumi
JHU Clinical: Song, Murphy, Choti

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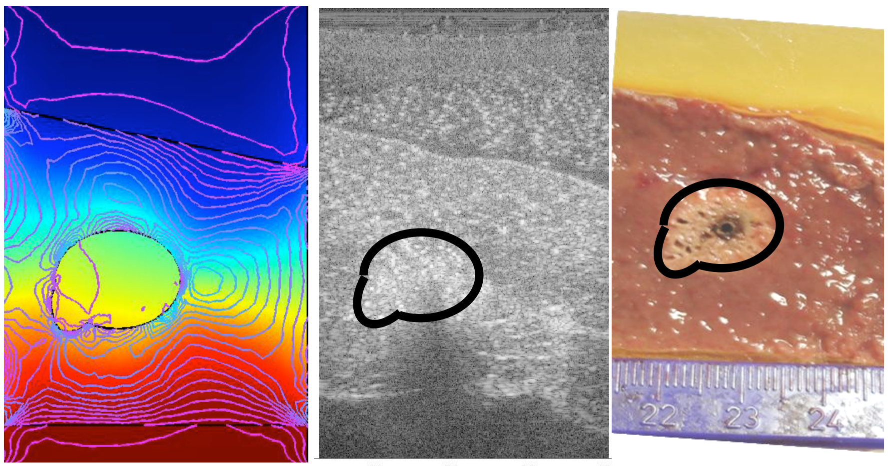
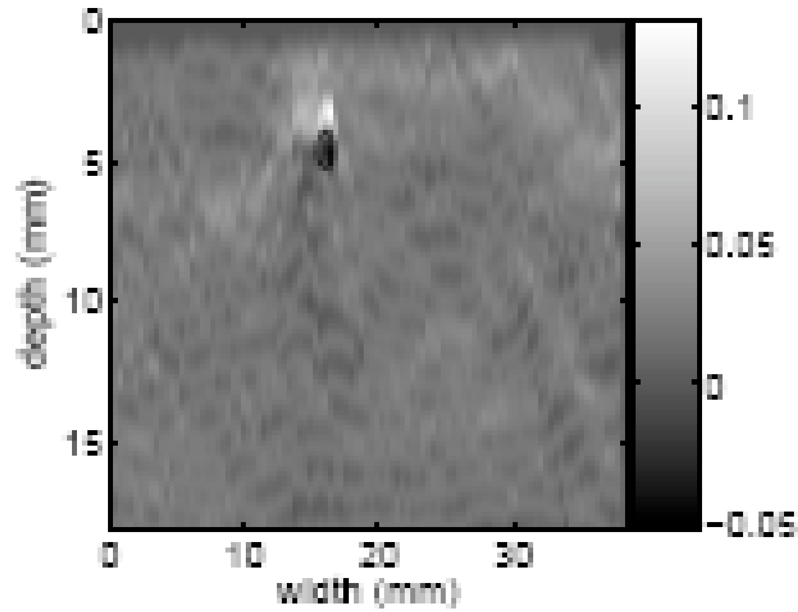
Ultrasound Elastography For Guidance

A combination of palpation, imaging, and image processing





(c)

JHU Clinical: Zellars, Song, Choti
JHU Radiology: Boctor
JHU Engineering : Hager
Queen's: Fichtinger, Abolmaesumi

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New Challenges: Surgical Assistance

- Provide more complete information to the surgeon
  - pre-operative images (preferably registered to view)
  - instra-operative images (e.g. ultrasound)
  - force, tissue stiffness, oxygenation
- Improve dexterity and reduce size
  - robots for micro-surgical applications
- Provide physical guidance
  - improve safety through “no-fly” zones
  - improve repeatability through guidance (virtual rulers)

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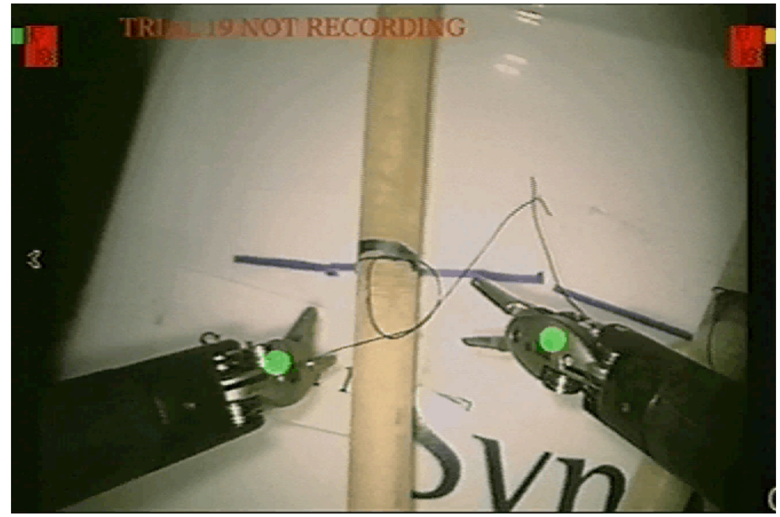
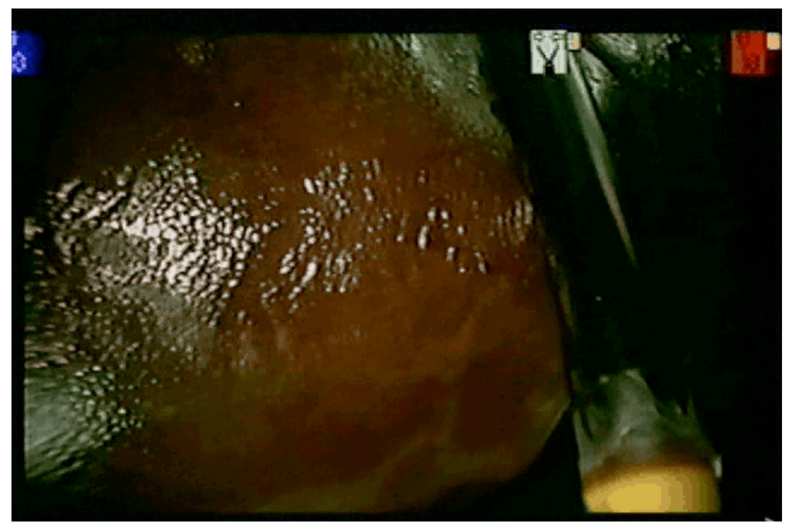
Example: Augmented Reality in Robot-Assisted Surgical Systems





Clockwise from upper left: daVinci surgical robot; Information overlay of force information on daVinci display (Okamura *et al.);* Real time overlay of ultrasound images on daVinci display (Taylor *et al.*)

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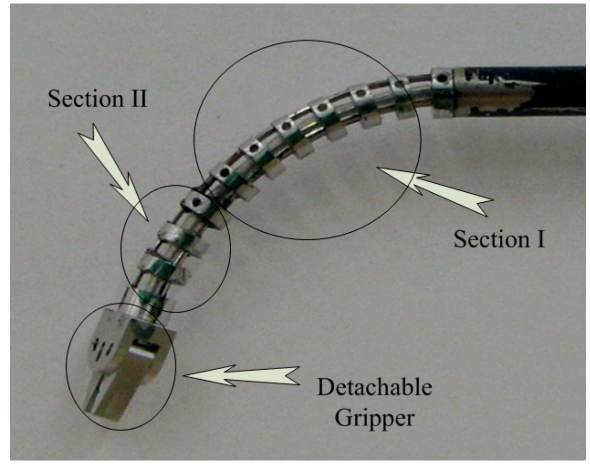
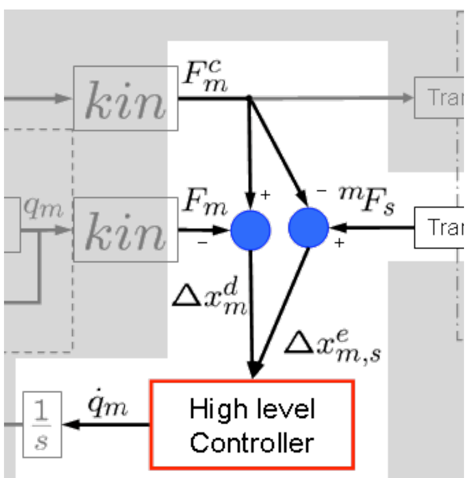
Snake Robot for Minimally Invasive Surgery

Simaan, Kapoor, Wei, Xu, Kazanzides, Taylor, Flint

- Intended for use in the throat and upper airways
- Each arm consists of a 4-DOF tool manipulation unit that positions a 4-DOF snake-like wrist and a simple gripper
- Integrated with teleoperation master and virtual fixtures





Dr. Paul Flint of the JHU otolaryngology department

Surgeon's view using a standard training phantom

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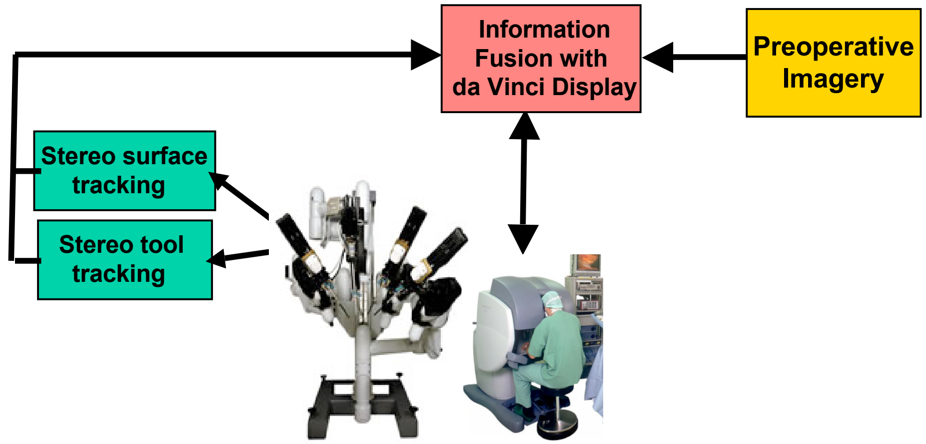
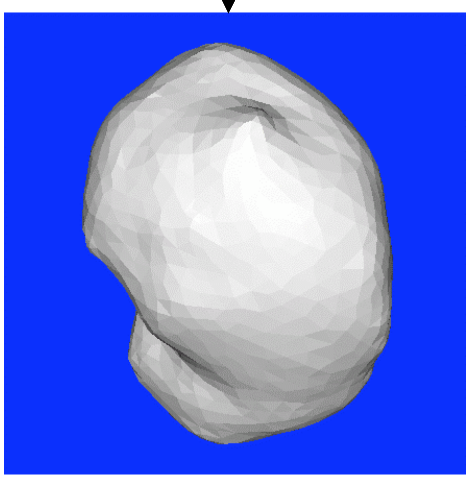
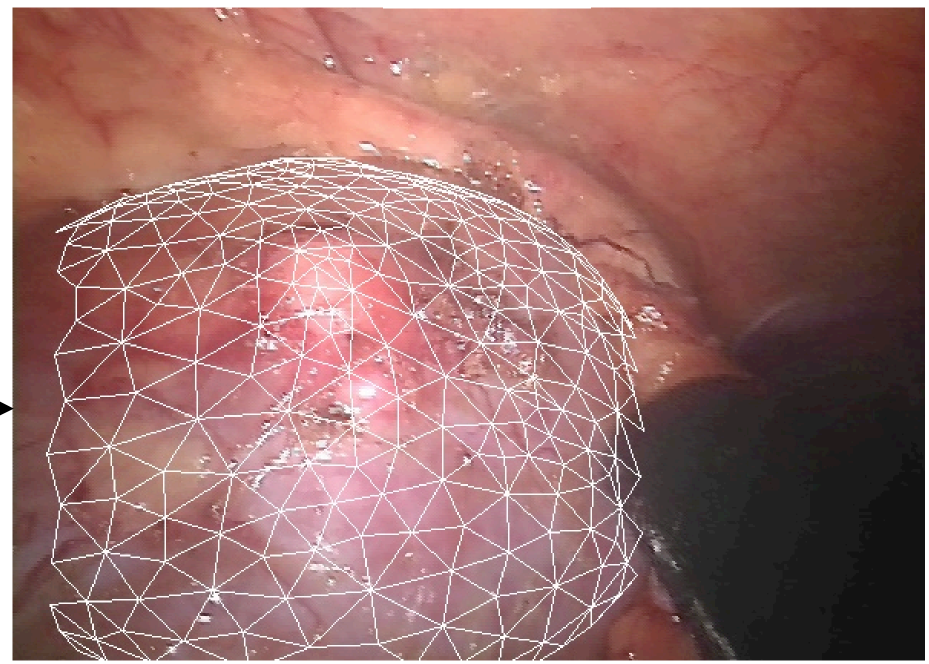
Video to CT Deformable Registration







Vagvolgyi, Hager, Taylor

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Some Closing Observations

- CIS market is not yet well-defined
  - Intuitive was able to rapidly follow the market, ISS was not
  - Time to original conception to market is long: 10-15 years!
- Key to safe, widely accepted systems:
  - Simplicity
  - High relevance
  - Leave the surgeon "in the loop"
- Differing objectives means a wide variety of systems
  - Surgical Assistance: put the eyes and hands of surgeon in places they could not otherwise go
  - Surgical CAD-CAM: increase accuracy, precision, repeatability

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Three Learning Objectives

- To understand the regulatory and commercial challenges for new medical devices
- To understand the two broad paradigms of computer-assisted interventional systems.
- To be aware of current trends in CIS

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Self-Assessment Questions

- Why are soft-tissue interventions difficult to automate?
- What is the meaning of image registration?
- What is ultrasound elastography?
- What are two limitations of current minimally invasive surgical systems?
- What is the typical time from initial concept to market for new paradigms of devices?

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